Chapter (1)

Introduction

1.1 General:

Considering the need for low-cost construction materials especially in the rural areas in Sudan, the production, and the use of the durable low cost building materials such as lime and Pozzolana which are available in big quantities in many parts of the Sudan, become of very great importance. Pozzolana and lime can be produced with much less sophisticated technology than Portland cement. This means that Pozzolana and lime can be produced at relatively low cost and requires much less Pozzolana exchange than cement.

Like many other developing countries Sudan suffers from housing shortage against the ever increasing demand not only due to the continuous displacement from rural to urban areas because of war, drought and natural disasters, but also dwellings are needed for returnees after peace. Conventional materials, such as concrete, timber, bricks and steel, used in walls and roofs, which contribute up to over 90% of the cost of low cost dwelling, are beyond the reach of most of the poor population. On the other hand traditional materials, mainly earth products and thatch, are subject to weathering, insect attack and fire hazard. The solution to this problem is thought to be by using substitute materials produced or developed from traditional construction materials to reduce the cost to a minimum.

Soil, being one of the traditional materials, offers many advantages when used as construction material. These include availability, ease of use, cheapness, suitability to most parts of the building, and that it is environment friendly. The disadvantages of soil are being less durable, poor in tension, lacking of acceptability among social groups and institutions. Stabilizers are used to increase the resistance of soil to weathering, and hence improve its durability.

The stabilizers used include chemical and/or mechanical means. Chemical stabilizers include cement, lime, gypsum and lime/Pozzolana cement. Other low cost materials are mainly types of bricks with many alternatives of binding materials, the traditional cement and low cost Cement. Ali (2008)

Thus, use of the durable low cost building material such as lime and Pozzolana which are available in large quantities in many parts of the Sudan, become of very great importance. Developing the mechanism of interaction between lime and Pozzolana, offers the best, economic and durable proportion of lime- Pozzolana mixtures. Pozzolana as stated by Ali(2008), El-Zamzami(2003) and Hammid (2002), can also be used to

replace about 20 to 50 % of Portland cement according to the building application. This can reduce the cost of the building, since the cement is one of the building materials that affect the total cost of the building. For some applications, lime and Pozzolana can be used to manufacture lime-Pozzolana cement with simple technology by intergrading of 70% by mass of Pozzolana with 30% by mass of hydrated lime.
Natural deposits of Pozzolana are available in many regions in northern, eastern and western Sudan. Al-Saleem, A. M.(2006).

1.2 Statement of the Research Problem:

Building materials in Sudan have gained great importance in recent years due to the rapid urban and rural development that covered almost all the states of Sudan, due to the many and varied infrastructure project, and the qualitative leap in the growth of housing. The major obstacle to this development, especially for the state of Darfur, has been the cost and availability of building materials.
Cement as one of the components of the concrete mix plays a primary role in the cohesion of the mixture. But it is expensive and contributes to pollution of the environment. Therefore research is required to investigate some of the indigenous materials such as Pozzolana to replace or even to eleviate the use of cement in building for durable and cost effective dwellings.
So carrying out a research study to reduce dependence on cement using natural materials such as Pozzolana to replace certain percentages by cement would be interesting and of great benefit. This is mainly due to the discovery of large amounts of Pozzolana in Sudan for example at Jebel Marra in the west, Bayouda desert in the north, Algregrieb in Gezira area along Blue Nile, Ban Gadded area at Sabaloka north of Khartoum and Abu Hadied in northern Kordofan. In Darfour there are huge quantities of natural industrial minerals such as Pozzolana and marble. Therefor the use of supplementary materials in blended cement and concrete may lead to reduction in construction cost. This has led to the idea of investigating the suitability of these natural materials to be incorporated in blended cement as partial cement replacement, and as alternative to Portland cement and fired clay bricks.
The proposed study is intended to collect data about the locations of natural Pozzolana deposits materials at Jebel Marra in the west of Sudan and to examine their quality and suitability in the construction industry as a natural material, which can be used as supplementary of part of the cement.

1.3 Objective of the Study:

The general objective of this study is to add to the body of knowledge of the use of Pozzolana as building material in Sudan.

The study aims specifically at:

1. To identify some locations of some natural Pozzolana materials in Sudan and presenting available geological map for Natural Pozzolana deposits in the area of the study. (At Jebel Marra in the western Sudan).
2. Characterization of Natural Pozzolana at some location in Jebel Mara, including chemical and physical properties.
3. Production of some blended cements using different replacement ratios of Pozzolana from the study area.
4. Physical and chemical characterization of produced cements.
5. Comparison of blended produced cements with different cement types namely type I, type II and type IV.
6. Production of concrete blocks from blended cements and study their effect in lowering cost of buildings and lowering cost of concrete blocks themselves.
7. Recommendations for further study on the Jebel Marra Natural Pozzolana including mineralogical composition and their used in production of other types of cements example low heat cements, sulphate-resistance cements etc.

1.4 Methodology of Study:

The methodology of research adopted to achieve the objectives will be through the following:

Phase1: Literature Review

Where state of the art and basic concepts of the research problem will was revised and the related literature and relevant data will be collected and studied. This will be achieved by collecting various data and information through various sources including books, journals, historical documentary including previous case studies, international symposia studies and papers, from the internet and other sources. Then the main features of the proposed work were formulated. Pointing out the locations of the deposits, collection of samples to be used in the study will then be carried out.

Phase2: Experimental Work

Chemical, physical and mechanical tests were carried on the samples collected in phase1above.

Chemical testing to evaluate Pozzolanity of tested Pozzolana samples.
Mechanical and physical testing of and their blends prepared samples.

Phase3: Analysis and Discussion of Result:

- Analysis of obtained results.
- Drawing conclusions and recommendations.

1.5 Research Thesis Structure:

This thesis consists of five chapters. The outlines of these chapters are as follows:

Chapter One: Introduction: deals with a general introduction to the research problem, its statement, the objectives of the research, the methodology adopted and the research thesis structure.

Chapter Two: presents a literature review and devotes parts of its sections to a general background on Pozzolana Definition, History, Distribution, Types and Advantages**.** Deals with General Pozzolana, types and uses. Outlines the availability and the effect of added Pozzolana in Sudan. Presentation of a summary of some studies and papers that are directly related to the research problem

Chapter Three: Deals with the experimental program, materials properties and experimental procedure, and laboratory tests conducted.

Chapter Four: Presents the results of laboratory tests and the analysis and discussion of these results.

Chapter Five: Presents a summary list of the finding of the research, draws conclusions and recommendations. Suggestions for future studies are also included in the chapter.

Chapter (2)

Literature Review

2.1 Introduction:

Pozzolanas are materials containing reactive silica and/or alumina which on their own have little or no binding property but, when mixed with lime in the presence of water, will set and harden like cement. The chemical composition of Pozzolanas varies considerably but the following can be taken as a rough guide:

Silica + Alumina + Iron Oxide - Not less than 70 percent.

Other oxides and alkalis - Not more than 15%.

Loss on ignition – Not more than 15% of the active oxides. Silica is normally considered to be the most important and should not normally fall below 40 per cent of the total, indeed some of the best Pozzolanas have silica contents above 90 per cent. Carbon is a common constituent in Pozzolana and its content should be as low as possible, below 12 per cent is normally recommended. Plant ashes will often have higher carbon contents, unless the airflow on combustion is carefully controlled. Higher carbon contents can be tolerated but will result in lower strength cements, Neville (1995) and Lea (2004).

As stated by Rafat (2008) and Azmar (2004) the more commonly accepted classification concerns the origin of Pozzolanas and therefore a first subdivision is between natural and artificial materials. Natural materials do not require any further treatment apart from grinding. Artificial Pozzolanas result from chemical and/or structural modifications of materials originally having no or only poor Pozzolanic properties. The latter can be residues of certain production methods or products manufactured from selected raw materials.

According to Tikalsky (2001) Pozzolana is defined as natural or artificial materials with alumino- siliceous composition, which in itself possesses little or no cementitous value but will, in fine powder form and in the presence of moisture, chemically reacts with calcium hydroxide at ordinary temperatures to form compounds possessing cementitous properties.

2.2 History of Pozzolana:

As stated by Parhizkar (2010) human beings have used natural pozzolans from 6000-7000 years ago. The oldest reported example of a hydraulic binder, dating from 5000-4000 B.C., was a mixture of lime and natural Pozzolana, a diatomaceous earth from the Persian Gulf. The next oldest report of its use was in the Mediterranean region where the Pozzolana was volcanic ash produced from two volcanic eruptions between 1600 and 1500 B.C. The first is Santorini volcano, Greece, which erupted during Vesuvius, Italy. The second is the volcano which erupted in A.D. 79.

Volcanic ash was first used as a Pozzolana by Romans from deposits close to village of Pozzuoli, near Naples-hence the name Pozzolana or

Pozzolana was derived. Scientists have proven that the ancient Greeks began to use natural Pozzolana-lime mixtures to build water-storage tanks sometime between 700 B.C and 600 B.C. This technique was then passed on to the Romans about 150 B.C. Tikalsky (2001).

John (2007) claims that according to Roman engineer Vitruvius Pollio who lived in the first century: "The cements made by the Greeks and the Romans were of superior durability, because neither waves could break, nor water dissolve the concrete." The Romans developed lime Pozzolana cement (LPC) technology. Many great ancient structures, such as the Colosseum, the Pantheon, the Bath of Caracalla, as well as other structures that are still standing in Italy, Greece, France, Spain and the islands in the Mediterranean Sea, were built with natural Pozzolana-lime mixtures. Many of them have lasted more than two thousand years.

The development of hydraulic cements based on lime-Pozzolana mixtures led to radical changes in building during the Roman era. The increased strength of lime-Pozzolana mixtures, their hydraulic properties and good resistance to seawater, permitted the construction of not only arches and vaults but also marine structures. Lime-Pozzolana mortars were also used as waterproofing renders in the lining of baths, tanks and aqueducts.

The durability of the material is attested to by the many remains of Roman structures still in evidence today. The Roman port at Cosa was built of Pozzolana that was poured underwater, apparently using a long tube to carefully lay it up without allowing sea water to mix with it. The three piers are still visible today, with the underwater portions in generally excellent condition even after more than 2100years.

Lea (2004) shows that despite their long history of use in construction and after the invention of Portland cement, Pozzolanic materials still continue to be the current topic for research and subject for international conferences. This can be attributed to their complex interactions with cement and lime, to the large variety of types and properties, to the several technical and economical advantages involved in their use in construction.

2.3 Definition of a Natural Pozzolana:

Pozzolana is defined in ACI 11 6R (1985) as: a siliceous or siliceous aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. The typical chemical and mineralogical analysis of some natural Pozzolanas, presented by Mehta (1987) are shown in Table 2.1

Table 2.1: Typical chemical analysis of some natural Pozzolana (Mehta 1987)

Pozzolana	Percent by weight							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Alkalis*	L.O.I	Total
Santorian	65.1	14.5	5.5	3	1.1	6.5	3.5	99.2
Rheinish trass	53	16	6	7	3	6	6.0	91
Phonolite	55.7	20.2	2.8	4.2	1.1	10.8	3.6	98.4
Roman tuff	44.7	18.9	10.1	10.3	4.4	6.7	4.4	99.5
Neapolitan glass	54.5	18.3	4	7.4	1	11	3.1	99.3
Opaline shale	65.4	10.1	4.2	4.6	2.7	1.4	6.3	94.7
Diatomite	86	2.3	1.8	-	0.6	0.4	5.2	96.3
Rhyolite pumice	65.7	15.9	2.5	3.4	1.3	6.9	3.4	99.1
Jalisco pumice	68.7	14.5	2.3	-	0.5	8.3	5.6	99.9
Pudahuel glass	68.8	12.7	2.3	2.4	0.7	7.5	4.3	98.7
Chilean Pozzolana	70	14.4	1.1	1	0.3	7.2	4	98
Bolivian Pozzolana	56.5	15.4	0.7	10.3	0.3	7.2	5.1	95.5
Turkish Pozzolana	68.5	11.5	0.5	-	-	2.7	14.7	97.9

*****Alkalis = % Na_2O+ 0.658%K_2O

Natural Pozzolana is defined as:
Either a raw or calcined natural material that has pozzolanic properties (for example, volcanic ash or pumicite, opaline chert and shales, tuffs, and some diatomaceous earths).
ASTM C 618 covers coal fly ash and natural Pozzolana for use as a mineral admixture in concrete. The natural pozzolanas in the raw or calcined state are designated as Class N pozzolanas and are described in these specifications as:
Raw or calcined natural pozzolans that comply with the applicable requirements for the class as given herein, such as some diatomaceous earth; opaline chert and shales, tuffs and volcanic ashes or pumicites, any of which may or may not be processed by calcinations and various materials requiring calcination to induce satisfactory properties, such as some clays and shales. Similar materials of volcanic origin are found in Europe, where they have been used as an ingredient of hydraulic-cement concrete for the past two centuries.
ACI 225.R (1999) cover raw or processed natural pozzolans are used in the production of hydraulic-cement concrete and mortars in two ways: as an ingredient of blended cement, or as a mineral admixture. Fly ash and silica fume are artificial pozzolans and are covered in ACI 232.IR (2000).

2.4 Characterization of Pozzolanas:

As explained by Neville (1995) and Lea (2004) Pozzolanas, by their diverse and varied nature, tend to have widely varying characteristics. The chemical composition of pozzolanas varies considerably, depending on the source and the preparation technique. Generally, a Pozzolana will contain silica, alumina, iron oxide and a variety of oxides and alkalis, each in varying degrees. This presents problems for small scale manufacturers wishing to use pozzolanas in a lime or OPC - Pozzolanas mix.

2.4.1 Chemical Characterization:

The two primary characteristics of a Pozzolana are its ability to react with lime and its ability to form reaction products with binding properties upon combing with lime, Rogers (2011). Silica and alumina are the reactive components that are responsible for the combination with calcium hydroxide and formation of cementitous compounds, specifically the calcium silicate hydrates (C-S-H) and calcium aluminum hydrates (C-A-H). Not all siliceous materials are Pozzolanic, and there is no a clearly-defined limit for which siliceous materials will and which will not produce a Pozzolanic reaction. As with hydraulic lime, the amount of silica that is soluble, or combinable, is important in predicting the formation of C-S-H. Materials with a high percentage of silica that is amorphous tend to be more pozzolanic because amorphous silica is more soluble than crystalline silica. Crystalline silica is slower or does not have a pozzolanic reaction at all and, as a general rule, the larger the crystals the less rapid the reaction. Also, calcium hydroxide and silica combine at different rates for different materials and the reaction can sometimes be very slow as stated by Lea (2004).

It is reported by Dean (1974), that loss on ignition is generally equal to the carbon content.

To determine the chemical characteristics of Pozzolana it is common to use X-ray fluorescence (XRF), Atomic Absorption Spectrophotometer (AAS), X-Ray Diffraction (XRD), inductively coupled plasma (ICP), and colourimetric methods. These analyses are important since the total percentage of silica, alumina and iron of Pozzolanas give a good indication of the quality of the produced Pozzolanic material.

Most pozzolanic materials compare the chemical composition according to the (ASTM C-618), (IS: 1344: 1981), (IS: 3812:1981).

Chemical composition also suggests the possible areas of application of pozzolanas. Table 2.2 shows the chemical composition according to the Indian and American standards of Pozzolanas.

The ASTM classes in Table 2.2 are as follows:

- **Class N*-**Raw or calcined natural pozzolans that comply with the applicable requirements for the class as given in Table 2.2, such as some diatomaceous earths, opaline cherts and shales, tuffs and volcanic ashes or pumicites, calcined or uncalcined and various materials requiring calcination to induce satisfactory properties, such as some clays and shales.

- **Class F**-**Fly ash normally produced from burning anthracite or bituminous coal that meets the applicable requirements for this class as given in Table 2.2. This class fly ash has Pozzolanic properties.

Table 2.2: Standard chemical requirements of pozzolanas

Major oxides (%)	Class of Pozzolana				
	(ASTM C618-2000)			(IS :1344-81)	(IS : 3812.1981)
	N*	F**	C***	Calcined clay	fly ash
Silica + Alumina + Iron	70.0	70.0	50.0	70	70
Silica min				40	35
Calcium Oxide max,				10	
Magnesium Oxide (MgO),				3.0	5.0
Sulfur trioxide (SO_3), max,	4.0	5.0	5.0	3.0	2.75
Moisture content, max,	3.0	3.0	3.0		
Water-soluble material				1.0	
Loss on ignition, max,	10	6.0*	6.0		12
Available alkalies, as equivalent, as Na_2O, max	1.5	1.5	1.5	3.0	1.5

- **Class C***-**Fly ash normally produced from lignite or sub bituminous coal that meets the applicable requirements for this class as given herein. This class of fly ash, in addition to having Pozzolanic properties, also has some cementations properties.
  Natural pozzolans are classified by (ASTM C 618-200), (AASHTO M 295) as Class N Pozzolans. (ACI 232.IR 2000) provides a review of natural Pozzolans.

2.4.2 Physical Characterization:

In most cases no direct correlation can be found between chemical content and reactivity. Other characteristics of the Pozzolana also affect its reactivity, such as fineness and crystalline structure.

Pozzolana fineness is controlled in most cases by limiting the amount retained on the 45 µm (No. 325) sieve by wet sieving. Reactivity has been found to be directly related to the quantity passing this sieve, as the coarser particles generally do not react in a reasonable time in concrete. ASTM C618 limits the amount retained to 34% for natural pozzolans.

The strength activity index with Portland cement measures strength of 50 mm (2 in), cubes made using 80% Portland cement and 20% Pozzolana mixed to constant flow and tested at 7 and 28 days, and is considered only as an indicator of reactivity and does not measure the compressive strength of concrete containing the Pozzolana. It provides no information on the optimum proportion of Pozzolana for use in concrete, as shown in Table 2.3.ASTM C 311(2002).

Table 2.3: Physical requirement of Pozzolana

Characteristic	Requirements	
	ASTM C 618	IS :1344-1981
Fineness - Specific surface in m^2/kg	-	250 - 320
Fineness -Amount retained when wet-sieved on 45 µm (No. 325) sieve, max, %	34	-
Strength activity index With Portland cement %	75	80
Strength activity index: With lime MPa	-	3 - 4
Soundness	0.8	0.8
Drying shrinkage, Max%	-	0.1-0.15

2.4.3 Assessment of Pozzolanicity:

As defined by South (2009), the property of pozzolanas, possessing little or no cementing value, to react with CaO or $Ca(OH)_2$ in the presence of water and produce highly cementitious water insoluble products, is called Pozzolanic reactivity. The meta-stable silicates present in self-cementitious Pozzolanas react with calcium ions in the presence of moisture to form water insoluble calcium-alumino-silicate hydrates. The Pozzolanic activity depends upon many parameters such as fineness, amorphous matter, chemical and mineralogical composition, and the unburned carbon content or loss on ignition of the Pozzolanas.

South (2009), also states that several investigators have reported that when Pozzolana is pulverized to increase fineness, its Pozzolanic activity increases significantly. However, the effect of increase in specific surface area beyond 6000 cm^2/g is reported to be insignificant.

2.4.3.1 The Strength Activity Index with Portland cement:

The test for strength activity index (SAI) is used to determine whether Pozzolana results in an acceptable level of strength development when used with hydraulic cement in concrete. Since the test is performed with mortar, the results may not provide a direct correlation of how Pozzolana will contribute to strength in concrete (ASTM C311–2002).

2.4.3.2 Some factors that affect the Activity of Pozzolana:

Neville (1995), states that the factors that affect the activity of Pozzolana are:

1. Silica Oxide+ Alumina Oxide + Ferric Oxide content.
2. Amourpheness

3. Fineness .
4. Quantity of reactive silica.

2.5 Distribution of Natural Pozzolana:

2.5.1 Global Distribution of Pozzolana:

Volcanic pozzolanas are widely distributed in the world. Figure 2.1 shows the major deposits of volcanic pozzolanas on 6 continents.

These deposits occupy more than 122 locations of the Pozzolana from 32 different countries. These countries are: Canada, Canary Islands, Chile, Colombia, Cuba, Dominican Republic, Ecuador, Egypt, England, Fiji, Finland, France, Germany, Ghana, Greece, Guatemala, Hungary, Iceland, India, Italy, Japan, Madagascar, Morocco, New Zealand, Rumania, Sicily, Sudan, Tanzania, Trinidad, Turkey, USA, USSR, and Yugoslavia. Robert (1990).

Useful pozzolanic materials are not all of volcanic origin. Many other pozzolanic materials like diatomaceous earth can be found around the world and also numerous deposits of gaize soft, porous, siliceous sedimentary rocks are found in Ardennes and Meuse valleys in France. This is usually burnt at 900°C and blended with OPC. This material has been used in many marine structures in French ports. Lea (1970).

As stated by Robert (1990), there may be more countries which contain pozzolanic materials for which detailed scientific evaluations have not yet occurred. These countries may not have started the exploitation for various reasons or may not have brought the existence of such materials to the attention of the technical community.

In the last 30 years, the USA and European countries were compelled to lower their quality criteria so that waste materials such as fly ash could be used as a substitute for natural Pozzolana.

The pozzolanic ash with Portland cement is the weight of cement that can be replaced by one unit weight of pozzolanic ash without altering the concrete compressive strength at a given age.

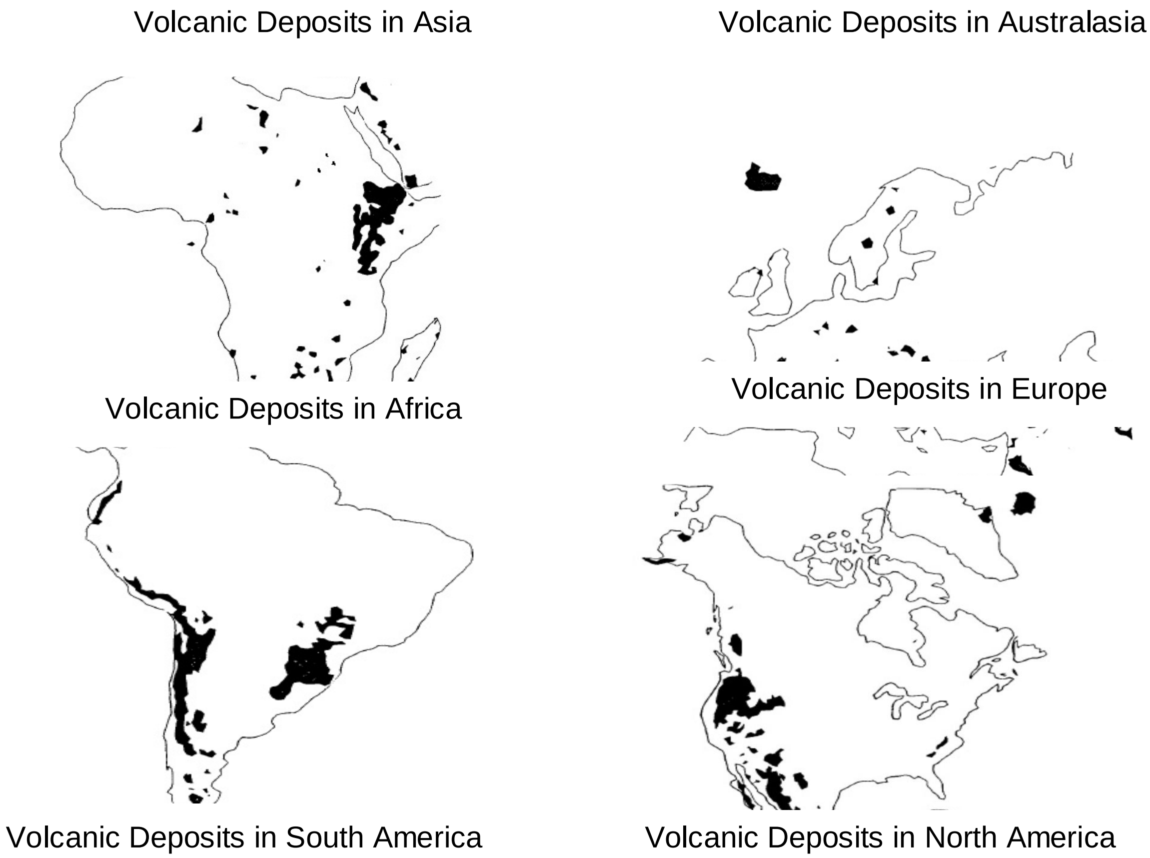


Figure 2.1: World Wide Deposits of Natural Pozzolanas. Robert (1990).

2.5.2 Pozzolana in Sudan:

There are many types of Pozzolanic materials in Sudan, especially natural Pozzolana. But the geological surveys for these materials are not available. There are indicators of volcanic ash presence in each of Jebel Marra in the west, Abu Hadied in northern Kordnfan, Bayouda desert in the north and Gedaref in the East. Also diatomite earth exists in North Darfur, Kabkabiyya area, Jebel Katwal northern Kordofan, and Algregrieb Gezira area along Blue Nile. There are also other types of materials like (Pumice), Obsidian and Scoria but they need to be detailed studied to determine their economic vaibility. The industrial Pozzolana include remnants of the brick industry and the sugar industry waste ash (Baggase) that resides in sugar factories in huge quantities and they are dangerous because they are self-burning materials. Elphial et.al (1999).

With all of that there are no available detailed geological studies of the following areas North Kordofan, area of Kabkabiyya and Jebel Katwal, but there are some indicators, Algregrieb in Gezira area along Blue Nile, Elphial et.al (1999).

Mammon (2004) stated that investigations revealed that most of natural Pozzolanas in Sudan were associated with Tertiary volcanics and Quaternary lake deposits. According to compressive strength results, the natural Pozzolanas in Sudan can be classified into three grades, high grade Pozzolanas represented by obsidian (Sabaloka), diatomite (Gezira), and volcanic tuffs (Bayouda), moderate grade Pozzolanas including pumice (Bayouda), Quaternary lake depots (Abu Hadied), and low grade Pozzolanas in the form of natural burnt clay. Quantitatively and qualitatively the most promising deposit is the volcanic tuffs at Bayouda.

Mammon (2004) shows that the strength of Lime-Pozzolana cement can be improved remarkably by very fine grinding, other factors such as Pozzolana/ lime ratio, curing condition and use of additives may also affect the strength properties. However, generally the degree of fineness outweighs the previously mentioned factors. Figure 2.2 shows the locations of natural Pozzolana in Sudan as presented by GRAS(2014). Figure 2.3 shows Location of differnt types of Pozzolana materials in Sudan. Table A Appendix B shows the chemical analysis of some Pozzolanas in Sudan.

2.5.2.1 Distribution of local Natural Pozzolanas:

The main locations for natural Pozzolana in Sudan are the following:

1. Pozzolanas in Jebel Marra:

The vast Jebel Marra volcanic field, located in Darfur province of western Sudan, is the youthful Deriba caldera. The 5-km-wide, steep-walled caldera, located at the southern end of the volcanic field, was formed about 3500 years ago at the time of the eruption of voluminous air fall pumice and pyroclastic flows that traveled more than 30 km from the volcano. Ash eruptions at Deriba caldera may have continued into early historical time and fumarolic activity has been observed on the flanks of a small pyroclastic cone within the caldera Vail, J.R (1972). (See Photo graph 2.1). Figures 2.4 and 2.5 show that the Location map for Classified Natural Pozzolana deposits in the area of the Study at Jebel Marra as presented by Philibert et.al. (2010).

Photo graph 2.1: Volcanic field in Jebel Marra Vail, J.R 1972

2. Pozzolana in Meidob Volcanic Field

The alkaline Meidob volcanic field located in western Sudan which covers an area of about 5000 km^2 with nearly is 700 Pliocene-to-Holocene vents. The volcanic field was constructed over an uplifted Precambrian igneous and metamorphic basement and is elongated in an E-W direction (Bisschop and Partners B.V 2001).

The Meidob Hills have been built up entirely from volcanic material. Field work and photo interpretation led to the identification of 695 volcanoes, which include scoria cones 66%, mesa flows 9%, maars and tuff rings 7%, composite cones and strongly eroded volcanic relicts 19% Gerhrd Frams et.al (1997).

Basaltic scoria cones and associated lava flows dominate, but trachytic-phonolitic lava domes, tuff rings, and maars (maar is a volcanic crater that forms when magma contacts ground water to produce a steam explosion) are among the youngest volcanic products. Basaltic scoria cones are scattered throughout the field; their lavas have produced a broad lava plateau. The central part of the field consists of younger phonolitic lava flows, trachytic pumice-fall deposits, ignimbrites, and maars. The youngest dated eruptions about 5000 years ago produced a tuff ring and a lava flow (Bisschop and Partners B.V 2001). (See Photo graph 2.2).

Photo graph 2.2: Medob Volcanic Field Gerhrd Frams et.al (1997)

3. Pozzolana in Algregrieb:

Raw Pozzolana are located in Algregrieb area on both sides of Khartoum – Madani highway and there are several cities neighboring Algregrieb village, north (Wad Balal, Alakawra, Eldonab, WadAlvadny, Wadhaja, Arbjee, Alhsahissa) and south (Fdass Alhalimap, Fdassa Alamerab, Alnshisabh, Wadmadani). Areas neighboring Algregrieb village are characterized by agriculture (Mammon (2004), (Elabeid (2005) and Mohamed (2010)).

4. Pozzolana in Bayuda Volcanic Field:

The Bayuda volcanic field is located near the center of the Bayuda desert in North East Sudan. The numerous small cinder cones that trend horizontally across the center of the volcanic field erupted along a WNW-trending line. Lava flows, one of which erupted about 1100 years ago, are visible in Photo graph 2.3, but about 10% of the vents are explosion craters. Bayuda was constructed over Precambrian and Paleozoic granitic rocks, which form the darker areas at the lower right. Suleiman (2008).

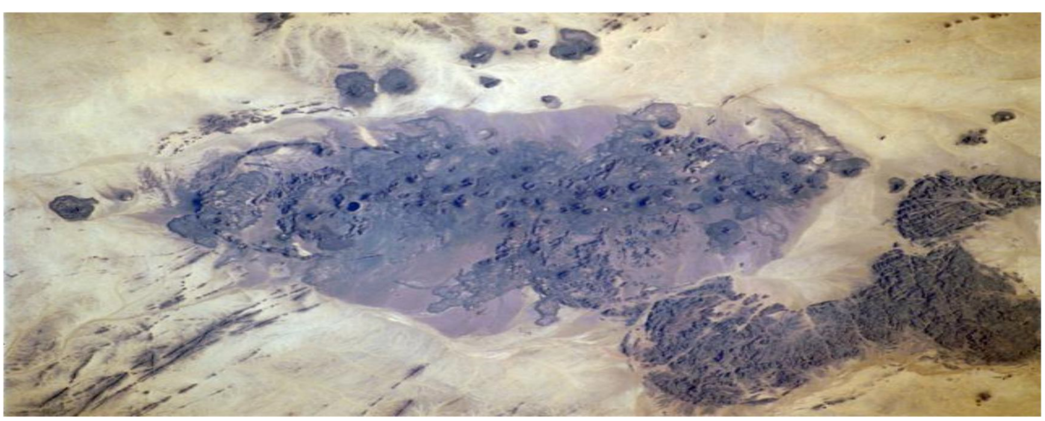


Photo graph 2.3: Bayuda Volcanic Field Suleiman (2008)

2.5.2.2 Artificial Pozzolanas in Sudan:

Artificial Pozzolana in Sudan can be classified into three groups:

I. Burnt or clacined clays:

Hamid (2002), examined the pozzolanity of some local fired clay from three locations in Sudan (Blue Nile clay, kaolin clay, and black cotton clay) through the use of these clays in pozzolanic cement and lime-Pozzolana mortar after the identifications of physical and chemical properties of these clays.

II. Agricultural Wastes Pozzolanas in Sudan:

Bagasse is a by-product of the sugar industry. It is the solid part of sugar cane that is rejected after the extraction of the sugar syrup. In the Sudan, there are five operating sugar factories located in New Halfa in Kassala State, Genied in Gezira State, Sinnar in Sinnar State and Kenana and Assalaya in White Nile State. Eljack (2008) studied bagasse ash from the power station of Kinana Sugar company. He found that the ash brought from Kenana consists of respectful amount of carbon and organic materials. This was due to the incomplete combustion of bagasse fibers in the boiler's system. So it became necessary to recondition the samples for use as pozzolanic material by re-ashing again at 700°C in the laboratory furnace to exclude the high carbon content. Table A in Appendix B, shows the results of chemical analysis of Kinana bagasse ash. Other artificial Pozzolana can be obtained from agricultural wastes such as sunflower, bamboo, corn, rice straw, wheat, groundnut shell.Ibrahim (2014).Those are widely available in Sudan. The problem of which of them to use is associated with the percent of silica and ash content in each plant.

III. Blast furnace slag:

Steel Slag in Sudan Giad Factory in Khartoum produces steel slag as
the major waste during the manufacture of iron and steel.
The daily production of steel slag is 15–20 tons.

2.6 Types of Pozzolana:

A wide variety of siliceous or aluminous-siliceous materials may be Pozzolanic. Pozzolanas can be divided into two groups: Natural Pozzolanas and Artificial Pozzolanas. The following is a brief description of these types.

2.6.1 Natural Pozzolanas:

Natural Pozzolanas include materials of volcanic origin such as volcanic ash, tuffs, pumice, obsidian, and materials of sedimentary origin such as diatomeous earth and moler. Natural Pozzolana is defined according to ASTM C-618 (2000) as: "...either a raw or calcined natural material that has Pozzolanic properties (for example, volcanic ash or pumice, opaline chert and shales, tuffs, and some diatomaceous earths).”

ASTM C-618 (2000) covers coal fly ash and natural Pozzolana for use as a mineral admixture in concrete. The natural Pozzolana in the raw or calcined state are designated as Class N natural Pozzolana and are described in these specification by (Robert, 1990). “Raw or calcined natural pozzolans, Figure 2.1 shows the world wide deposits of Natural Pozzolanas.

The detailed definition of the main examples of natural Pozzolanas are as follows:

2.6.1.1 Diatomateous Earth:(Lea (2004)):

Clays and the diatomaceous earths are sedimentary rocks which are capable of combining with lime. The former originates from the alteration of igneous rocks whereas the latter forms from the siliceous skeletons of microorganisms (diatoms) deposited in fresh or sea waters. Since both materials result from deposition in water in spite of their different origin, it is not surprising that diatoms and clay minerals occur mixed together. The silica content increases as the clay mineral content decreases.

The opposite occurs for alumina.

2.6.1.2 Gaize: (Lea (2004)):

Gaize is a Pozzolana found in France that is not of volcanic origin but a porous sedimentary rock consisting mainly of opal. The material is usually calcined at temperatures around 900° C (1620° F) before it is used as a Pozzolana or as a component of Portland-Pozzolana cement (ACI 232.1R-2000). Gaize contains 30-35 per cent of active silica, which is easily soluble in potassium hydroxide solutions and confers a certain Pozzolanic activity to the rock. Gaize contains up to 50 per cent quartz and substantial amounts of clay minerals. Since these minerals can reduce the workability of mortars.

2.6.1.3 Bauxite: (Lea(2004)):

Bauxite is the most important aluminum ore which is mainly water soluble aluminum oxide. It consists largely of the minerals gibbsite Al(OH)3, boehmite AlO(OH), and diaspore α-AlO(OH), together with the iron oxides goethite and hematite, the clay mineral kaolinite and small amounts of anatase TiO_2.

2.6.1.4 Volcanic Tuff: (Cronin (2001))

Tuff is a volcanic or volcaniclastic rock formed of material that accumulated on or around the volcano after an eruption. Tuff has a pyroclastic texture. Ash-fall tuff is a fine-grained rock composed of volcanic ash. Other examples of tuff may have the look of a coarse breccia (or concrete with angular aggregate), with broken angular pieces of whatever was blasted out of the volcano or carried along in a pyroclastic flow. Sometimes, older tuff layers can be metamorphosed by the heat and weight of subsequent tuff deposition into a dense silica-rich rock called a welded tuff.

2.6.1.5 Pumice: (Cronin (2001)):

Pumice is a frothy, gas-filled volcanic rock in which the walls of the gas bubbles and gas tubes are composed primarily of volcanic glass. Pumice is typically a light-toned rock (white, gray, tan) whose very low density (due to the gas bubbles) allows it to float in water; at least until the bubble structure fills with water.

Typical pumice is siliceous (rhyolite or dacite) in composition illustrated pumice and rhyolite tuff, but the lightest and most vesicular pumice is of basaltic composition. Volcanic glass forms naturally when magma is cooled so rapidly that the atoms do not have time to connect with one another in regular lattice structures. As a result of its irregular structure, glass is unstable and eventually breaks down (devitrifies) to form a variety of minerals that are stable at Earth's surface temperature and pressure. (See Photo graph 2.4).

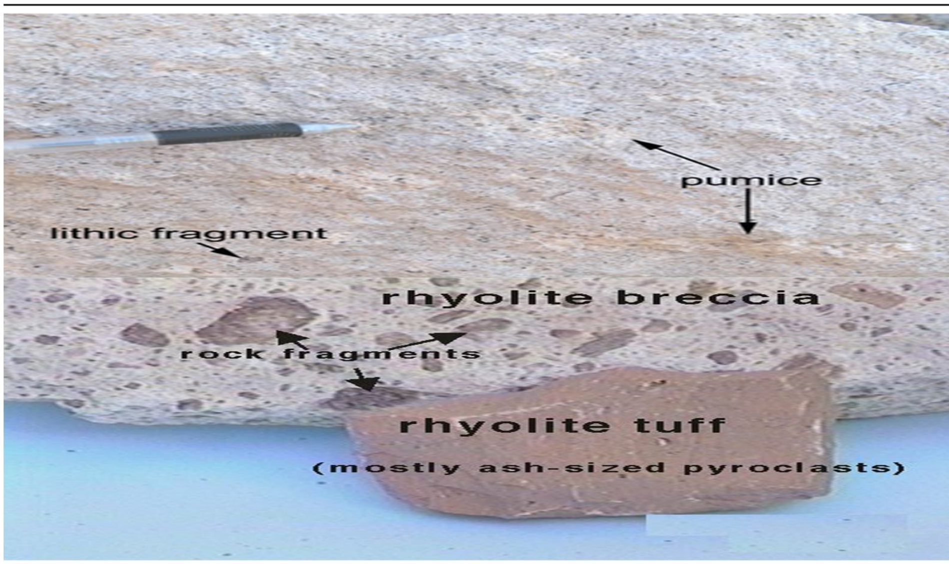


Photo graph 2.4: Pumice and welded tuff (Cronin (2001))

2.6.1.6 Volcanic Ash: (Siddique (2008)):

Volcanic ash consists of powder-size to sand-size particles of igneous rock material that have been blown into the air by an erupting volcano see Photo graph 2.5. Volcanic ash consists of fragments of pulverized rock, minerals and volcanic glass, created during volcanic eruptions, less than 2 mm (0.079 in) in diameter. The term volcanic ash is also often loosely used to refer to all explosive eruption products (correctly referred to as tephra), including particles larger than 2mm.

Ash is also produced when magma comes into contact with water during magmatic eruptions, causing the water to explosively flash to steam leading to shattering of magma. Once in the air, ash is transported by wind up to thousands of kilometers away. Spence, et.al (1983).

The types of minerals present in volcanic ash are dependent on the chemistry of the magma from which it was erupted. Considering that the most abundant elements found in magma are silica (SiO_2) and oxygen, the various types of magma (and therefore ash) produced during volcanic eruptions are most commonly explained in terms of their silica content John N. Faick, (1963).

Photo graph 2.2 shows basaltic and dacite magma eruption. Low energy eruptions of basalt produce a characteristically dark colored ash containing 45%-55% silica that is generally rich in iron and magnesium . The most explosive rhyolite eruptions produce a felsic ash that is high in silica (>69%) while other types of ash with an intermediate composition (e.g. andesite or dacite) have a silica content between 55-69%.

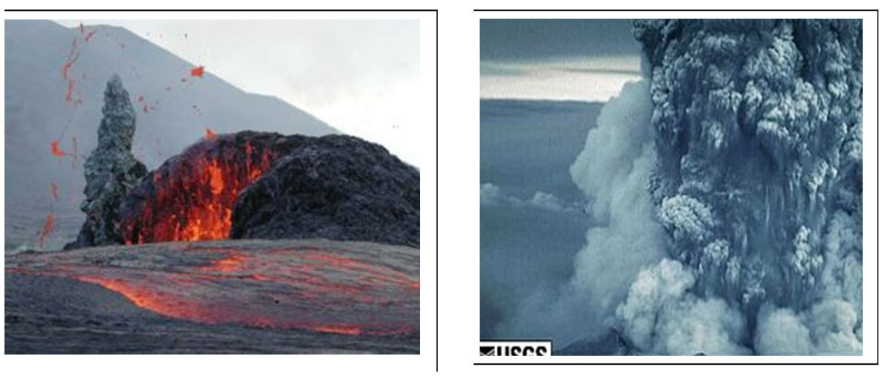


Photo graph 2.5: Volcanic Ash Basaltic Lava, (2003) (Siddique (2008))

2.6.2 Artificial Pozzolanas:

Artificial pozzolanas include a variety of industrial wastes, by-product and processed materials such as fly ash, blast furnace slag, silica fume, burnt clay and shells, metakoline and ash from agricultural wastes (rice husk ash, groundnut shell ash, bamboo leave ash and sugar cane baggase).

Definitions of examples of artificial Pozzolanas are as follows:

2.6.2.1 Coal Fly Ash (FA): (Rafat, (2008)):

Coal Fly ash (FA) is a by-product of the combustion of pulverized coal in thermal power plants. It is removed by the dust collection systems from the exhaust gases of fossil fuel power plants as very fine (Wesche, 2005), (Siddique et.al 2011),(ASTM C618-2000).Fly ash particles size primarily depends upon the type of dust collection equipment. It is generally finer than Portland cement. The Diameter of fly ash particles ranges from less than 1 to 150 micron.

The chemical composition of fly ash is determined by the types and relative amounts of incombustible material in the coal used. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline), aluminum oxide (Al_2O_3) and calcium oxide (CaO), both being endemic ingredients in many coal bearing rock strata.

2.6.2.2 Ground Granulated Blast Furnace Slag (GGBS): (Rafat (2008) and Ramezanianpour (2014))

GGBS is a by-product of the manufacturing of iron in a blast furnace where iron ore, limestone and coke are heated up to 1500°C.When these materials melt in the blast furnace, two products are produced –molten iron, and molten slag. The molten slag comprises mostly silicates and alumina from the original iron ore, combined with some oxides from the limestone. The process of granulating the slag involves cooling of molten slag through high pressure water jets. The granulated slag is further processed by drying and then grinding in a rotating ball mill to a very fine powder, which is GGBS.

2.6.2.3 Burned Clay and Shale :(Massaza (2004)):

Clay minerals gain a distinct pozzolanic activity when burned at temperatures between 600° and 900°C. These artificial pozzolanas are mostly composed of silica and alumina.

2.6.2.4Groundnut Shell Ash (GSA): (Alabadan, et.al (2006)):

The Groundnut shell is obtained after threshing/separating the shell from the nut using the threshing machine. The ash is obtained by burning the groundnut shells on an iron sheet in the open air under normal temperature. The possible use of Groundnut Shell Ash (GSA) will considerably reduce the cost of construction and as well as reduce or eliminate the environmental hazards caused by such waste. The utilization of this pozzolanas as a replacement for OPC will go a long way in actualizing the dreams of most developing countries of scouting for cheap and readily available construction materials. Groundnut shell ash has been used in concrete as a partial replacement material for cement.

2.6.2.5 Rice Husk Ash (RHA): (Rafat (2008) and Siddique and Khan (2011))

Rice-husk (RH) is an agricultural by-product material. It constitutes about 20% of the weight of rice. It contains about 50% cellulose, 25–30% lignin, and 15–20% of silica. When rice-husk is burnt rice-husk ash (RHA) is generated. On burning, cellulose and lignin are removed leaving behind silica ash. The ash typically contains approximately 90% silica and is therefore an excellent Pozzolana. The ash produced by controlled burning of the rice husk between 550°C and 700°C temperature for 1 hour transforms the silica content of the ash into amorphous phase. The reactivity of amorphous silica is directly proportional to the specific surface area of ash. The ash so produced is pulverized or ground to required fineness and mixed with cement to produce blended cement.

2.6.2.6. Silica Fumes (SF): (Siddique and Khan (2011)):

Silica fume (SF) is a byproduct of the smelting process in the silicon and ferrosilicon industry. The reduction of high-purity quartz to silicon at temperatures up to 2000°C produces SiO_2 vapours, which oxidize and condense in the low temperature zone to tiny particles consisting of non-crystalline silica. By-products of the production of silicon metal and the ferrosilicon alloys having silicon contents of 75% or more contain 85–95% non-crystalline silica. The by-product of the production of ferrosilicon alloy having 50% silicon has much lower silica content and is less pozzolanic. Therefore, SiO_2 content of the silica fume is related to the type of alloy being produced. Silica fume is also known as micro silica, condensed silica fume, volatilized silica or silica dust. (See Photo graph 2.6).

Photo graph 2.6: Silica Fume Powder (Siddique and Khan (2011))

2.6.2.7 Sugar Cane Baggas Ash (SCBA): (Goyal, et.al (2007):

Sugarcane is one of the major crops grown in over 110 countries and its total production is over 1500 million tons. After the extraction of all economical sugar from sugarcane, about 40-45% fibrous residue is obtained, which is reused in the same industry as fuel in boilers for heat generation leaving behind 8 -10 % ash as waste, known as sugarcane bagasse ash SCBA. The SCBA contains high amounts of un-burnt matter, silicon, aluminum and calcium oxides. It is a very valuable Pozzolana material if carbon free and amorphous ash could be obtained by further combustion.

2.6.2.8 Bamboo Leaf Ash: (Dwivedi, et.al (2006):

The ash is obtained by firing Bamboo leaf in an open atmosphere and then heating it at 600°C for 2 hours in a furnace. Bamboo leaf is an amorphous material containing amorphous silica.

2.6.2.9. Meta Kaolin (MK): (Rafat (2008) and Siddique and Khan (2011)):

Metakaolin (MK) is a pozzolanic material. It is obtained by calcination of kaolinitic clay at a temperature between 500° C and 800° C. The raw material input in the manufacture of metakaolin ($Al_2Si_2O_7$) is kaolin clay. Kaolin is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. Kaolinite is the mineralogical term that is applicable to kaolin clays. Kaolinite is defined as a common mineral, hydrated aluminum disilicate, the most common constituent of kaolin. In the case of metakaolin, the change that is taking place is dehydroxylization, brought on by the application of heat over a defined period of time. (See Photo graph 2.7).

Photo graph 2.7: Metakaolin (Calcined clay) (Siddique and Khan (2011))

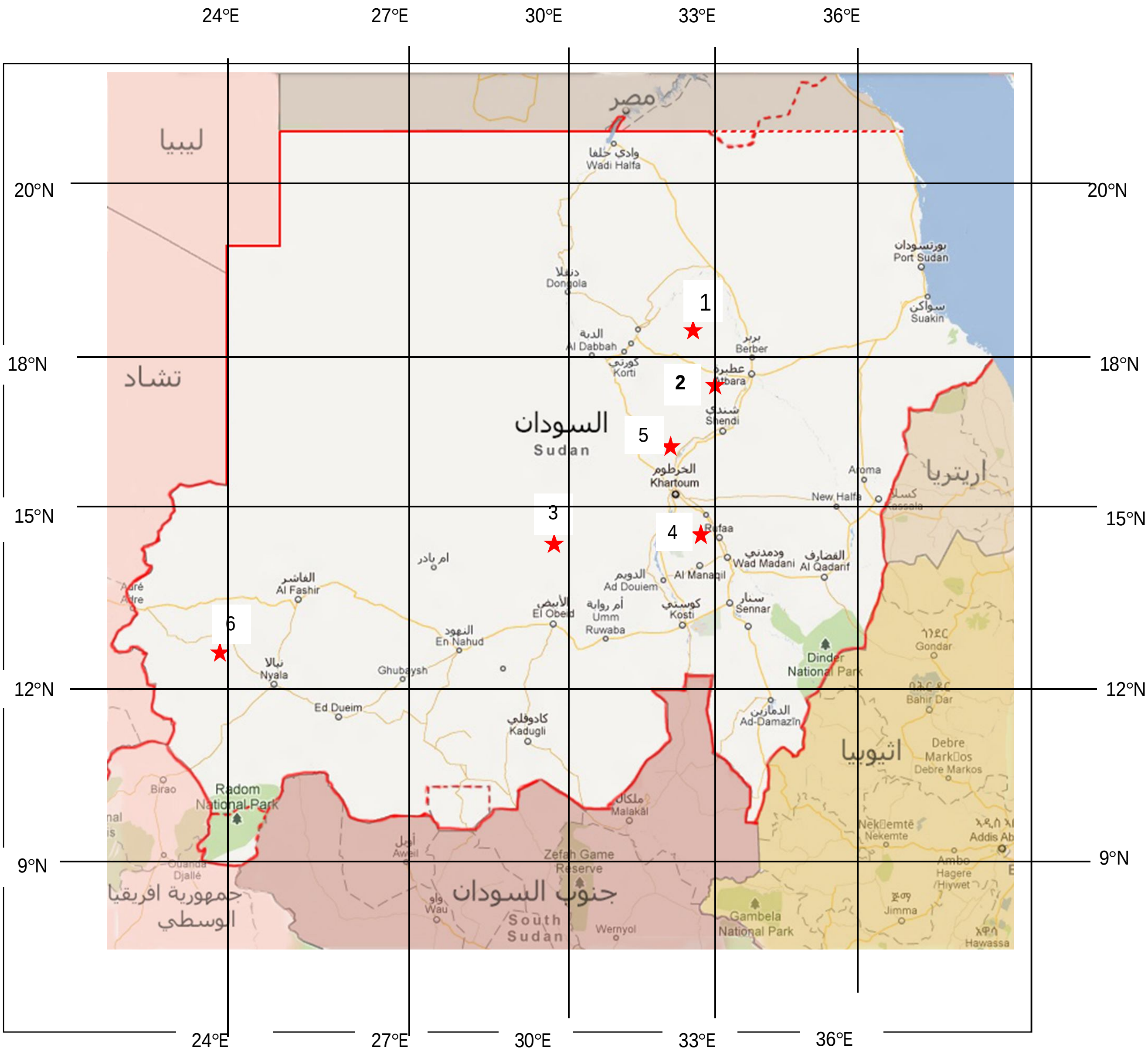


Figure 2.2: Locations of Natural Pozzolana in Sudan (GRAS 2014)

Legend:

1. Northern Bayuda Volcanic Ash
2. Southern Part of Bayuda Volcanic Ash
3. Abu Hadied Deposites (Northern Kordofan State) Volcanic Ash
4. Gregrieb Diatomite Deposits (Gezira State)
5. Ban Gadied Obsidian (Sabaluka Plateau)
6. Kass , Melem, Tina, Ktroum and Nyrtiti Volcanic Ash(Janub Darfour Jebel Marra)

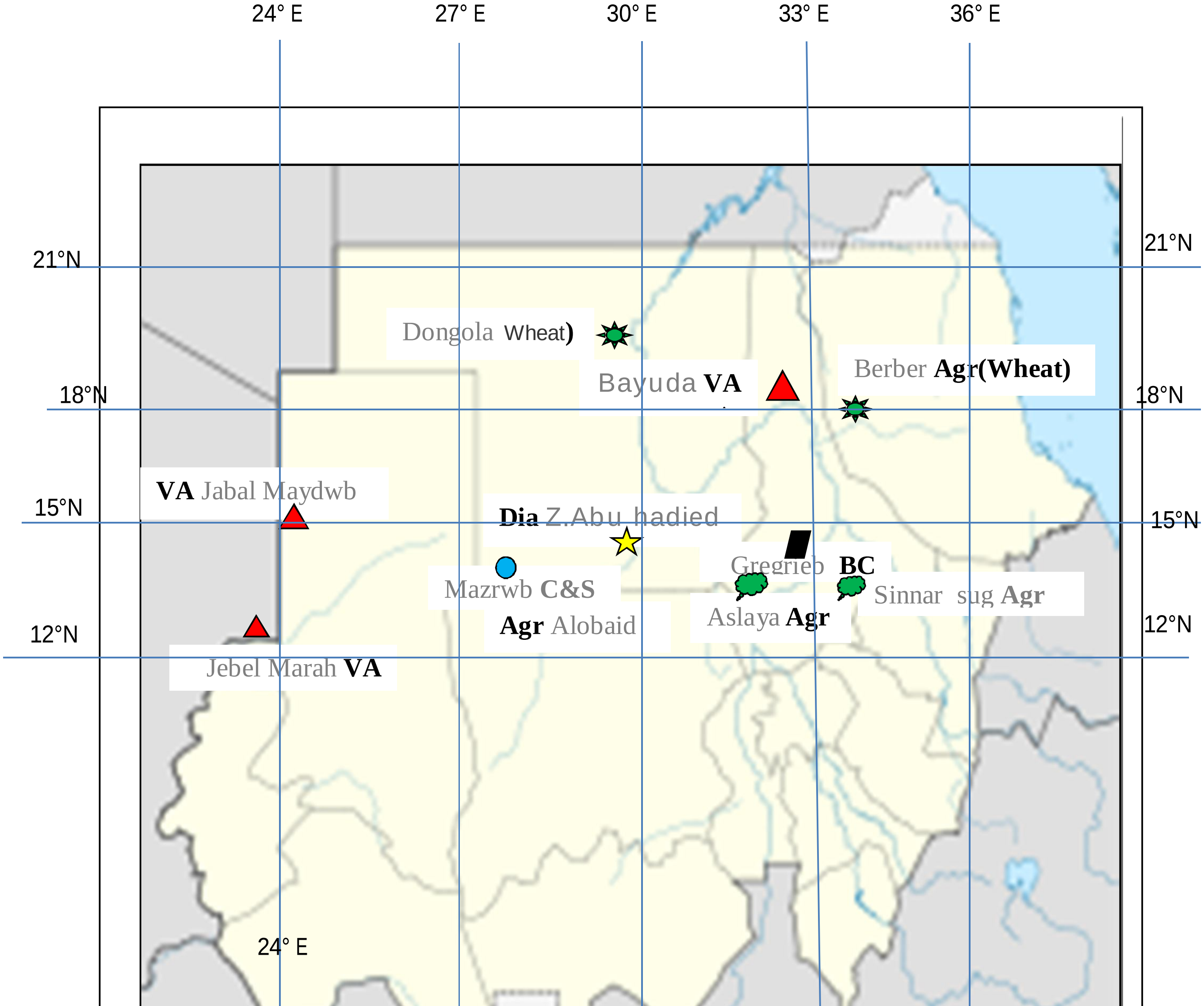


Figure 2.3: Location of Natural and Artificial Pozzolana Material in Sudan

Legend:

▲	VA = Volcanic Ash	(Natural)
☆	Dia= Diatomateous earth	(Natural)
●	C&S= Clay & Shell Pozzolana	(Artificial)
☁	BC= Black Cotton Soil Pozzolana	(Artificial)
✸	Agr= Agriculture Pozzolana: Sugar Cane and Wheat	(Agriculture)

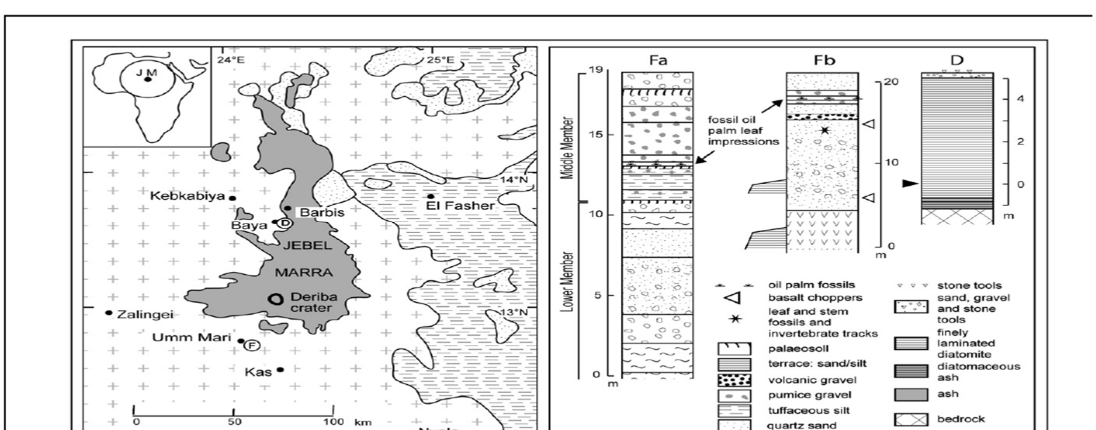


Figure 2.4: Location of Jebel Marra volcano, the diatomite site D east of Baya Philibert (2010)

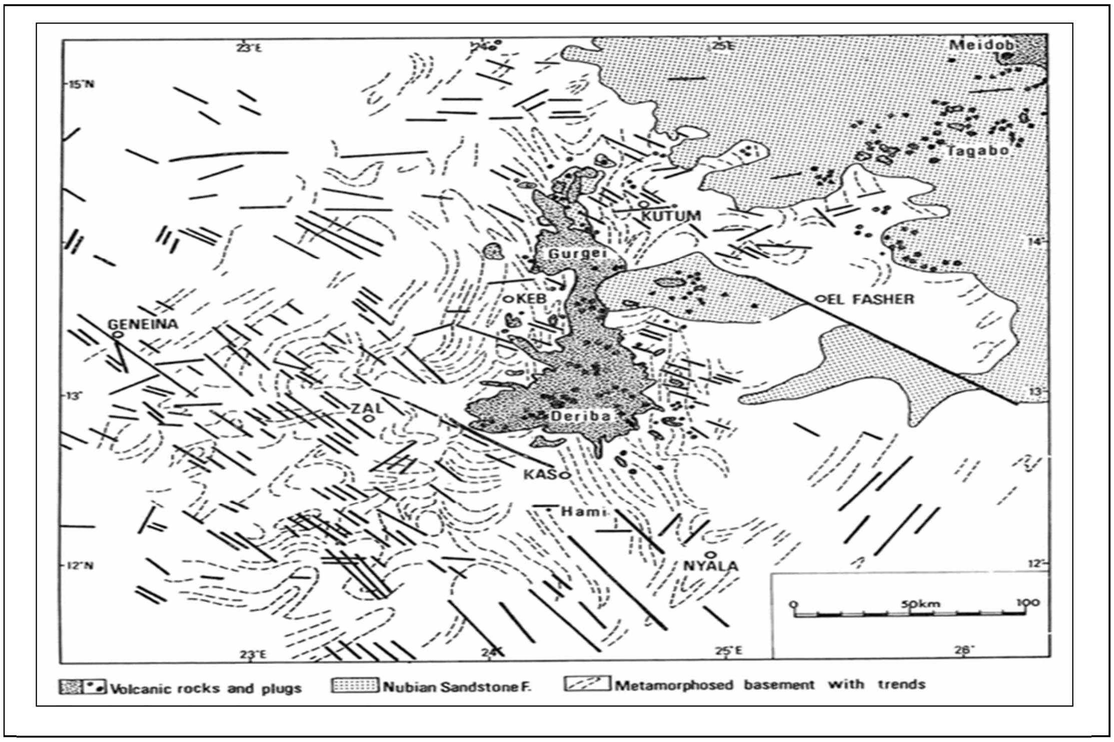


Figure 2.5: Regional geological map of Jebel Marra volcanic area vial (1972), Philibert (2010) and GRAS (2014)

three major advantages. Firstly, the properties of the cement will be improved. Secondly, as the costs of a Pozzolana are usually low and certainly well below that of lime or OPC, overall cost will be significantly reduced. Thirdly is the lowering carbon dioxide emitted during Portland cement production. Elijah (1995).

In OPC-based concretes pozzolanas are used to replace up to 30 per cent of OPC for use in structural applications and up to 50 per cent for non-structural purposes. The United Nations Centre for Human Settlements (UNCHS), estimates that only 20% of the worldwide use of cement requires the strength of OPC, and another 40% has intermediate strength requirements, and the remaining 40% used for applications such as mortars, plasters, foundation concrete, concrete blocks and soil stabilization, where low grade cements could be used Elijah (1995).

(Table B in Appendix B) shows countries which officially permit pozzolans: cement blends to be specified according to the standard for Argentina, cement allow anywhere from 10% replacement. Iceland to 50% replacement, China and Indonesia. Italy allows any amount of Pozzolana to be used as long as the specifications with respect to activity are met Robert (1990).

As previously mentioned, it is not necessary to use OPC for all purposes of construction industry. In fact pozzolanic cements can be more appropriate to a wide range of applications of construction. For this reason many countries worldwide produce and utilize natural pozzolanas in construction industry. Table C in Appendix B shows estimated world production of pozzolanic materials. As OPC is an expensive commodity in Sudan, usage of pozzolanic materials can minimize the cost. In addition pozzolanic cement has a number of significant technical advantages over the plain OPC. According to Mehata (1987), these advantages are explained below:

2.7.1 Increasing Compressive Strength:

At the early ages, Pozzolana addition to Portland cement lowers at late ages values than reference OPC age. As time goes on, Pozzolana keeps on reacting with the calcium hydroxide produced by cement hydration and increasing the compressive strength by producing additional C-S-H. As time the mixture gain strength and the strength approach that of pure OPC. Pozzolanic reaction keeps on until there is no free calcium hydroxide available in the mass and the compressive strength exceeds reference OPC.

2.7.2 Increasing Resistance to Chloride Attack:

Concrete deterioration caused by the penetration of chloride occurs faster when chloride ions react with calcium hydroxide to form strongly expanding hydrated calcium oxychloride. The expansion of hydrated calcium oxychloride enlarges the micro-cracks and increases the permeability that causes quicker chloride penetration and more damage.

Pozzolana added to cement can react with almost all the free calcium hydroxide and form a much denser paste. Thus, the penetration of chloride can be minimized and the penetrated chloride ions cannot find calcium hydroxide with which it can react. Lea (2004).

2.7.3 Increased Resistance to Sulfate Attack:

The calcium hydroxide produced by hydrating OPC is readily subject to sulphate attack which can cause a serious deterioration of the concrete, particularly in area with ground waters containing soluble sulphate, or in concrete in contact with sea water. In Portland-Pozzolana cements, the calcium hydroxide combine with Pozzolana to form more stable silicate or aluminates hydrate and therefore sulphate resistance is increased. Concrete made with Portland- Pozzolana cement is also more resistant to acid attack, although this is probably due to a reduction in permeability rather than any chemical reaction. Lea (2004).

2.7.4 Reduced Alkali-Aggregate Reaction:

Alkali-aggregate reaction sometimes called concrete cancer is caused by a reaction between the alkali environment of concrete and certain types of aggregate containing a form of silica which react with alkalis. Expansion due to alkali-aggregate reaction can be a serious problem with concrete structures. This undesirable expansion causes micro-cracks between hardened cement paste. Some experiments show that substituting only 25% of natural Pozzolana for OPC can reduce alkali-silica expansion by 70 %. Lea (2004).

2.7.5 Reduced Heat of Hydration

When Ordinary Portland cement hydrates it produces heat, known as the heat of hydration. The heat evolved during the hardening of Portland cement concretes is reduced by the substitution of Pozzolana though not proportionately to the degree of substitution since the reaction between lime and Pozzolana itself evolves some heat. As a rough approximation the percentage reduction in heat evolution at 7 to 28 days may be taken at about one-half the percentage substitution, but it varies appreciably for different Pozzolanic cement. Lea, F.M (2004) and Intermediate Technology Group (1992).

2.7.6 Reduced Permeability:

The permeability of a concrete made with a Portland-Pozzolana Cement will be reduced due to reduction of pore size in the concrete. Reduced permeability is particularly important in hydraulic structures and contributes to the increased sulphate and acid resistance of Portland-Pozzolana Cement. The permeability of concretes at early ages is not much influenced by the substitution of Pozzolana for Portland cement, but at longer ages under conditions of wet curing it becomes progressively lower. Lea, F.M (2004) and Intermediate Technology Group (1992).

2.7.7 Improved Workability:

Workability is a term used by the construction industry to describe the cohesiveness and water retaining ability of concrete or mortar.

A highly workable mix will have the desirable quantities of good cohesion, high water retention and low amount of bleeding (grout loss). Poor workability is a characteristic often associated with lean mixes (Low cement). It makes them difficult to place and can result in rapid drying which will result in a reduction in strength. In general, the use of Portland-Pozzolana Cement will improve workability, particularly for lean mixes. However for rich cement mixes, especially those with a high Pozzolana content, the reverse may be true due the increased demand of water of the Pozzolana. Intermediate Technology Group (1992).

2.8 Use of Pozzolana in Sudan:

2.8.1 Use of Pulverized Fuel Ash (PFA) in Sudan:

Dafalla (2006), presented a thesis on effect of PFA on fresh and hardened concrete. Mass concrete structures, such as dams, always require special measures to be taken to produce a qualified concrete. He stated that the use of PFA in concrete has become an accepted practice partly due to the large body of research work conducted in the area of blended cement to have a consistent concrete and to eliminate heat of hydration as well as to improve the quality of concrete. His research was formulated to evaluate the performance of concrete when PFA was used at Merowe Dam project, as a replacement of cement in the range 0% to 35% and changing the water –cement ratio from 0.45 to 0.65 in increments of 0.05. After full curing compressive strength tests were performed. His results showed low strength recorded in the early age with the increment of PFA.

2.8.2 Utilization of Pozzolanas in Sudanese Construction Industry:

A workshop held in 1999 on Pozzolana utilization in the construction industry in Sudan, jointly organized by the Sudanese Organization of Economic Alternatives, the Building and Road Research Institute of University of Khartoum and Sudan Engineering Society estimated that Pozzolana alone, as an alternative for OPC have a capital business share of around 6,000,000 USD per annum:

1. As for the use of Pozzolanas in Sudanese construction industry, calcined clays were used in 1920s to construct Sennar dam.

2. Khafja, a local term for a mixture of wasted bricks aggregate plus lime and/or cement is normally used for roofing in traditional Sudanese building also use in roof in confusing: it in a plaster on trip of roof as water proof of to enhance inclination.
3. Merowe dam, the presence of Bayouda Dessert Natural Pozzolans (BDNP) vicinity of 50 Km.
4. Also due to the existence of large sugar industry in Sudan, there is a potential of using baggase ashes as pozzolanic material in Sudan. Apart from these cases, there are neither sound engineering practice nor a drive and will to utilize pozzolans in domestic construction industry. Suleiman, (1999).
The lack of using pozzolans as cement replacement material may be attributed to scarce information on engineering properties of pozzolana blended cements. This trend is common almost in all African countries, apart from limited experiments in Egypt, Rwanda, Tanzania and Kenya. Also, it may be due to the industry's benefits imparted by blended Pozzolana cement. However, Mammon and EL-Zamzami, (2010) published a paper characterizing samples of BDNP using Indian standard. Their study was carried out from a geological perspective and involved chemical analysis, x-ray diffraction and compressive strength of lime and BDNP mixes.

The need for cement in the Sudanese construction industry has increased significantly in the last few years. This increase is due to the initiation of a vast public work construction program. Thus large quantities of cement have been imported to cover the specific needs of the construction sector. Despite the recent establishment of several new cement factories, the cost of Sudanese cement per tone is still far higher than its average international cost. International average cost per tone is 70 USD while producing Sudanese cement costs about 100USD and about 130USD to the end consumer in Khartoum (Alssalam Cement Factory Management Personal communication 2010).
Moreover, one of the challenges facing the Sudanese cements and concrete industry is production of durable concrete especially in coastal areas and economical concrete nationwide. The utilization of Bayouda desert volcanic ash and other similar resources may be the key for addressing these challenges. Bearing in mind the vicinity of Bayouda dessert to the Port-Sudan and the accessibility to Khartoum, there is a potential market for using this material in coastal area for resisting chloride and sulphate attacks. Suleiman (1999).

2.8.3 Use Blended Cement in Concrete Hollow Blocks:

Cement concrete hollow blocks have an important place in modern building industry. They are cost effective and better alternative to burnt clay bricks by virtue of their good durability, fire resistance, partial resistance to sound, thermal insulation, small dead load and high speed of construction. Concrete hollow blocks being usually larger in size than the normal clay building bricks, require less mortar and help in achieving, fast of construction. Also building construction with cement concrete hollow blocks provides facility for concealing electrical conduit, water and sewer pipes wherever so desired and requires less plastering.

The concrete hollow block is the main building material for walls of single-storey buildings (such as houses and schools) in South Darfur State.

As the cost of cement in Darfur is double the cost found in the rest of Sudan, viable alternatives need to be found to keep the production cost of concrete hollow blocks competitive. Lime, volcanic ash, and other Pozzolana are viable alternative binders, since several deposits of limestone and Pozzolanas exist in Darfur.

One of the environmental problems associated with traditional fired clay bricks is deforestation, as a result of the massive use of firewood in its production. It is estimated by different sources that one third of the forests in Darfur was lost between 1973 and 2006. UN-HABITAT (2009).

If all estimated 400,000 families currently displaced in Darfur return to their places of origin and reconstruct their destroyed homes utilizing the traditional building practices, with wood as the main structural element, they will need to find and cut an estimated 16 million mature trees. In light of the ongoing documented deforestation, this would be an environmental and economic disaster that must be avoided UN-HABITAT (2009). The construction of one room using fired clay bricks needed to find and cut an estimated 14 trees, see Photographs 2.8 and 2.9.

In Darfur UN-HABITAT has identified Stabilized Soil Block (SSB) technology as the one that can potentially provide an alternative building material for the re-construction challenge facing the returning population in Darfur. The technology allows for zero consumption of firewood and structural timber in building construction. The SSB cost effectiveness has been proved by comparing the cost of fired clay bricks construction with the SSB alternative showing a percentage saving of 54% through the adoption of the latter Table E, Appendix B. But the shift from fired clay brick to stabilized soil block was limited due to the lack of machines and skilled labor. The table also shows 50% saving by using hollow concrete blocks instated of burnt bricks. Using blended cement in the blocks can further increase the saving in cost.

Photo graph 2.8: Environmental threats, UN-HABITAT (2009) Transportation of wood to brick kilns

Photo graph 2.9: Brick kiln fired with wood Environmental threats UN-HABITAT (2009).

2.9 Review of Studies on Pozzolanity and cement Replacement:

As stated in section 2.2, Pozzolanic materials continue to be the current topic for research and subject for international conferences. The following sections present a brief review pr some of the studies on Pozzolanity and cement replacement that is related to this research problem.

Hamid (2002), examined the pozzolanity of some local fired clay from three locations in Sudan (blue Nile clay, kaolin clay, and black cotton clay) through the use of these clays in pozzolanic cement and lime-Pozzolana mortar after the identifications of their physical and chemical properties besides three choosen types of lime, focusing on the compressive strength for the mortar and pozzolanic cement cubes. The physical and chemical properties of these pozzolanas produced from these clays were found to flow the international requirements and the strengths obtained from the tests gave the possibility to use pozzolanic cement and mortar from these clays in building.

El-zamzami (2003), studied the components, requirements, and physical and chemical properties of the pozzolanic cement. The author concluded that partial replacement of cement with Pozzolana can change the properties of cement through the reaction between Pozzolana and calcium hydroxide resulting from cement hydration. This partial replacement (up to 30%) decreases the strength of the cement in the first days of hydration, but the strength increases with the time. He found that the addition of Pozzolana to cement can also decrease the heat of hydration so that the pozzolanic cement is suitable for the mass concrete. In addition the use of the pozzolanic cement reduced the alkali-aggregates reactivity.

Middendorf et.al (2005), had used a finely ground lime-Pozzolana binder (LPB) as an active mineral addition to the binder in concrete to reduce the amount of cement used in high and ultra-high performance concrete. The very fine limestone particles, having size between 0.1and10 μm, can fill the gaps between OPC and the gaps between fine aggregate grains. The result is a much denser matrix. Their results suggested that the quantity of cement can be reduced while maintaining equivalent strength by using a systematic procedure to optimize the OPC/LPB ratio while maintaining a constant water/fines ratio and constant consistency.

Moncada and Godbey (2005), had provided comparative field laboratory test data for lime-Pozzolana and Portland cement -lime mortars including compressive strength, sand carrying capacity, board life (setting time), and unit masonry yield, under different curing conditions. They found that the high lime-Pozzolana content mortar (HL-P) laid more bricks, had higher yield, significantly longer board life, and significantly lower early compressive-strength than the high cement content mortar

(HCC). Water retention and sand carrying capacity for the high lime-Pozzolana mortar were higher and the air contents were lower.

Atiemo (2005), presented a detailed description of Pozzolana production in Gana, which can be used to replace at least 30% cement for shelter construction. The final product Pozzolana cement had been found to confirm to international standards and suitable for housing delivery. He also proofed that the use of Pozzolana cement a technically and economically viable option. The equipment of Pozzolana production also can be fabricated locally and the production process is quite simple.

Frias et.al (2005), discussed in their paper, the effects of using different pozzolonic materials as a partial cement replacement material in mortar mixes. An experimental study of mortar made with Ordinary Portland cement (OPC) and 12% of OPC, replaced by different pozzolanic materials such as Fly Ash, Rice Husk ash, Silica Fume, Calcined Clay (Grog) and Slag (GGBS) were tested for the strength and durability properties, to determine the effect of these materials on mortar properties and was compared to control mortar mix. Mortar specimens were tested for compressive strength at age of 3, 7 and 28 days and flexural strength at age of 28 days. To investigate the mortar for its durability, the specimens after initial curing of 28 days were immersed in fresh water with solutions of 10% sodium sulfate (Na_2SO_4) and 10% magnesium sulfate ($MgSO_4$) for another period of 3 months. Through this period, the specimens were tested for compressive strength at 60, 90 and 120 days to evaluate its durability.

Al-Saleem (2006), studied the effect of ground natural Pozzolana which was incorporated in concrete at 20% as partial cement replacement on the properties of concrete. The properties of fresh concrete did not show significant change for both commercial blended Pozzolana cement concrete and pozzolanic concrete containing 20% Pozzolana. The blended Pozzolana cement containing more than 12% Pozzolana showed lower compressive strength compared to that of cement at all ages. These results suggest that local natural Pozzolana ground to fineness similar to cement are not fully activated. Several activation methods can be used to activate the pozzolanic reaction. The activation by calcinations did not show any benefit. However, activation by elevated temperature curing showed promising results for the increase in the strength development.

Ronald et.al. (2006), stated that alleviating poverty and reducing environmental pollution in less developed countries are important goals of sustainable development. Lower building costs and reduced pollution should make development more sustainable. Most often, concrete is made with Portland cement, produced in developed countries. Byproducts of Portland cement production are carbon dioxide and particulate matter, environmental pollutants that harm human health. Natural Pozzolanas are substitutes for Portland cement that include: diatomaceous earth volcanic ash and rice husk ash. They considered technology transfer from the United States of America to the Philippines. North America is more developed than is Southeast Asia and thereby provides a model for technology transfer in less developed parts of the world. They used Geographic Information Systems to map cement resources, safe drinking water sanitary toilet facilities, and makeshift housing. They stated that regions where poverty is prevalent and natural pozzolans are available can be targeted to develop more sustainable construction.

Velosa and Veiga (2008), concluded that Metakaolin is an adequate pozzolanic addition for lime mortars, providing adequate mechanical and water behavior characteristics for application in conservation mortars. They also conclude that a further advantage of lime/Pozzolana mortars is their lower environmental impact, when compared to cement mortars. They reached an important conclusion that the use of greater percentages of Pozzolana in a mortar doesn't necessarily imply improved characteristics. They found that for each particular pozzolanic product there are specific formulations that produce better results for the application that is being considered.

Ahmet and Sukru (2009), studied in their paper the effect of particle fineness on properties of Pozzolana Portland cement Mortars. The paper studied the change in particle fineness effects firstly setting times and the other properties like compressive strength and volumetric changes. The effects of the change in cement particle fineness on the properties of Portland Pozzolana cement were studied. Experiments were conducted with samples of Portland Pozzolana cement in five different fineness values. They found that as particle fineness increased, the first seven days compressive strengths of these types of cements increased and their setting times decreased. In addition, they had seen that when particle fineness increased, volume expansion values increased a little.

Mohja Mohamed (2010), presented an experimental investigation on the use of the natural Pozzolana in concrete mixes. The local natural Pozzolana used in her study was obtained from location in "Al-Grayegreeb" at central Sudan. The natural Pozzolanas were used to partially replace Portland cement with 10%, 20%, and 30% by mass of binder. Other mixes of burnt Pozzolana with lime were used at 10%, 20%, and 30% by mass. Comparisons of the setting time, compressive strength and workability were performed with control mix. She found that replacement with up to 20% Pozzolana can increase the initial setting time. Compressive strength depended on Pozzolana percentage and curing time. With Burnt Pozzolana and lime high compressive strength and increase in workability and setting time were noticed. She concluded that natural Pozzolana in Sudan (Al-Grayegreeb) can be used in concrete to replace the cement content.

Dabluk (2010), stated in his research that many materials are used to manufacture concrete to get high strength and to reduce the cost by locally available materials. He studied using Pozzolana of Volcanic ash excavated from the mountains in Bayoda desert as a partial replacement for cement and in different percentages of cement weight of 0%, 10%, 20%, 30%. The compressive strength of concrete was measured in different ages of 7, 14, 28 and 91 days. Also lime was added to Pozzolana of Volcanic Ash in the same previous ratios to study their properties to define the best quantities to be added to the concrete to get sufficient strength and to recognize the compressive strength development with time. The mix design for concrete mixture depended on decreasing the water content whenever the ratio of used Pozzolana is increased. Then the values of slump were close despite the difference of the ratio of Pozzolana or Pozzolana and lime, so as to get the highest available values for compressive strength of concrete.

It became evident to him from the tests results of the compressive strength for the different mixtures when the Pozzolanas of the volcanic ash were used in concrete in the ratio of 10% of the cement weight achieved the highest compressive strength values from all the other mixtures. In comparing the results among the mixtures in which pozzolanas with lime was used in the ratios of 0%, 10%, 20% and 30%, the highest value for compressive strength was found when the percentage of the pozzolanas of volcanic ash and lime was 30%.

Olauyi and Olusolake (2010), studied Compressive strength of Volcanic / Ordinary Portland cement Laterized concrete. Their study investigated the effect of the partial replacement of cement with volcanic ash (VA) on the compressive strength of laterized concrete. 192 cubes of 150mm dimension were casted and cured in water for 7,14,21 and 28 days of hydration with cement replacement by VA and sand replacement with by laterite both ranging from 0% to 30% respectively. While a concrete mix 28days target strength of $25\ N/mm^2$ was adopted, the result show that the density and compressive strength of concrete decreased with increase in volcanic ash content. The 28 days, density dropped from 2390 Kg/m^3 to 2285 kg/m^3 (4.4% loss) and the compressive strength from 25.08 N/mm^2 to 17.98 N/mm^2 (28% loss) for 0% to 30% variation of VA content with no laterite introduced. The compressive strength also decreased with increasing laterite concrete, the strength of the laterized concrete however increased as the curing age progressed.

Fareed Ahmed (2010), studied of compressive strength of concrete with coal power plant fly ash as partial replacement of cement and fine aggregate. The research study comprised concrete cubes made with OPC (Ordinary Portland Cement) and with different concentrations of fly ash replacing cement and fine aggregate. To achieve the aim of the study, total 81 concrete cubes were cast. Of the 81 cubes, 9 cubes were made with normal concrete, 36 cubes were made by replacing 25, 50, 75 and 100% of fine aggregate with fly ash and 36 cubes were made by replacing 10, 25, 50, and 75% of cement with fly ash. The cubes were 6"x6" in cross-section, and the mix design was aimed for 5000 psi. After proper curing of all 81 cubes, they were tested at 3, 7 and 28 days curing age. By analyzing the test results of all the concrete cubes, the following main findings were drawn. The compressive strength of concrete cubes made by replacing 100% fine aggregate by fly ash was higher than the concrete cubes made with OPC at all 3, 7 and 28 days curing ages. On the other hand, the compressive strength of concrete cubes made by replacing 10 and 25% cement by fly ash was slightly lower than the concrete cubes made with OPC at all curing ages, whereas, the compressive strength of concrete cubes made by replacing 50 and 75% of cement by fly ash were quite lower than the concrete cubes made with OPC at all curing ages.

Ose and Jackson (2012), examined Compressive strength and workability of concrete using natural Pozzolana as partial replacement of ordinary Portland cement. Their study investigated the use of natural clay Pozzolana as partial replacement of Portland cement in the production of concrete. Concrete cubes measuring 150mm×150mm×150mm were made from six different concrete mixes prepared by using Pozzolana to replace 0%,10%, 20%, 30%, 40% and 50% of Portland cement by mass. The workabilities of the fresh concrete mixes evaluated using the slump test and compacting factor test while compressive strengths of concrete cubes were evaluated at 7, 14, 21 and 28 days. The maximum compressive strength at all ages of testing was obtained at 30% replacement, corresponding to an increase of 3%,12%,24% and 19% compared to the 7-day, 14-day, 21-day and 28-day compressive strengths. Workability decreased with an increase in replacement percentage. They concluded Pozzolana can be used to partially replace ordinary Portland cement in the production of concrete without compromising strength.

Amit Mittal (2013), carried out parametric Study on use of Pozzolanic Materials in Concrete. The study discussed the utilization of pozzolanic materials in concrete as partial replacement of cement and stated that it is gaining immense importance today, mainly on account of the improvements in the long-term durability of concrete combined with ecological benefits. Fly ash, Ground Granulated Blast Furnace Slag (GGBS) and High Reactive Metakaolin (HRM) were the pozzolanic materials, which conformed to thrir requirements which being largely available in India. To study the effect of partial replacement of cement by these pozzolanic materials, they conducted studies on concrete mixes with 350 to 500 kg/cum cementitious material at 30%, 40%, and 50% replacement levels of fly ash; 50% and 60% replacement levels of GGBS and 7.5% and 10% replacement levels of HRM. In this paper, the effect of these pozzolanic materials on workability, setting time, density, air content, compressive strength, modulus of elasticity and permeability by Rapid Chloride Permeability Test (RCPT) were studied. Based on this study, compressive strength vs. W/C curves were plotted so that concrete mixes of grade M15 to M45 with different percentage of any of these pozzolanic materials can directly be designed.

Zoubir et.al (2013), studied the effect of Lime and Natural Pozzolana on Dredged Sludge Engineering Properties. They pointed out that dredging practices are a challenge for the development and maintenance of dams and ports activities. In geotechnical engineering, the valorization of dredging sediments and their use in public works increasingly prospected by researchers these last years. Several additives, such as cement, lime and mineral additives such as fly ash, silica fume and rice husk ash had been used for stabilization of soft soils. Lime as an additive is most commonly used to stabilize fine soils due to its effectiveness and economic usage. The study investigated the use of natural Pozzolana combined with lime for the stabilization of dredged dam sludge. Laboratory tests were undertaken to study the effect of natural Pozzolana, lime or a combination of both on the sludge’s engineering properties. Natural Pozzolana and lime were added to sludge at ranges of 0–20 and 0–8%, respectively. Consistency, compaction, unconfined compressive strength tests (UCS) and shear strength were performed on untreated and treated sludge samples to assess the physical and mechanical characteristics of the sludge. Treated samples were cured for 1, 7, 28 and 90 days. The results showed that the dredged sludge can be successfully stabilized by combining natural Pozzolana and lime.

Alaband et.al (2013), examined Ordinary Portland cement (OPC) and Bambara Groundnut Shell Ash (BGSA) concrete. 10%, 20%, 30%, 40% 50% and 0% ash was used in the mix to replace cement. The strength of cement/ash concrete increased with curing period but decreased with increasing ash percentage. The highest strength was 31.24 N/mm^2 and

20.68 N/mm^2 at 28 days for 0% and 10% ash respectively. They concluded that substitution of cement with ash in concrete formation was relatively possible not exceeding 10%.

Ravikumar et.al (2013), carried out experimental studies on strength and durability of mortar containing Pozzolanic materials. The paper discussed the effects of using different pozzolonic materials as a partial cement replacement material in mortar mixes. In the experimental study mortars made with Ordinary Portland cement (OPC) and 12% of OPC, replaced by different pozzolanic materials such as Fly Ash, Rice Husk ash, Silica Fume, Calcined Clay (Grog) and Slag (GGBS) were tested for the strength and durability properties. To determine the effect of these materials on mortar properties the result was compared to control mortar mix. Mortar specimens were tested for compressive strength at age of 3, 7 and 28 days and flexural strength at age of 28 days. To investigate the mortar for its durability, the specimens after initial curing of 28 days were immersed in fresh water with solutions of 10% sodium sulphate (Na_2SO_4) and 10% magnesium sulphate ($MgSO_4$) for another period of three months. Through this period, the specimens were tested for compressive strength at 60, 90 and 120 days to evaluate durability.

Daniel Yaw Osei (2013), examined ash Pozzolana and Palm Kernel Shells as replacements of Portland cement and crushed aggregate granite in concrete. The properties of concrete using Pozzolana and palm kernel shells as replacement of Portland cement and crushed granite were investigated. Twelve concrete mixes were produced by combining Pozzolana and palm kernel shells (PKS) to replace 10%, 20%, 30% and 40% of Portland cement and 20%, 30% and 40% crushed granite respectively in 1:2:4 control mixes. The workability of the fresh concrete mixes was evaluated using the compacting factor test. The compressive strengths and densities were evaluated at 7days, 14 days and 28 days. They found that the density and workability of concrete decreased as the Pozzolana and palm kernel shells content increased; however the maximum strength at each palm kernel shell replacement was reached at 20% Pozzolana replacement. The 28-day compressive strength ranged from 8.01N/mm^2 to 14.21N/mm^2, whereas the density ranged between 2163 kg/m^3 to 2317 kg/m^3. They stated that the effects of Pozzolana and PKS on the density and workability of concrete were similar, however their effects of the strength of concrete were remarkably different. Pozzolana and PKS can be used as partial replacement of Portland cement and crushed granite in the production of lightweight concrete.

Suleiman (2014), stated that Pozzolanas are natural or artificial materials that contain active silica and alumina, which on their own have little or no binding property. However when mixed with lime and water, they will set and harden like cement. Volcanic pozzolans are formed by volcanic lava resulting from pyroclastic events. The final product is hyper cooled by the action of the lava being thrown into the air where it cools rapidly below a certain threshold temperature. This product is primarily glass but with crystalline phases. The chemical composition range of these products is quite large but is characterized by a high SiO_2 content. He claimed that the ancient Greeks between 600 and 700 BC used Pozzolana for construction purposes and their techniques were later passed on to the Romans. A large quantity of untapped volcanic pozzolans (pumice, tuff and volcanic ash) in the Bayuda volcanic field was the area of his study. Chemical, physical, and mechanical tests were conducted to assess the suitability of using naturally occurring Pozzolana as a cement mortar additive.

According to the results recorded in his study volcanic Pozzolana can be used as cement replacement up to 30% for use in structural concrete applications which could compete OPC in quality and up to 50% for use in non-structural purposes such as mortars, plasters, renders, walling blocks and roofing tiles.

Ibrahim (2014), discussed in this paper evaluation of Jebel Marra Volcanic Ash as supplementary cementitious material for Use in Blended Cements. The increasing cost and scarcity of Portland cement has impacted negatively on the delivery of affordable housing and infrastructural development in many parts in Sudan, especially in Darfur. This work focused on the evaluation of the pozzolanic characteristics of the volcanic ash obtained from Jebel Marra (mountains) as potential. The study investigated the chemical, physical, and mineralogical substituent characteristics of the volcanic ash and its reactivity toward lime and cement. In addition, the compressive strengths of blended mortar containing volcanic ash different in percentage were tested at 7, 28, and 90 days. X-Ray Fluorescence and X-ray diffraction techniques were used for chemical and mineralogical analysis respectively. His results of the chemical analysis showed that the sum oxides of Silica, Alumina and Iron were 83.75%. The strength reactivity with lime was 4.2MPa, while the 28-days compressive strengths for the replacement level with cement 10%, 20%, 30%, 40%, and 50% were 38.9, 35, 29.33, 28.64, and 25 MPa respectively, against 41.33Mpa., for the control mix. These results indicated that the Jebel Marra Volcanic Ash possesses pozzolanic characteristics and is thus potential cementitious material for use in blended cement.

A/Ellatif and Mohamed (2014), studied the quality of Natural Pozzolanic Materials at Bayoda desert in Northern Sudan. The objective of their study was to find other alternative binding materials that can be blended with OPC to enhance the properties of fresh and hardened concrete as well as to reduce the cost of cement. Three Pozzolanic samples, were brought from different location at Bayoda desert. The samples were grounded firstly and tested for the chemical contents and after that mixed partialy replaced in the ratio of 0%, 10%, 20%, and 30% by weight of OPC to form concrete to detect the fresh and hardened properties of the mix. The recorded results showed that all the three samples were reactive material with amorphous silica and alumina that fulfilled the requirement of the Pozzolanic properties. The better strength tests were reached with sample with OPC, in comparison with pure OPC, gave some enhancement in workability of the mixes compared to pure OPC mix. Their recommendation was that the quality of natural pozzolanic material at Bayoda desert is good and confirmed with the standard properties of natural Pozzolana, can be mixed with OPC in the proportions to be used as pozzolanic cement to enhance some properties of concrete and mortars.

CHAPTER 3

Experimental Work

3.1 Introduction

To reach the purposes of this research, an experimental program is designed to measure the chemical and physical properties of Pozzolana, cement, fine aggregate, coarse aggregate, mortar and concrete.. The study mainly focuses on characterization of Pozzolana of south Darfour and their utilization to produce low cost cementing materials. Broadly the experimental program consists and materials properties and concrete, mortar and concrete hollow blocks. It is detailed as follows:

1. Characterizations of materials to be used (physical and chemical properties).
2. Studying the effect of replacement levels on physical properties of fresh concrete and mortar.
3. Determinations of compressive strength of concrete from different blends at, 7, 28 and 90 days.
4. Determinations of compressive strength of blended mortar from different blends at, 2 and 28 days.
5. Determinations of the degree of the optimum proportion of Pozzolana for use in concrete, mortar and concrete hollow blocks.
6. Determinations of compressive strength of concrete hollow blocks at 28 days.
7. Determinations of chemical and mineralogical composition of 20% replacement blended cement.

3.2 Materials Selection:

The Materials used in the study are sand, cement, volcanic ash, coarse aggregate and water.

3.2.1 Portland Cement:

Ordinary Portland cement (OPC) of strength class 42.5 procured from Berber Cement Company was used throughout this research. It was standardized according to (Sudanese Standard 3998,2008), (EN-196-6 clause 4:1991, 2011/170/6) and (BS 12:1996). The physical and the chemical composition of the cement are shown in Tables 3.1 and 3.2 respectively. Appendix A Table A3 contains the chemical analysis of the OPC used.

Table 3.1: Physical Analysis of Berber OPC

Physical Properties	Berber OPC	EN.196 and BS 12:1996-2003
Specific gravity	3.15	2.53
Fineness(Retaining in Sieve No 90µm)	2%	Maximum 10%

Setting time: Initial (min) Final (hour)	 80 3	 Minimum 45 Maximum 10

Table 3.2: Chemical Composition of Berber OPC

Component %	Berber (OPC)	EN.196 and BS 12:1996-2003
LOI	2.09	3~5
SiO_2	20.62	20~25
CaO	62.58	60~70
Al_2O_3	4.38	3~8
Fe_2O_3	3.62	2~4
MgO	2.77	1~4
SO_3	2.42	1~5
Na_2O	0.28	≤1
K_2O	0.41	≤1

There are some factors, which have great role on compressive strength of the cement. These factors are derived from the chemical analysis of the sample as shown in Table 3.3 Jackson (2004) the factors are obtained as follows:

a. Lime Saturation Factor (LSF): the LSF controls the ratio of alite to belite in the clinker. A clinker with a higher LSF will have ahigher proportion of alite to belite than a clinker with low LSF. Typical LSF are 0.92-0.98. At LSF=1.

LSF is ratio of CaO to the other three main oxides. It is calculated as:

LSF= CaO -0.7 SO_3/(2.8 SiO_2+1.2 Al_2O_3+0.65 Fe_2O_3)……………...(3.1)

∴ for Berber OPC:

LSF= 62.85-0.7*2.42/(2.8*20.62+1.2*4.38+0.65*3.62=0.93

b. Silica Ratio (SR): A high SR means that more calcium silicates are present in the clinker on the cost of aluminates and ferrite.

SR (also known as the silica modulus) is defined as:

SR= SiO_2/ (Al_2O_3+ Fe_2O_3)……… ……………….(3.2)

∴ For Berber OPC:

SR= 20.62/(4.34+3.62)= 2.6

SR is typically between 2.0 and 3.0

c. Alumina Ratio (AR): AR is defined as:

AR= Al_2O_3 / Fe_2O_3 ……………………………….(3.3)

Which is obtained for Beber OPC as:

AR= 4.34/3.62 = 1.2

This determines the potential relative proportion of aluminates and ferrite phases in the clinker. An increase in clinker AR means there will be proportionally more aluminates and less ferrite in the clinker. In OPC clinker AR is usually between 1 and 4.

d. OPC Clinker: The Bogue Calculation

The Bogue calculation is used to calculate the approximate proportion of the four main minerals in Portland cement clinker.

The standard Bogue calculation refers to cement clinker, rather than cement, but can be adjusted for use with cement although the result is only approximate. The calculation is an extremely useful and widely-used calculation in the cement industry. The calculation assumes that the four main clinker minerals are pure minerals with compositions: calculated as follows:

- **Alite: C_3S or Tricalcium Silicate:**

C_3S = 4.071 CaO -7.0624 SiO_2-1.4297 Fe_2O_3-6.7187 Al_2O_3……….(3.4)

For Berber OPC:

C_3S = 4.071*62.58- 7.6024*20.62- 1.4297*3.62- 6.7187*4.38=63.4%

- **Belite: C_2S, or Dicalcium Silicate:**

C_2S = 8.6024 SiO_2+ 1.0785 Fe_2O_3+ 5.0683 Al_2O_3- 3.071 CaO…..(3.5)

For Berber OPC:

C_2S = 8.6024*20.62+ 1.0785*3.62+ 5.0683*4.38- 3.071*62.58=11.3%

- **Aluminate Phase: C_3A, or Tricalcium Aluminate:**

C_3A = 2.6504 Al_2O_3– 1.6920 Fe_2O_3 ……….……………………..(3.6)

For Berber OPC:

C_3A = 2.6504*20.62 – 1.6920*3.62= 5.5%

- **Ferrite phase C_4AF, or Tetracalcium Alumino Ferrite:**

C_4AF = 3.0432 Fe_2O_3 ....(3.7)

For Berber OPC:

C_4AF = 3.0432*3.62= 11.0%

Table 3.3 shows the Bogue composition and the strength factors of Berber OPC.

Table 3.3: Bogue composition of Berber OPC

Material	**Bogue Composition (%)**						
	C_3S	C_2S	C_3A	C_4AF	LFS	SR	AR

Berber (OPC)	63.4	11.3	5.5	11	0.93	2.6	1.2
EN.196 and BS 12:1996-2003	50~70	10~30	5~10	5~15	0.92~0.98	2~3	1~4

3.2.2 Fine Aggregate:

White Nile sand procured from Algitiaina, was used in present study. The sand was washed, dried, and sieved into different fractions with particle size distribution, specific gravity and absorption. It satisfies ASTM C-128 standards as shown in Table 3.4 (Appendix A Table A6).

Table 3.4: Properties of Fine Aggregate

Property	**Requirement by (ASTM C-128)**	**Test result**
Bulk Specific Gravity	2.5~2.75	2.64
SSD Specific Gravity	2.5~2.75	2.65
Apparent Specific Gravity	2.5~2.75	2.66
Absorption %	≤ 2%	0.25

3.2.3 Coarse aggregate:

Western Omdurman uncrushed course aggregate nominal size 20mm was used in this research with specific gravity and absorption, satisfying ASTM C-127 standards as shown in Table 3.5 (Appendix A Table A5)

Table 3.5: Properties of Coarse Aggregate

Property	**Requirement by (ASTM C-127)**	**Test result**
Bulk Specific Gravity	2.5~3	2.88
SSD Specific Gravity	2.5~3	2.89
Apparent Specific Gravity	2.5~3	2.92
Absorption %	≤ 2.5	0.38

3.2.4 Water:

Water is one of the most important materials required to produce mortar paste and concrete. Tap water from Khartoum city water network was used for the production and curing of the concrete and mortar cubes.

3.2.5 Pozzolana:

The Pozzolana samples used in this investigation were collected from four areas of Jebel Marra Volcanic Ash (JMVA). They were representative samples of volcanic ash, from Nyertity (NVA) at the western side of Jebel Marra, from Tina area (TVA), from Kotrom area (KTVA) and from Melem area (MVA) at the eastern side of Jebel Marra. These areas are shown in Figure 3.1. The ashes from these different sources were first studied for chemical and physical composition. The samples were obtained by pulverized quartering process and grounded and sieved to less than 45-μm grain size. They were characterized using chemical and physical analysis according to ASTM C 618. Appendix A Tables A1, A2 and A4, shows that the physical and chemical properties of Pozzolana requirements by Standard Specifications.

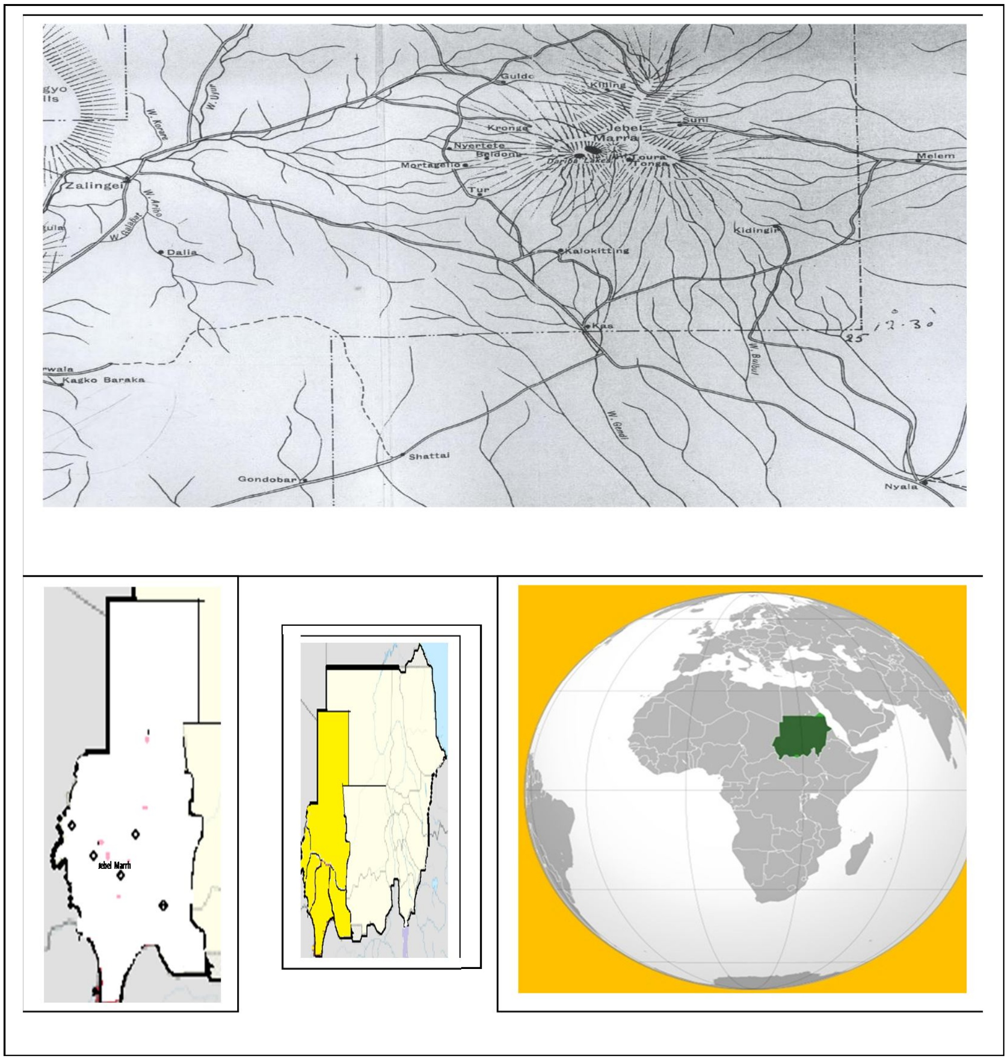


Figure 3.1 Location map of Natural Pozzolana Deposits in the Area of the Study. (At Jebel Marra in the West).

3.2.6 Coarse Aggregate Used in Concrete Hollow Blocks:

The particles retained on the No.4 or 4.7mm Indian standard sieve was designated as coarse aggregate used in hollow blocks. The maximum size of the coarse aggregate that may be used in cement concrete hollow blocks is 12.5mm. However, the particle size of the coarse aggregate should not exceed one third thickness of the thinnest web of the hollow blocks.

In this work for the determination of different characteristics of selected materials, many apparatus and instruments were used. See Appendices B photo graph 1.

3.3 Physical Characterizations of materials:

The physical properties such as fineness and specific gravity of the cement, sand, Pozzolana, and aggregate used in this study were determined in accordance with EN.196 , BS 12:1996-2003 and ASTM C-618. Also the consistency of cement paste and setting time were according to EN 196-3, ASTM-C187, slump and compressive strength of concrete were according to EN.123 and BS 1881-102.

3.3.1 Determination of Fineness:

Pozzolana is controlled in most cases by limiting the amount retained on the 45μm (No. 325) sieve by sieving and the Blaine air permeability test. Reactivity has been found to be directly related to the quantity passing this sieve, as coarser particles generally do not react. The maximum fineness recommended by the American standards for Pozzolana (ASTM-C618) limits the amount retained to 34% for natural Pozzolana. In this study fineness was determined by dry sieving using sieve 45μm (No.325).The test was carried out at MTE-CSA Laboratories.

3.3.2 Determination of Specific Gravity:

Specific gravity is the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Stones having low specific gravity are generally weaker than those with higher specific gravity values. Specific gravity of the cement, sand and Pozzolana was determined using a thermostatically controlled oven in accordance with ASTM-C127 and ASTM-C128. The tests were conducted at SUST-SL. The results are shown in appendices A Tables A5 and A6.

Specific gravity of the cement and Pozzolana were determined using a Le- Chartelier flask in accordance with IS 2720 part 3, at Central Laboratory for Technical Services and Calibration (CLTSC), the values obtained are shown in Table 3.6 and appendices A Table A4.

3.3.3 Determination of Grading using Sieve Analyses:

Sieve analyses are performed on aggregates used to get the weight of sample retained on each sieve and to determine the particle size distribution. The fine and coarse aggregate generally occupy 60%-75% of the concrete volume (70% to 85% by mass), and strongly influence the fresh and hardened concrete properties, mixture proportions and economy. Sieve analyses reveal the size makeup of aggregate particles – from the largest to the smallest, fine aggregate generally with most particles smaller than 5mm (0.2in), coarse aggregate larger than 5mm and generally between 9.5mm and 37.5mm.
A gradation curve or chart showing how evenly or unevenly the sizes are distributed between largest and smallest is created in this test, as shown in appendix A Tables A7 and A8 . How an aggregate is graded has a major impact on the strength of the base or on the properties and performance of concrete in accordance with AASHTO T-11 and T-27. Tables 3.6 and 3.7, show the sieve analysis of the fine aggregate and coarse aggregate respectively.

Table 3.6: Sieve Analysis of Fine Aggregate

Sieve No	% Passing AASHTO T11 & T27)	Fine Aggregate % Passing
(9.5mm)	100	100
No. 4 (4.75mm)	95 ~100	98.87
No. 8 (2.36mm)	80 ~ 100	94.7
No. 16 (1.18mm)	50 ~ 85	72.15
No. 30 (600µm)	25 ~65	64.35
No. 50 (300µm)	5 ~ 30	12.11
No. 100 (150µm)	0.0 ~ 10	6.08

Table 3.7: Sieve Analysis of Coarse Aggregate

Sieve No	% Passing (AASHTO T11 & T27)	Coarse Aggregate % Passing
" 2	100	100
"$1\,^{1}/_{2}$(37.5mm)	90 ~ 100	95.08
"$^{3}/_{4}$(19mm)	35 ~ 70	60.80
"$^{1}/_{2}$	25 ~ 50	37.31
"$^{3}/_{8}$(9.5mm)	10 ~ 40	16.67
"$^{3}/_{16}$(4.75mm)	0.0 ~ 5	1.14

3.3.4 Determination of Pozzolanic Activity:

The standard test method for flow of Hydraulic-cement mortar using the ASTM C 1437 is used to determine how much mortars specimen flows when it is unconfined and consolidated. The mortar flow is like a slump test for concrete and is used to measure relative workability but with different mould dimensions. Changes in flow indicate unpredictability in the materials and/or the batching procedure that may not be observed from slump testing alone. Mortar flow is most responsive to water content and air content. It is also more responsive than the concrete slump test of stiff concrete mixtures. The flow value must be $\pm$ 5 of the control mix flow shown in Table 3.8. The results of Pozzolana and water/ ratio are shown in Table 3.9. Mix properties for reactivity

The perceantage flow are calculated using:

$$\text{Flow (\%)} = \frac{SD-OD}{OD} *100 \qquad (3.8)$$

Where:

SD= Spread diameter

OD= Original diameter

Table 3.8: Data and Result of Mortar Flow Test for OPC (control)

Mix constituents gm				Water/binder			Flow%	Average flow
Sand	Cement	VA	Water	Ratio	Original diameter	Spread diameter		
1375	500	0	242	0.484	10	10.9	9	9.25
1375	500	0	242	0.484	10	10.95	9.5	

Table 3.9: Mix Proportion for Pozzolanic Reactivity with OPC

Mix constituents gm					Water/binder
Pozzolana code	OPC	VA	Water	Sand	Ratio
NVA	400	100	242	1375	0.48
MVA	400	100	252	1375	0.50
TVA	400	100	258	1375	0.52
KTVA	400	100	270	1375	0.54

Pozzolanic activity cannot be determined just by quantifying the presence of silica, alumina, and iron. The amount of amorphous material usually determines the reactivity of a natural Pozzolana. The constituents of a natural Pozzolana can exist in various forms, ranging from amorphous reactive materials to crystalline products that will react either slowly or not at all (Spence and Helmreich 1983).

The pozzolanic activity with strength activity index (SAI) with Portland cement is:

$$SAI = (A/B) *100 \qquad (3.9)$$

Where:

A = average compressive strength of test mix cubes.
B = average compressive strength of reference mix cubes.
Standard cube mortars were molded both from the control mixture and from a Pozzolana mixture that follows the requirements of (ASTM C109 -1999) for investigating compressive strength. Portland cement was replaced by Pozzolana under test at a rate of 10%, 20% and 30% by weight of cementation materials. (ASTM C618- 2005) specifies 75% at 28 days.

3.3.5 Determination of Standard Consistency:

The standard consistency of a blended cement paste is defined as the consistency which will permit the specific vicat plunger to penetrate to a point 5 to 7 mm from the bottom of the vicat mould. The blended cement was weighed and a paste was made by adding 29% water, observing that the gauging time is below 5 minutes. The paste was placed in the vicat mould and the plunger was released. If the penetration of the plunger was less or more than the specified value in BS:12 and ASTM C 187 the test was repeated by making fresh blend paste with different percentages of water.

3.3.6 Determination of Initial Setting Time:

The starting of the setting process of a blended cement paste is based on this property. The working time available with particular cement depends on initial setting time. The required cement paste was prepared, with cement or cement plus Pozzolana in case of blended cement and the water required for standard consistency as specified by BS:12 and ASTM C191-70 was used. The vicat mould was filled with this paste and the needle was released. The needle was observed to be piercing completely into the paste. The procedure was repeated until the needle failed to penetrate the cement paste for measured from the bottom of the mould. The period elapsed between the time when water was added to the cement and the time at which the needle failed to penetrate the required amount of penetration the initial setting time.

3.3.7 Determination of Final Setting Time:

The final setting time is used to describe the stiffening of cement paste. The needle for initial setting time was replaced by the annular attachment. The cement paste prepared to determine the initial setting time was placed beneath the attachment in the vicat apparatus. The attachment was brought down to the surface of the cement paste. Initially, both the central needle and the surrounding attachment made impression on the surface of the paste. Later when, the needle alone made the impression the time then was recorded as the final setting time as per BS: 12 and ASTM C 191-70.

3.3.8 Determination of Permeability:

The relationship between quality of concrete and Ultrasonic Pulse Velocity (UPV) of mortar specimens was studied by Yaman et.al (1998). According to ASTM C 597-97. The test is performed on each specimen at 2, 7 and 28 days. The UPV can be used for: the assessment of the uniformity and relative quality of concrete, the indication of the presence of voids and cracks, estimating the depth of cracks, evaluating the effectiveness of crack repairs, indicating changes in the properties of mortar, surveying of structures, and estimating the severity of deterioration or cracking. The ultrasonic pulse velocity depends on the density and elastic properties of the material being tested.
The UPV testing, described in ASTM C597-97, essentially consists of measuring travel time, T of ultrasonic pulse of 50 to 54 kHz, produced by an electro-acoustical transducer, held in contact with one surface of the mortar member under test and receiving the same by a similar transducer in contact with the surface at the other end. With the path length L, (the distance between the two probes) and time of travel T, the pulse velocity (V=L/T). Table 3.10 show that the higher the elastic modulus, density and integrity of the mortar, the higher is the pulse velocity. In this study, (UPV) is used as a nondestructive testing method to evaluate the effects of ultrasonic testing parameters such as transducer frequency and specimen geometry on cement mortars.

Table 3.10: General Guide lines for mortar quality based on UPV

Pulse Velocity (V)	Mortar Quality
> 4.0 km/s	Very good to excellent
3.5 ~ 4.0 km/s	Good to very good
3.0 ~ 3.5 km/s	Satisfactory but loss of integrity is suspected
< 3.0 km/s	Poor and loss of integrity exit

3.3.9 Determination of Compressive Strength:

Compressive strength is the most important property because it gives an indication of the mechanical strength of hardened cement and hardened concrete. The strength test appears in many specifications for Pozzolana and forms the basis for the ASTM Pozzolanicity Index. The compressive strength was determined by conducting tests on mortar cubes of standard dimensions,70mmx70mmx70mm (Photo 3.3). The moulds with specimen were kept in a moist room for 24 hours and then the moulds were detached from the specimens. The mortar cubes were kept in clean water for curing. Compressive strength was determined after 7 and 28 days, Three cubes were tested for each period and the average was reported as the compressive strength.
The same procedure was followed for testing concrete cubes except that the concrete cubes were of dimensions 150*150*150mm and testing ages

were extended to include the 90 days age. The details of mixes proportions are presented in Tables 3.13 and 3.14 the Pozzolana replacements were selected at 0%, 10%, 20% and 30% partial cement replacement by weight of cement content.

3.4 Concrete blocks:

3.4.1 Classification of Concrete Hollow Blocks:

Hollow (Open or Closed Cavity) Block is a block having one or more large holes or cavities which - either pass through the block (open cavity) or do not pass through the block (closed cavity) and having the solid material between 50 and 75 percent of the total volume of the block calculated from the overall dimensions (IS:2185:2005).

Solid Block is a block which has solid material not less than 75 percent of the total volume of the block calculated from the overall dimensions. The hollow concrete blocks shall conform to the following three grades:

Grade A - These are used as load bearing units and shall have a minimum bulk density of 1500 kg/m^3. These blocks have grades and minimum average compressive strengths as shown in Table 3.11.

Grade B - These are also used as load bearing units and shall have a bulk density between 1100 kg/m^3 and 1500 kg/m^3. These blocks have grades B (3.5) and B (5.0) that shall have minimum average compressive strengths of 3.5 and 5.0 N/mm^2 respectively at 28 days Table 3.11.

Grade C - Solid Concrete Block. The solid concrete blocks are used as load bearing units and shall have a bulk density not less than 1800 kg/m^3. These have grades C (4.0) and C (5.0) and shall have minimum average compressive strengths of 4.0 and 5.0 N/mm^2 respectively (Table 3.12).

The nominal dimensions of concrete block (Figure 3.2) are as follows:

Length: 400, 500 or 600 mm: Height: 200 or 100 mm Width: 50, 75, 100, 150,200, 250 or 300 mm. Water Absorption of the blocks is 10% maximum.

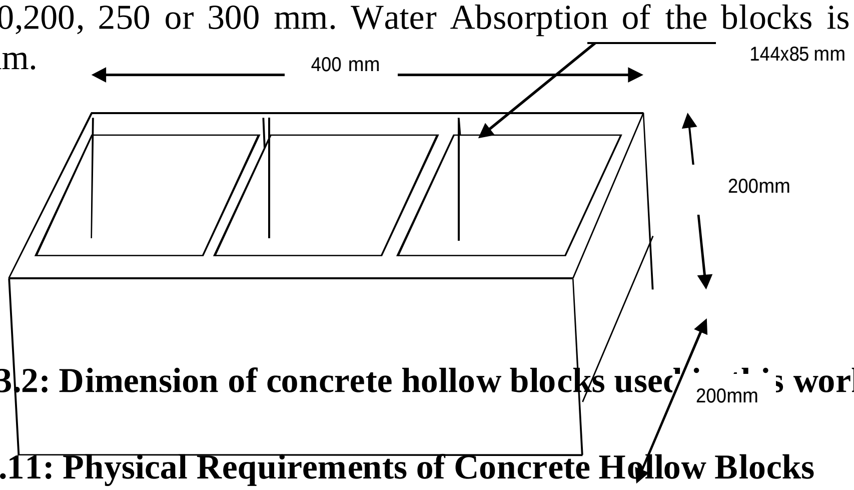


Figure 3.2: Dimension of concrete hollow blocks used in this work

Table 3.11: Physical Requirements of Concrete Hollow Blocks (IS:2185:2005).

Type	Grade	Density of Block Kg/m3	Compressive Strength 28 days
Hollow (open and closed cavity) load bearing unit	A(3.5)	Not less than1500	3.5
	A(4.5)		4.5
	A(5.5)		5.5
	A(7.0)		7.0
	A(8.5)		8.5
	A(10)		10
	A(12.5)		12.5
	A(15)		15
	B(3.5)	Less than 1500 but not less than 1100	3.5
	B(5.0)		5.0
Solid load bearing unit	C(5.0)	Not less than 1800	5.0
	C(4.0)		4.0

3.4.2 Testing and Curing Concrete Hollow Blocks:

Twenty four concrete blocks for each OPC-Pozzolana mix and three blocks for the control mix were tested for compressive strength at age of 28 days. The hollow blocks were removed from the moulds and protected for about 24 hours in a shelter away from sun and winds. Then, the hollow blocks were cured, by immersing them in a water tank, for 28 days.

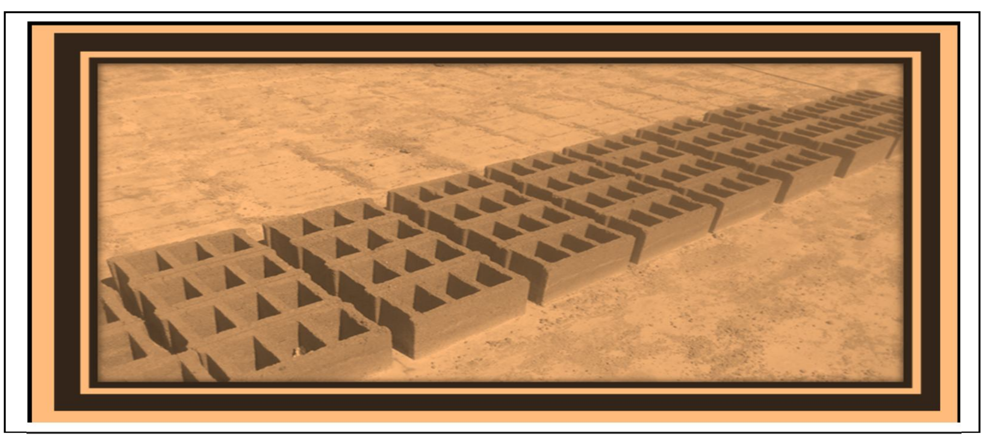


Photo 3.1: Casted concrete hollow blocks

3.5 Preparation and testing of concrete, mortar and concrete hollow blocks:

3.5.1 Concrete:

The materials used in this investigation are OPC, used as a base for all mixes, blended with volcanic ash. Firstly cement, fine and course aggregate were mixed, in a ratio of (1:2:4) in a mixer for one minute then water added, and all the materials mixed together.

Proportions to produce in all 13 blends, with the total of one hundred seventeen (117) specimens were prepared. The details of the mixes are given in Table 3.12.The cube specimens of standard size150mmx 150mm x150mm were casted for concrete. The moulds were covered in a plastic sheet with wet gunny sacks at the top to provide humidity during the hardening process. After 24 hours the specimens were demoulded and cured the specimens were cured in water for 7, 28, and 90 days and tested accordingly in order to establish the optimum strength mix proportions.

Table 3.12: Mixes Proportions for Concrete

Concrete code	Mass of Constituents(kg)			
	Cement	Pozzolana	Sand	Course Aggregate
(NM)	7.0	0.0	14	28
(NVA)10%	6.3	0.7	14	28
(NVA)20%	5.6	1.4	14	28
(NVA)30%	4.9	2.1	14	28
(MVA)10%	6.3	0.7	14	28
(MVA)20%	5.6	1.4	14	28
(MVA)30%	4.9	2.1	14	28
(TVA)10%	6.3	0.7	14	28
(TVA)20%	5.6	1.4	14	28
(TVA)30%	4.9	2.1	14	28
(KTVA)10%	6.3	0.7	14	28
(KTVA)20%	5.6	1.4	14	28
(KTVA)30%	4.9	2.1	14	28

3.5.2 Mortar:

The materials used in this investigation were OPC, used as a base for all mixes, blended with volcanic ash. Firstly cement and fine aggregate were mixed as a mortar mix of proportion of ratio (1:3) for one minute then 0.4% water added, and all the materials mixed together. Cube specimens of standard size 70mmx70mmx70mm were cast for mortar in different proportions to produce in all 13 blends, with the total of seventy eight (78) specimens. Blended Portland cement specimens containing 0%, 10%, 20% and 30% Pozzolana have been put in a curing tank for 2 and 28 days.

The three specimens that were cast for each proportion were tested at 2 and 28 days. And the final results of the test were the average of these three specimens result in N/mm^2 were recorded as the required strength. The tests were done at the MTE-CSA Laboratories. The details of mixes are given in Table 3.13.

The Pozzolana activity index tests were done to evaluate the pozzolaic properties. The pozzolanicity index is the ratio of the compressive strength of a Pozzolana mortar mix to that of a control made without Pozzolana, expressed as a percent.

Table 3.13: Mix Proportion for Mortar

Mortar code	% Replacement	Test age (days)	Number of specimens
(NM)	0	2\28	6
(NVA)10%	10	2\28	6
(NVA) 20%	20	2\28	6
(NVA) 30%	30	2\28	6
(MVA)10%	10	2\28	6
(MVA) 20%	20	2\28	6
(MVA) 30%	30	2\28	6
(TVA) 10%	10	2\28	6
(TVA) 20%	20	2\28	6
(TVA) 30%	30	2\28	6
(KTVA) 10%	10	2\28	6
(KTVA) 20%	20	2,28	6
(KTVA) 30%	30	2,28	6

3.5.3 Concrete Hollow Blocks Mixes:

A standard mix of one blended cement to six combined aggregate i.e. 1:2.5:3.5 (cement: sand: stone chips) was used for concrete hollow blocks. Batching was by weight and a constant water/cement ratio was used. Mixing was done manually on a smooth concrete pavement. For VA blending with OPC, each of the ashes was first thoroughly blended with OPC at the required proportion and the homogenous blend was then mixed with the aggregates. Water was then added gradually and the entire heap was mixed thoroughly to ensure homogeneity. Twenty seven concrete hollow blocks of 400 mm x 200 mm x 200 mm were produced. 12 blocks produced by 20% VA replacement another 12 blocks produced by 30% VA replacement and other three without replacement i.e. 0% VA to serve as control. The mix proportions are presented in Table 3.14.

Table 3.14: Ratio Used in Concrete Hollow Blocks (by mass)

Mortar	Blending ratio (By Weight %)	NO OF	Curing

code	(OPC)	(VA)	Sand	Stone Chips	Specimens	Age(days)
(Normal Mix)	1	0	2.5	3.5	3	28
(NVA) 20%	0.8	0.2	2.5	3.5	3	28
(NVA) 30%	0.7	0.3	2.5	3.5	3	28
(MVA) 20%	0.8	0.2	2.5	3.5	3	28
(MVA) 30%	0.7	0.3	2.5	3.5	3	28
(TVA) 20%	0.8	0.2	2.5	3.5	3	28
(TVA) 30%	0.7	0.3	2.5	3.5	3	28
(KTVA 20%)	0.8	0.2	2.5	3.5	3	28
(KTVA 30%)	0.7	0.3	2.5	3.5	3	28

CHAPTER 4
Results and Discussions

4.1 Introduction:

The results of characterization of the materials used in this work, both physical and chemical parameters are evaluated using variety of techniques to determine how the physical and chemical nature of materials would affect the performance. Then, the results for strength of mortars cubes, concrete cubes and the hollow blocks thoroughly stated and discussed to evaluate the optimum replacement percentage. The effect of the replacement on saving in cost is also evaluated considering a simple residential building.

4.2 Chemical Analysis of tested Jebel Marra Pozzolanas:

The results of the chemical analysis and standard requirements of Jebel Marra Volcanic Ash (JMVA), are presented in Tables 4.1 and 4.2. The chemical analysis was carried out at the chemical laboratory of the Geological Research Authority of Sudan (GRAS), Ministry of Mineral, Nile Avenue, Khartoum, Sudan, and results have been expressed as percentage. Tables A1 and A2 in appendix A contains the detailed chemical analysis results.

4.2.1 Nyertiti Pozzolana:

The result of the chemical analysis of Nyertiti Volcanic ash (NVA) as shown in Table 4.1and the standard chemical requirements for NVA in Table 4.2 indicated that the principal oxides of silica (SiO_2), Alumina (Al_2O_3) and Iron (Fe_2O_3) were substantially present in the samples investigated. The sum of oxides was 86.68%. The (alkalis= Na_2O % + 0.65 K_2O %) of the samples were found to be 7.4%, maximum loss on ignition less than 10% maximum, and $\mathbf{SO_3}$ was < 4.0%. These results are within the limitations for Pozzolana of ASTM C 618. Hence, the composition of NVA is suitable to be characterized as pozzolanic material, it is a good indication that material is pozzolanic.

4.2.2 Tina Pozzolana:

The result of the chemical analysis of Tina volcanic ash (TVA) as shown in Table 4.1 and the standard chemical requirements for TVA as shown in Table 4.2 indicated that the principal oxides of silica (SiO_2), Alumina (Al_2O_3) and Iron (Fe_2O_3) were substantially present in the samples investigated. The sum of oxides was 86.96% > 70% The (alkalis= Na_2O % + 0.65 K_2O %) of the samples were found to be 7.8% < 15% loss on ignition less than 10%, SO_3 was < 4.0%. These results are within the limitations for Pozzolana of ASTM C 618. Hence the composition of TVA satisfies the criteria for characterization as pozzolanic.

4.2.3 Melem Pozzolana:

Also the result of the chemical analysis of Melem volcanic ash (MVA)as shown in Table 4.1 and the standard chemical requirements for MVA as shown in Table 4.2 indicated that the principal oxides of silica (SiO_2), Alumina (Al_2O_3) and Iron (Fe_2O_3) were substantially present in the samples investigated. The sum of oxides was 86.12% > 70%. The alkalis are found to be 5% which is less than 15%, loss on ignition less than 10%, SO_3 was < 4.0%. These results are within the limitations for Pozzolana of ASTM C 618. There the composition of MVA satisfies the requirement for use as pozzolanic material.

4.2.4 Kotrum Pozzolana:

The result of the chemical analysis of Kotrum volcanic ash (KTVA) as shown in Table 4.1 and the standard chemical requirements for (KTVA) as shown in Table 4.2 indicated that the principal oxides of silica (SiO_2), Alumina (Al_2O_3) and Iron (Fe_2O_3) were substantially present in the samples investigated. The sum of oxides was 87.06% > 70% The (alkalis= Na_2O % + 0.65 K_2O %) of the samples were found to be 8.1% < 15% maximum loss on ignition less than 10%, maximum SO_3 was < 4.0%. These results are within the limitations for Pozzolana of ASTM C 618. There for the composition of KTVA satisfies the requirement for use as pozzolanic.

Table 4.1 Chemical Composition of Jebel Marra Pozzolana

Component %	Chemical composition of Jebel Marra Pozzolana			
	NVA	TVA	MVA	KTVA
SiO_2	64.5	62.40	60.60	60.90
Al_2O_3	16.31	18.47	18.59	19.80
Fe_2O_3	5.87	6.09	6.93	6.37
CaO	1.30	1.28	3.69	0.99
MgO	1.06	0.70	2.22	0.84
SO_3	0.02	0.03	0.02	0.03
Na_2O	4.15	4.89	2.72	5.56
K_2O	5.06	4.60	3.48	3.97
P_2O_5	0.13	0.14	0.14	0.14
TiO_2	0.56	0.58	0.74	0.66
LOI	2.20	4.50	6.60	6.60

Table 4.2: Chemical Requirements of Jebel Marra Pozzolana

	(NVA) Components	(TVA) Components	(MVA) Components	(KTVA) Components	Standard amount

Requirements	amount %	amount %	amount %	amount %	ASTM C618 %
$(Fe_2O_3$+ Al_2O_3+ $SiO_2)$	88.68	86.96	86.12	87.06	≤ 70
Calcium + Magnesium oxide + Alkalis	11.57	11.48	12.11	11.34	≥ 15
SO_3	0.02	0.03	0.02	0.02	≥ 4
Alkalis= Na_2O % + 0.65 K_2O % max. %	7.4	7.8	5.0	8.1	≥ 15
Loss On Ignition LOI, max. %	2.2	4.5	6.6	2.3	≥ 10

*** Note:** ≤ means not less than and ≥ means not greater than.

4.3 Physical Analysis of blended cement:

4.3.1 Water Consistencies:

Standard consistency can be measured by using the W/C ratio. The higher the W/C the more initial setting time needed. Initial and final setting times were determined for each blend is shown in Table 4.3.

The results presented in Table 4.3, indicate that replacement by any type of JMVA retarded the setting, but retardation was negligible and it was within limits specified in EN 196-3, ASTM C 187. It could have been due to the high adsorption capacity of JMVA. The higher the proportion of JMVA with higher the adsorption of water and hence the higher the amount of water retarding the setting time. Most natural pozzolanas tend to increase the water requirement in the normal consistency test as a result of their micro porous character and high surface area (ACI 232.1R 2000).

Table 4.3: Water consistencies, setting time limits of blended mixers

Mortar code	Consistency	Initial setting time	Final setting time

	%	(min)	(min)
(Normal Mix)	29.0	80	180
(NVA) 10%	29.5	95	190
(NVA) 20%	31.0	110	200
(NVA) 30%	32.0	115	225
(MVA) 10%	30.0	90	190
(MVA) 20%	31.5	95	210
(MVA) 30%	32.5	100	220
(TVA) 10 %	30.0	90	195
(TVA) 20%	32.0	98	200
(TVA) 30%	32.5	102	210
(KTVA) 10%	31.0	98	185
(KTVA) 20%	32.5	105	200
(KTVA) 30%	33.0	110	215

4.3.2 Setting Time Limits:

Table 4.3 shows the initial and final setting times of blended pastes and normal mix. The result indicates a delay in both the initial and final setting times of the blends as the quantity of the Pozzolana was increased in the mix. The exothermic reaction involved in the hydration of cement alone generates heat which contributes to the faster setting of the paste. The addition of the Pozzolana to the mix may have reduced the amount of heat generated; as a result, the paste gets to harden more slowly. The impact is clear where there is no addition of the pozzolanas (0% replacement) where the initial and final setting times were 80 and 180 minutes respectively, while at 30 % JMVA, the initial and final setting times were as high as 115 and 225 minutes respectively. The setting time delay was increasing as the percentages of Pozzolana were increasing, Table 4.4 shows that the maximum delay in setting time.

Table 4.4: Delay in Setting Time:

Mortar code	Consistency %	Initial setting time (min)	Final setting time (min)	Delay in initial setting time (min)	Delay in final setting time (min)
(NM)	29.0	80	180	-	-
(NVA) 30%	32.0	115	225	35	65
(MVA) 30%	32.5	100	220	20	60
(TVA) 30%	32.5	102	210	22	50
(KTVA) 30%	33.0	110	215	30	55

4.3.3 Ultrasonic Pulse Velocity (UPV):

Table 4.5 to Table 4.8, and appendix A Table A10, present the mean Ultrasonic Pulse Velocity (UPV) of cubical specimens. All the specimens were tested at 28 days. The mortar quality according to the standards in Table 3.11 is, also included in the tables. These show that the mortar quality for all, except two, mixes is good to very good. The quality for 30% NVA and 30% KTVA is very good to excellent. Figure 4.1 shows that the probability statistical analysis of ultrasonic pulse velocity for JMVA mortar. The Figure shows that the coefficient of variation is 3.48 , the mean of the samples is 3.88 and the correlation is 0.659.

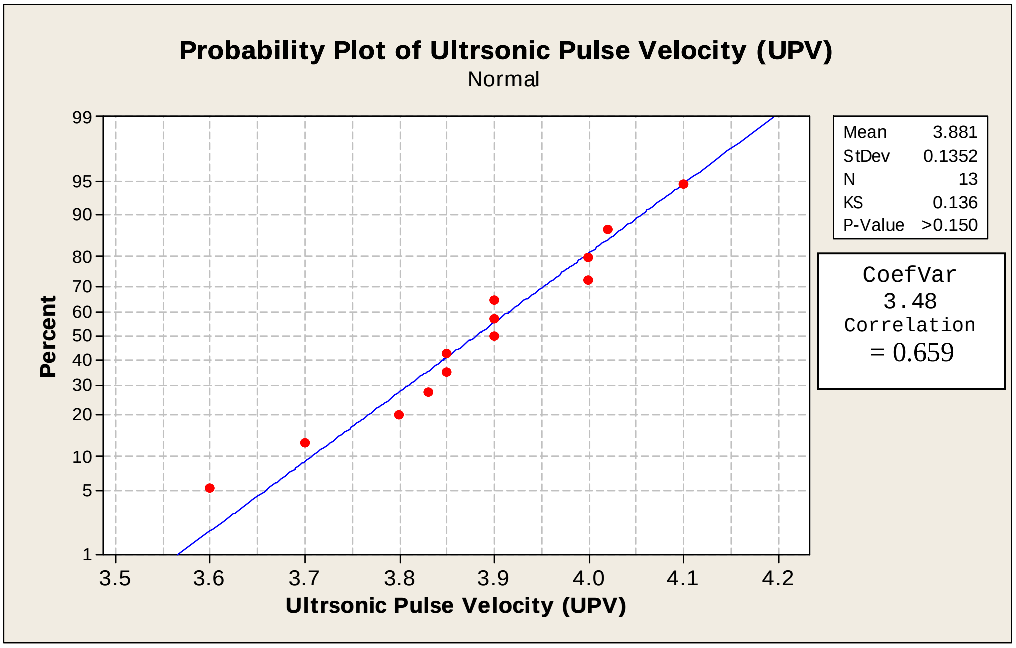


Figure 4.1: Statistical analysis for ultrasonic pulse velocity for JMVA mortar

Table 4.5: NVA Ultrasonic pulse velocity (UPV) at 28 days

Reference No	(NM)	(NVA) 10%	(NVA) 20%	(NVA) 30%
Specimen No 1 reading(μ sec)	18.3	17.2	17.2	17.2
Specimen No 2 reading(μ sec)	20.8	17.3	17.6	17.0
Specimen No 3 reading(μ sec)	18.7	18.2	17.2	17.5
Average Km/sec	**3.6**	**3.9**	**4.0**	**4.1**
*Mortar Quality	Good to very good	Good to very good	Good to very good	Very good to excellent

*(According to standard in Table 3.11)

Table 4.6: MVA ultrasonic pulse velocity (UPV) at 28 days

Reference No	(NM)	(MVA) 10%	(MVA) 20%	(MVA) 30%
Specimen No 1 reading(μ sec)	18.3	18.2	18.2	18.2
Specimen No 2 reading(μ sec)	20.8	18.0	18.0	18.0
Specimen No 3 reading(μ sec)	18.7	18.7	18.5	17.8
Average km/sec	**3.6**	**3.83**	**3.85**	**3.9**
*Mortar Quality	Good to very good	Good to very good	Good to very good	Good to very good

*(According to standard in Table 3.11)

Table 4.7: TVA ultrasonic pulse velocity (UPV) at 28 days

Reference No	**(NM)**	(TVA) 10%	(TVA) 20%	(TVA) 30%
Specimen No 1 reading(μ sec)	18.3	19.2	18.5	18.7
Specimen No 2 reading(μ sec)	20.8	18.3	19.2	18.0
Specimen No 3 reading(μ sec)	18.7	18.7	18.1	17.9
Average Km/sec	**3.6**	**3.70**	**3.80**	**3.9**
*Mortar Quality	Good to very good	Good to very good	Good to very good	Good to very good

*(According to standard in Table 3.11)

Table 4.8: Ktroum Volcanic ash (KTVA) main (UPV) of all specimens at 28 days

Reference No	**(NM)**	(KTVA)10%	(KTVA) 20%	(KTVA)30%
Specimen No 1 reading(μ sec)	18.3	18.0	17.0	17.8
Specimen No 2 reading(μ sec)	20.8	18.0	17.7	17.0
Specimen No 3 reading(μ sec)	18.7	18.5	17.5	17.5
Average Km/sec	**3.6**	**3.85**	**4.0**	**4.02**
Mortar Quality	Good to very good	Good to very good	Good to very good	Very good to excellent

*(According to standard in Table 3.11)

The effect of Pozzolana volcanic ash on the ultrasonic pulse velocity **(**UPV) was investigated for all specimens. Figure 4.2, presents the UPV for JMVA of the mortars used in the study determined at 28 days of age. It shows that when percentage of JMVA increases the UPV increases.

The variation of the relative UPV of mortar with replacement is presented in Figures 4.3 to 4.6. It can be seen from these tables that, the UPV ratio increases when the percentage of natural Pozzolana of Jebel Marra volcanic ashes (NVA, MVA, TVA and KTVA) increases.

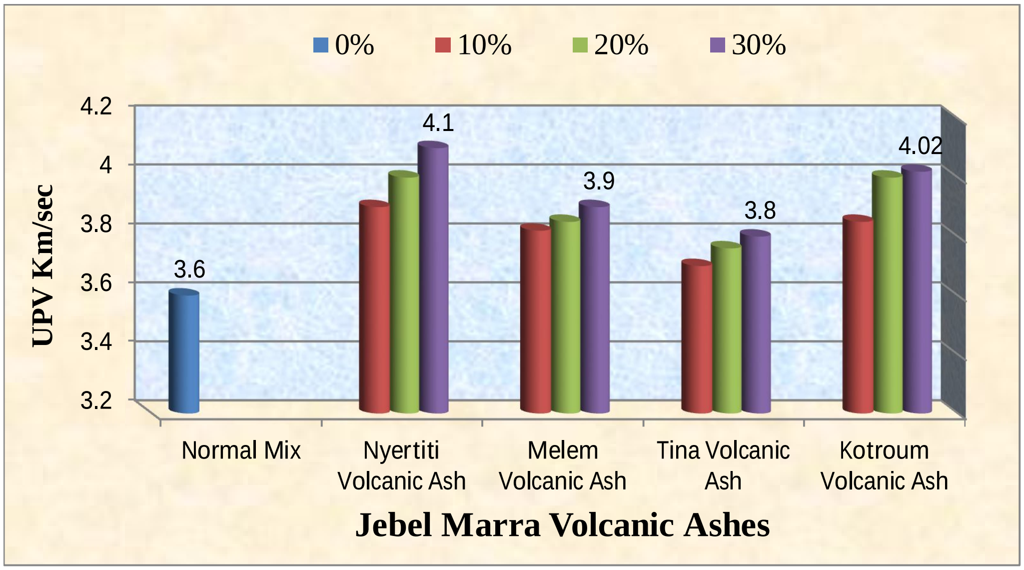


Figure 4.2: UPV **of different studied JMVA mortar mixes at 28 days**

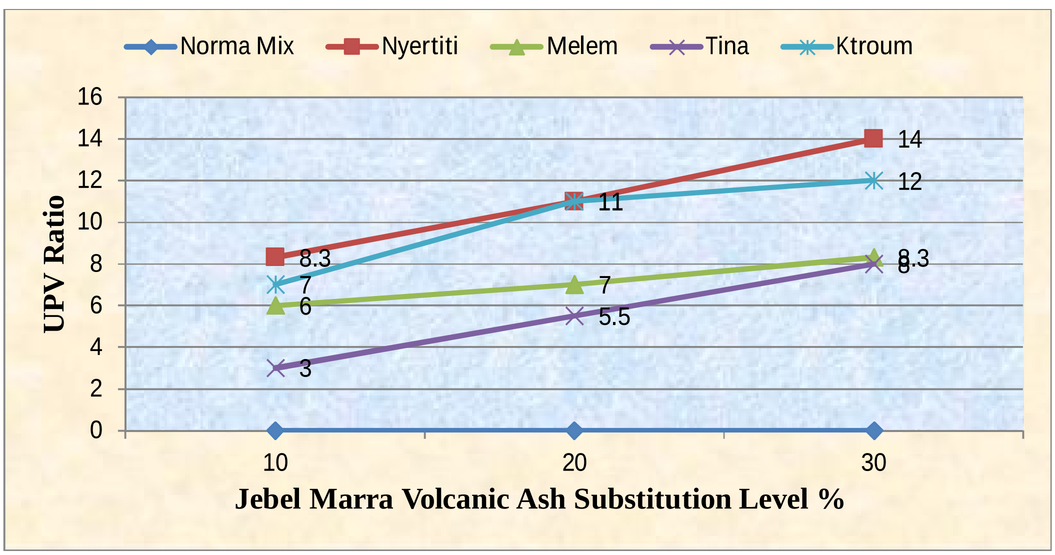


Figure 4.3: UPV Variation according to % Relative UPV of JMVA

4.3.4 Fineness of Pozzolanic Samples:

Table 4.9 shows that Nyertiti, Melem, Tina and Ktroum volcanic ashes specimens finerers test result as compared with ASTM requirement.
ASTM C 618 limits the max percent retained on sieve 325 (45µm) by 34% so all tested Pozzolana passing this requirement. NVA is finer than KTVA which in turn is finer than MVA and TVA which has the least fineness.

Table 4.9: Fineness of Nyertiti, Melem, Tina and Ktroum volcanic ashes

Pozzolana Specimen	Total Weight (gm)	% by Weight retained (gm) on sieve # 325 (45µm)	% by Weight Passing	% ASTM C618 Requirement retained sieve # 325 (45µm) max
(NVA)	100	14	86	34
(MVA)	100	18	82	34
(TVA)	100	28	72	34
(KTVA)	100	17	83	34

4.3.5 Specific Gravity (SG) Result:

Table 4.10 and Tables A4, A5 and A6 in appendix A show specific gravity for Ordinary Portland cement, sand, coarse aggregate, JMVA. All the specific gravity values are in the standard range. Each of JMVA samples has a specific gravity less than the specific gravity OPC. This means the cement is finer than the JMVA samples.

Table 4.10: The Specific Gravity (SG) of the Materials

Materials	OPC	Aggregate		Pozzolana			
		Fine	Coarse	NVA	MVA	TVA	KTVA
SPG	3.15	2.65	2.88	2.59	2.54	2.58	2.61

4.4 Strength and Strength Activity Index of Mortar:

4.4.1 Compressive Strength of Mortars:

The compressive strength of the mortars with OPC and JMVA were determined and the results are shown in Table 4.17 and appendix A Table A11. The reaction between Pozzolana and calcium hydroxide happens after the cement begins to hydrate. At the early age the strength and blended cement. Lower than reference OPC mortar.
With time, Pozzolana keeps on reacting with the calcium hydroxide, and as the compressive strength increases. Figure 4.4 shows the statistical analysis of mortar compressive strength. Accordingly coefficient of variation is 7.75, the mean of the samples is 41.05 N/mm² and the

correlation is 0.993. The results in Figures 4.5 to 4.8 show that the compressive strength increases by time. The high reduction in the compressive strength values observed in most of the mortar Pozzolana samples could be attributed to fineness.

The, high substitution has low compressive strength as seen in Figures 4.5 to Figure 4.8, but as the time goes on the strength increases. Thus, high substitution can be used in the long term strength projects and in non-structural use.

At 28 days, the compressive strength of mortar with 10%, 20% and 30% of NVA and KTVA is higher than that of the reference OPC mortar. Therefore NVA and KTVA can be used in mortar with up to 30% replacement. Figure 4.9 shows that after 28 days 20% replacement begins to exceed reference OPC in compressive strength, for all JMVA samples. Also it can be seen that the NVA samples gave the best results.

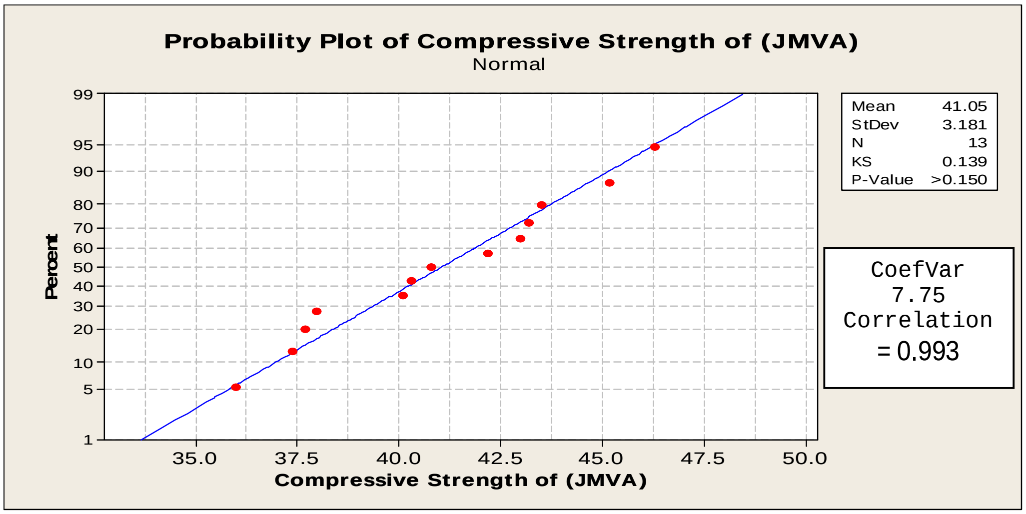


Figure 4.4: Variation and compressive strength of JMVA mortar (Statistical data)

Table 4.11 Compressive strength of blended mortars (Pozzolana mixed with OPC)

Sample designation	% Pozzolana Replacement	Compressive strength N/mm² Age (Days) 2 Strength	2 % increase	28 Strength	28 % increase
(NM)	0	20.4	-	40.8	-
(NVA)	10	20.7	+1	43.5	+6
	20	19.4	-5	46.3	+13
	30	17.8	-13	43.0	+5
(MVA)	10	18.0	-12	36.0	-12
	20	16.0	-22	40.1	-2
	30	15.0	-26	37.4	-9
(TVA)	10	20.0	-2	38.0	-7
	20	17.0	-17	40.3	-2
	30	15.0	-26	37.7	-8
(KTVA)	10	20.0	-2	43.2	+5
	20	18.7	-8	45.2	+10
	30	17.7	-13	42.2	+3

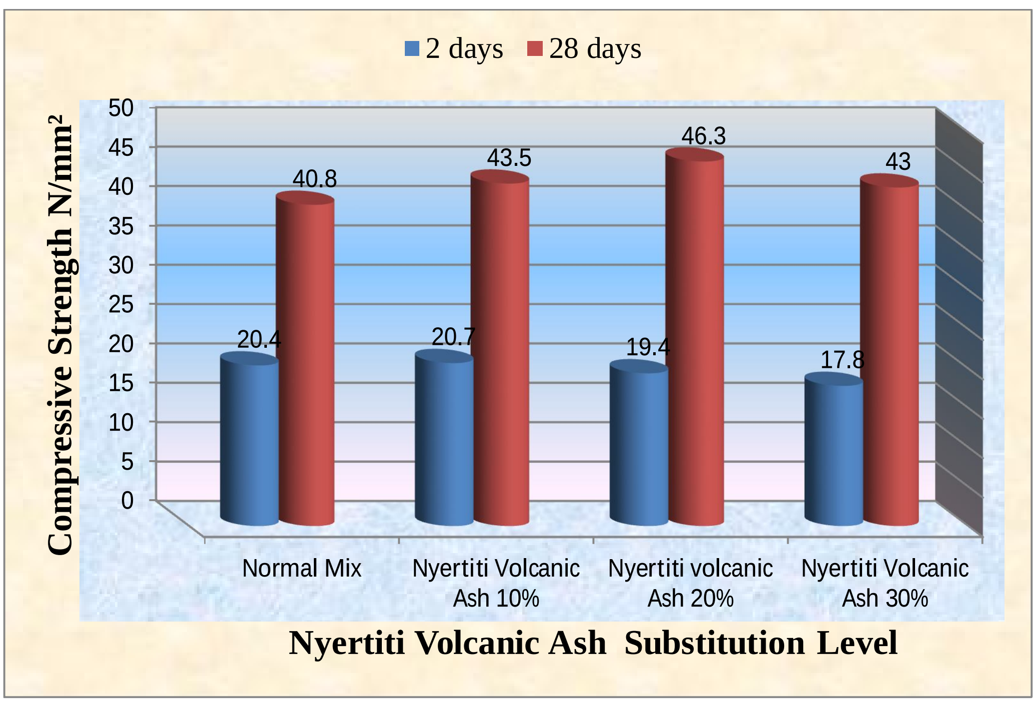


Figure 4.5: Compressive Strength of NVA blended mortar

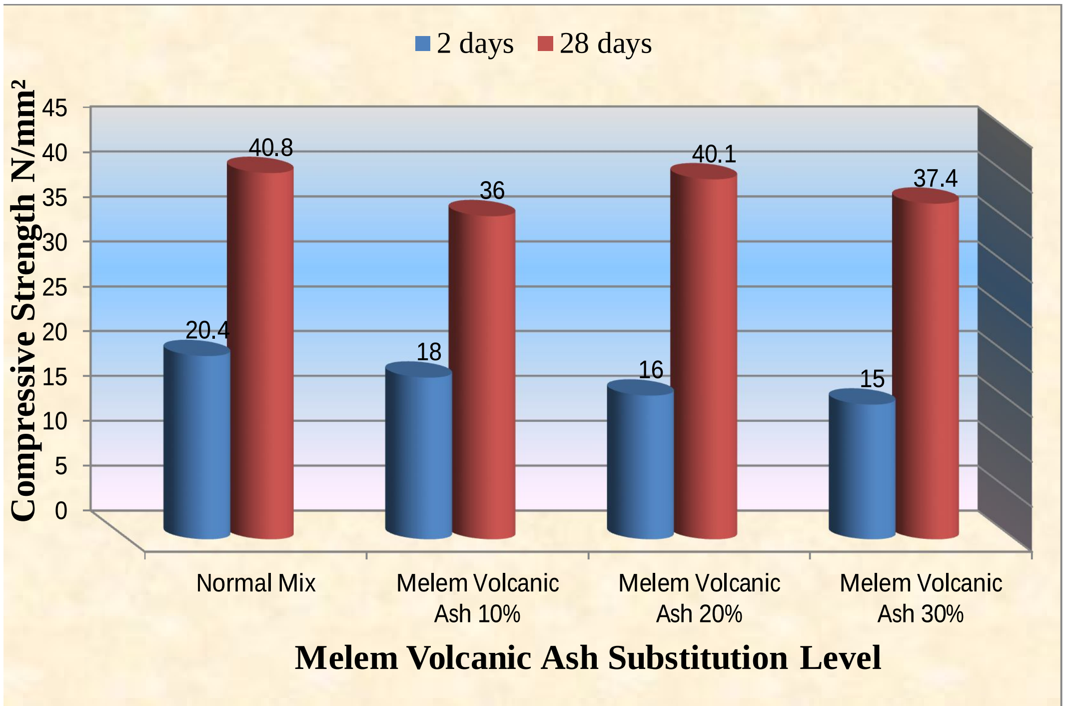
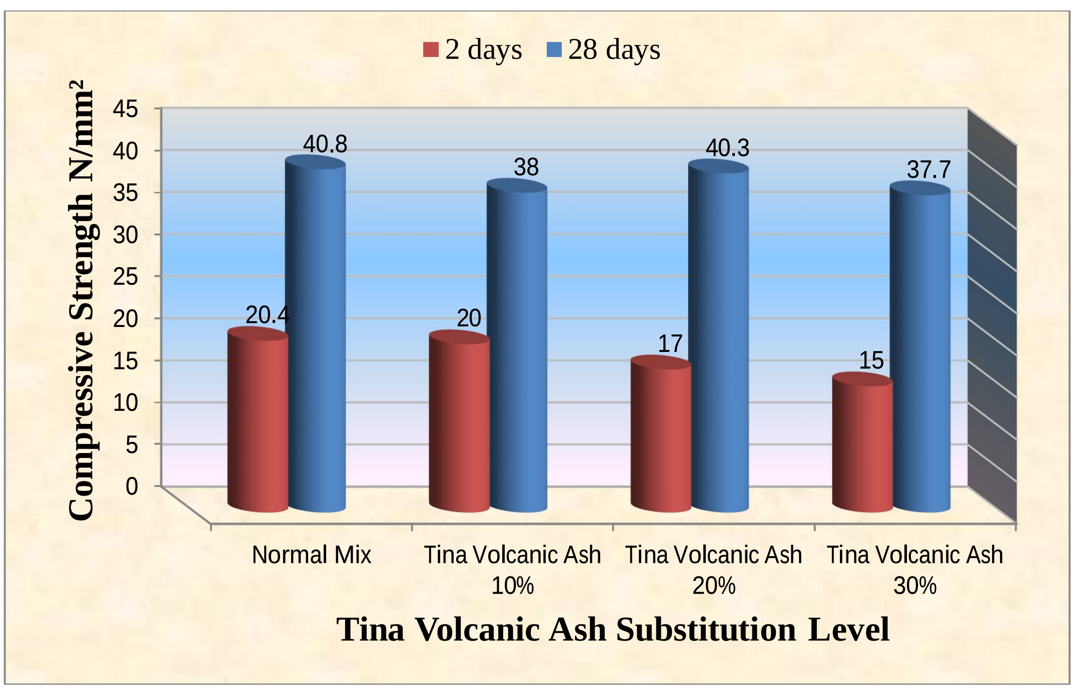


Figure 4.6: Compressive Strength of MVA blended mortar



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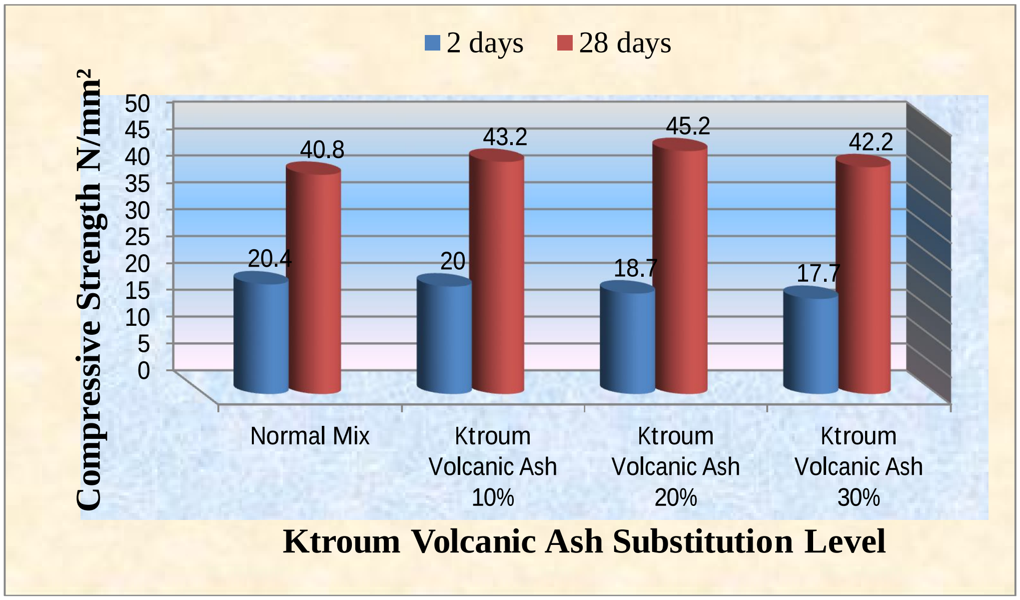


Figure 4.8: Compressive Strength of KTVA blended mortar

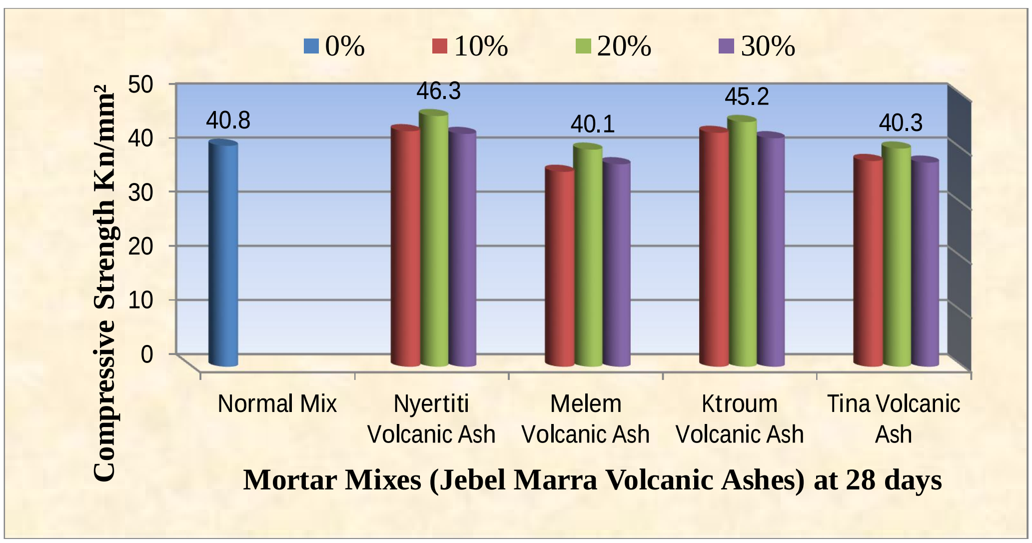


Figure 4.9: Compressive Strength of Mortar Mixes for all tested JMVA blended mortar

4.4.2 Strength Activity Index (SAI) of the Mortar Result

The strength Activity Index (SAI) of mortar results are shown in Table 4.12. It can be seen that all tested Pozzolanas give high SAI which are much higher than that specified by both ASTM and I. NVA give the highest value followed by KTVA.

Table 4.12: Strength Activity Index of tested Mortars

Sample designation	Strength Activity Index	Strength Activity Requirement %	
		ASTM C 618	IS 1344-1981
(NVA)	113	75	80
(MVA)	98		
(TVA)	105		
(KTVA)	110		

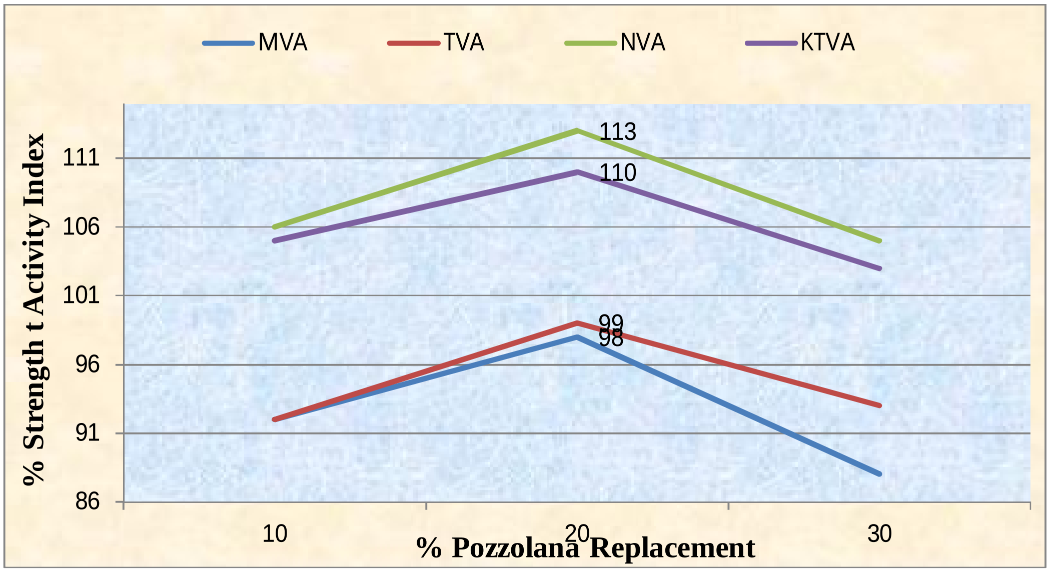


Figure 4.10: Variation of relative SAI in JMVA mortar

4.5 Workability and Strength of Concrete:

4.5.1 Workability Results:

The results of workability test are presented in Table 4.13 and Figures 4.11, 4.12 using slump test. These Show that when the replacement of OPC with Pozzolana increases, the workability of concrete increases. This shows the effect of Pozzolana, which work to generate a explain consignment of cement. This explained by Mindess et al (2003) by stating that the particles of Pozzolana are spherical acting like ball thus reducing friction between particles and thus workability improved, but this on expense of compressive strength.

Table 4.13: Workability of concrete by Slump Test

Replacement %	Workability Slump (mm)				
	(NM)	(NVA)	(MVA)	(TVA)	(KTVA)
0	30	-	-	-	-
10	-	55	60	60	50
20	-	60	65	65	60
30	-	70	75	70	65

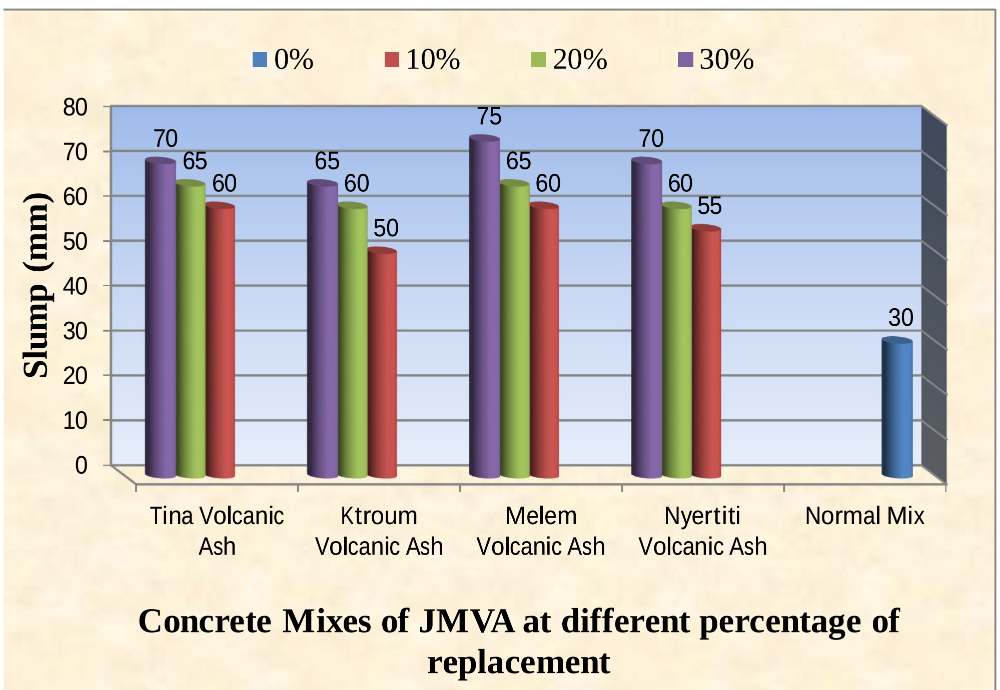


Figure 4.11: Slump of JMVA concrete Mixes

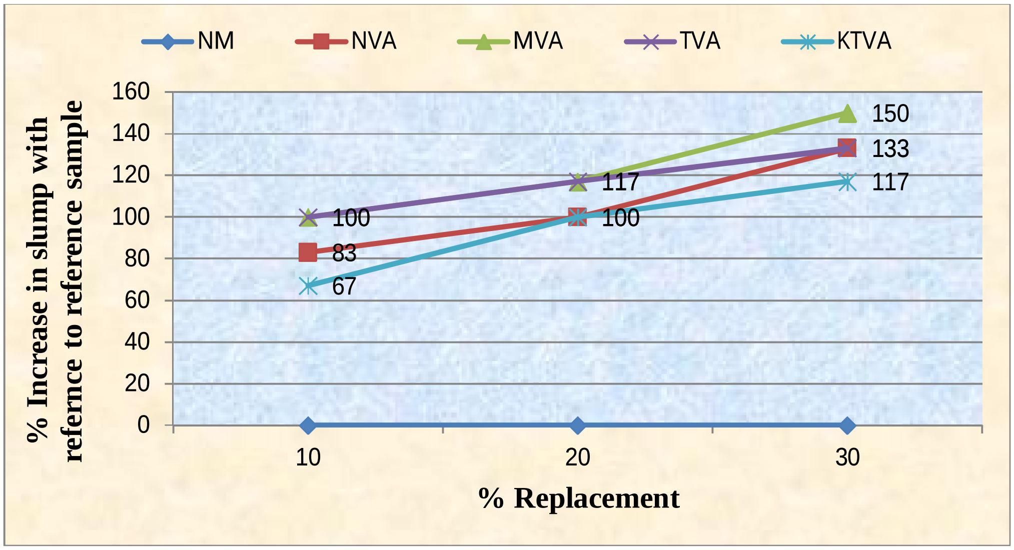


Figure 4.12: Effect of percentage of replacement and Pozzolana type on workability

4.5.2 Compressive Strength of Concrete Samples:

The results of compressive strength tests are presented in Table 4.14 and Figures 4.14 to 4.17. Figure 4.13 shows the statistical analysis in which the variation of test result using coefficient of variation is 7.4, the mean of the samples is 39.62 kN/mm² and the correlation is 0.895.

Table 4.14: Compressive Strength results of concrete at 7,28,90 days

Sample NO	% Replacement of Pozzolana	Compressive strength N/mm²					
		7 days		28 days		90 days	
			% Increase or decrease in strength relative to NM		% Increase or decrease in strength relative to NM		% Increase or decrease in strength relative to NM
(NM)	0	27.5	-	35.0	-	42.0	-
(NVA)	10	26.0	-5.4	34.5	-1.4	41.0	-2.4
(NVA)	20	30.0	+9	38.0	+10	45.0	+7
(NVA)	30	24.0	-12.7	28.0	-20	38.0	-9.5
(MVA)	10	25.0	-9	33.0	-5.7	37.0	-2.5
(MVA)	20	28.0	+2	37.0	+6	40.0	-12
(MVA)	30	24.0	-12.7	26.0	-25	36.0	-14.2
(TVA)	10	25.0	-9	32.0	-8	39.0	-7
(TVA)	20	29.0	+5	38.0	+9	43.0	+2.3
(TVA)	30	23.0	-16	27.0	-22	36.0	-14
(KTVA)	10	26.0	-5.4	34.0	-3	40.0	-5
(KTVA)	20	27.5	0	36.5	+4.2	42.0	0
(KTVA)	30	22.0	-20	27.0	-22	36.0	-14

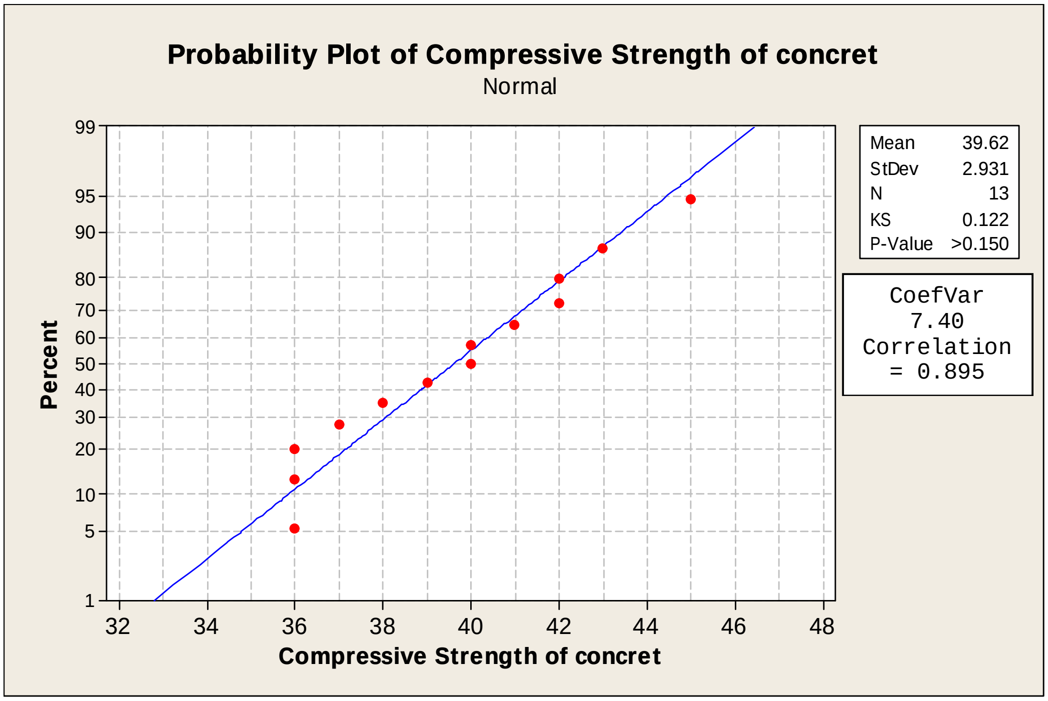


Figure 4.13: Statistic analysis of compressive strength concrete samples form (JMVA)

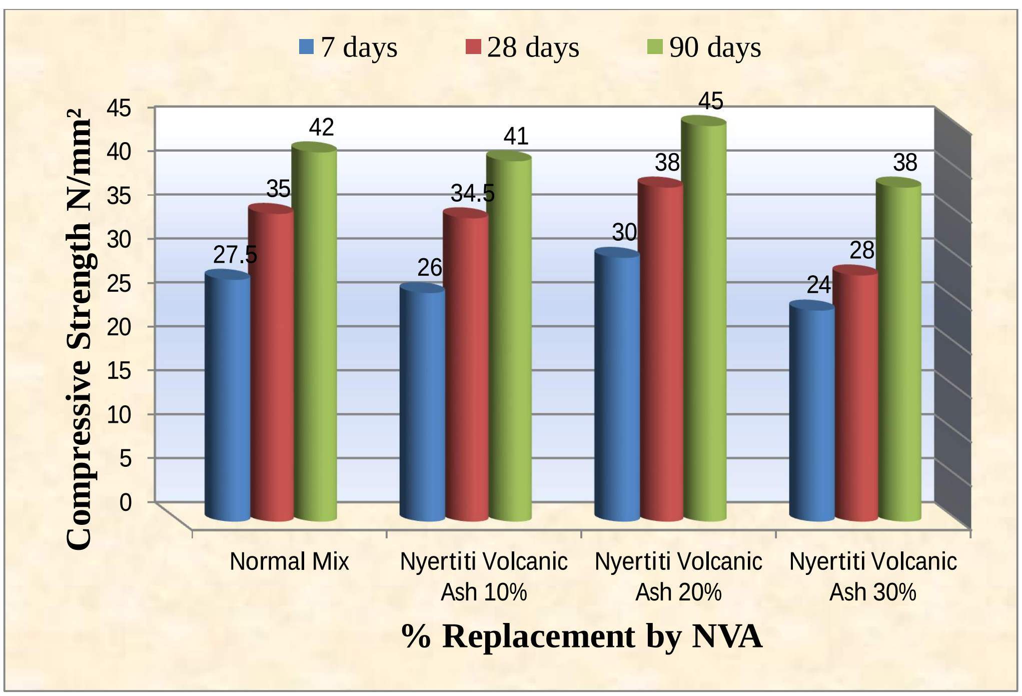
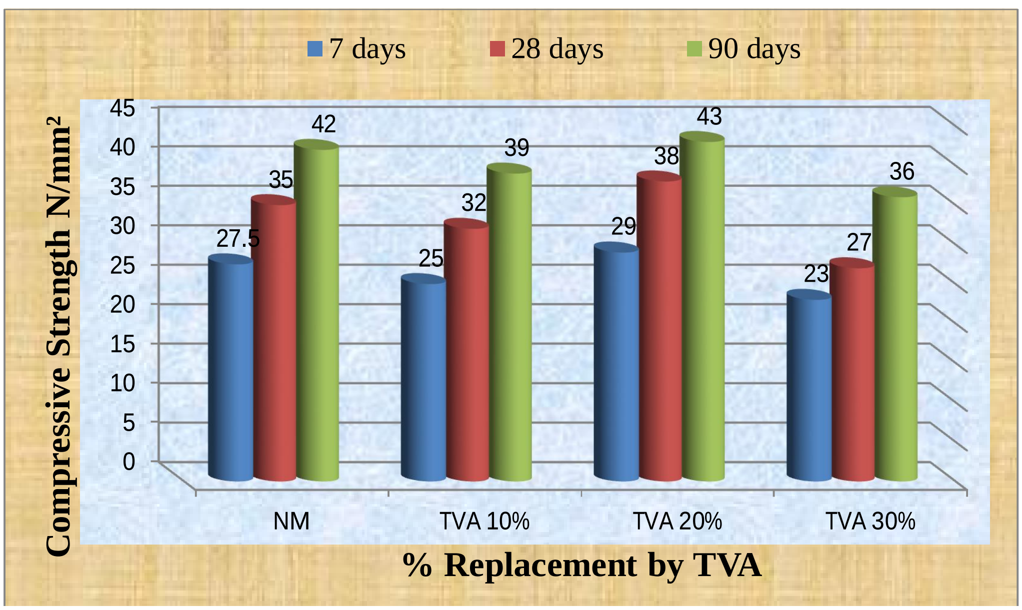


Figure 4.15: Compressive strength of MVA blended concrete at different ages and different replacement percentages



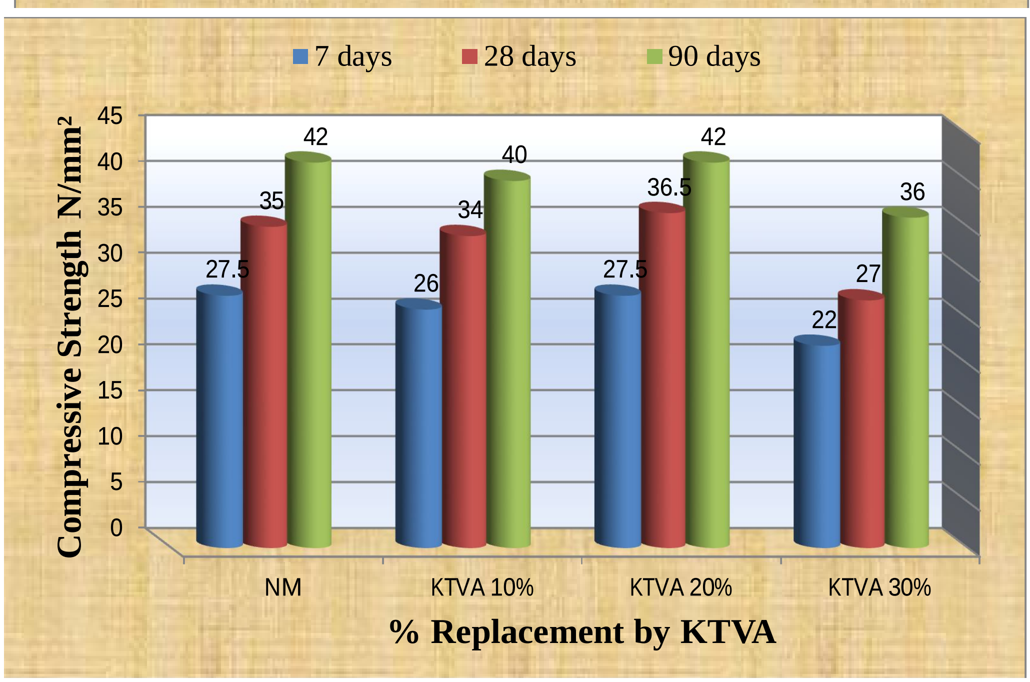


Figure 4.17: Compressive strength of KTVA blended concrete at different ages and different replacement percentages

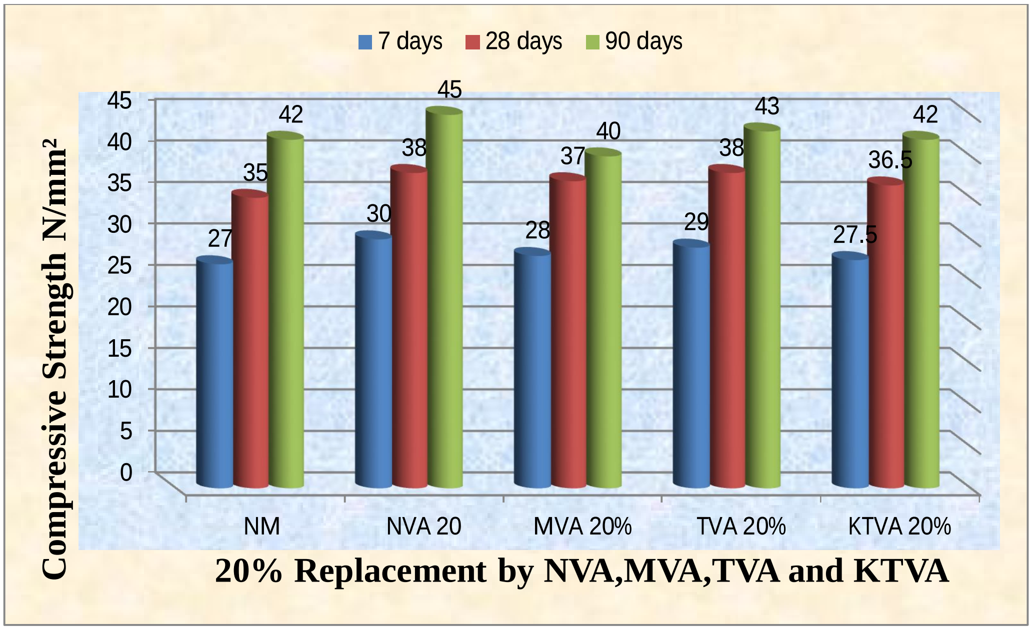


Figure 4.18: Comparison of Compressive strength of 20% replacement by different JMVA

The variation of compressive strength of concrete mixes with time is presented in Figures 4.21 show that the maximum value of compressive strength for concrete mixes using JMVA replacement of cement occur when using 20% Pozzolana replacement. Figure 4.18 displays the compressive strength using 20% replacement at 90 days. Maximum compressive strength occurs when using NAV. Strength decreases when the percentage of the JMVA replacement is 30%. The variations in compressive strength of the concrete mixes are presented in Figure 4.19 to 4.22. It is seen that the variation of strength shows similar trends with respect to Pozzolana replacement. In general, the compressive strength increases with age.

Pozzolanic reaction begins immediately after hydration of cement and there is continuons increase of strength. For 20% NVA replacement there is an increase of 10% in the 28 days strength compared to the control mix as can be seen from Figure 4.19. Similarly, the 7 days and 90 days compressive strength for 20% NVA show increases of 9% and 7% respectively compared to the compressive strength of the control mix. Concrete derives its strength from the pozzolanic reaction between silica in Pozzolana and the calcium hydroxide forming (C-S-H) liberated during the hydration of OPC. Also other samples in Figures 4.20 to 4.22 show a similar trend but with less increase and more decrease in strength. At low percentage of replacement, the quantity of silica is low, and thus a limited quantity of (C-S-H) is formed, although a large quantity of calcium hydroxide is liberated due to the relatively large quantity of OPC. However, at high percentage replacement, the quantity of silica in the mix increases the (C-S-H) that can be formed reduced due to liberation of small quantity of calcium hydroxide from the hydration of the relatively small quantity of OPC available. The strength of concrete at both low and high percentage replacement is therefore low. An optimum level of replacement exists at which compressive strength is maximum.

It is seen that from all figures that the average rate of strength growth is nearer to the normal mix for the first seven days, after which, the average rate of growth reduces. The rate of strength gain with respect to time is highest for concrete with 20% NVA replacement of OPC. This is due to optimum reactions which take place at 20% replacement.

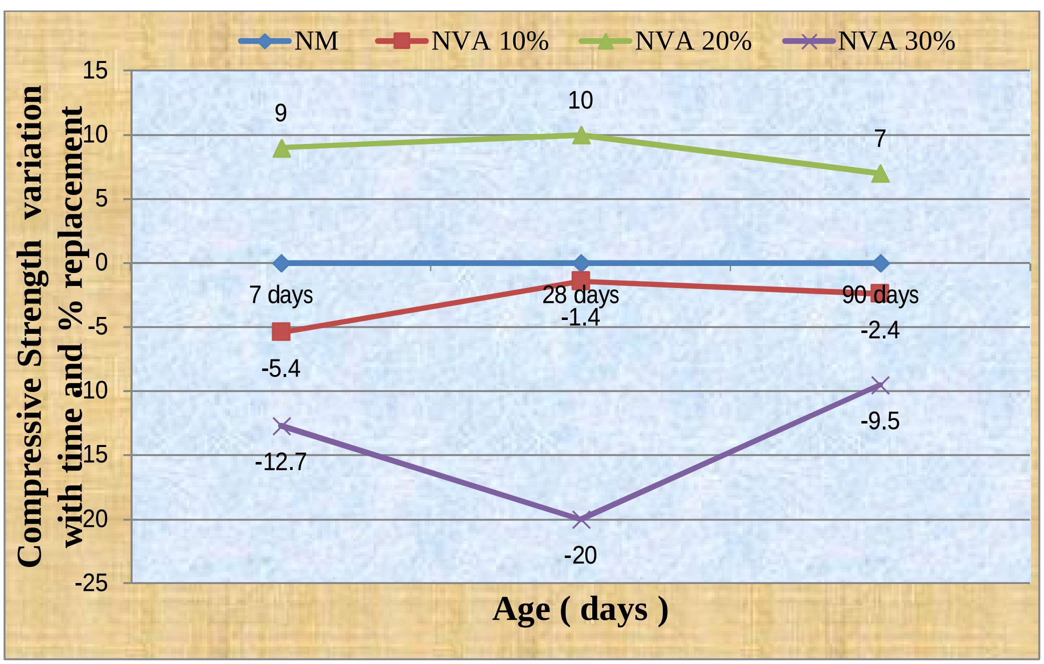
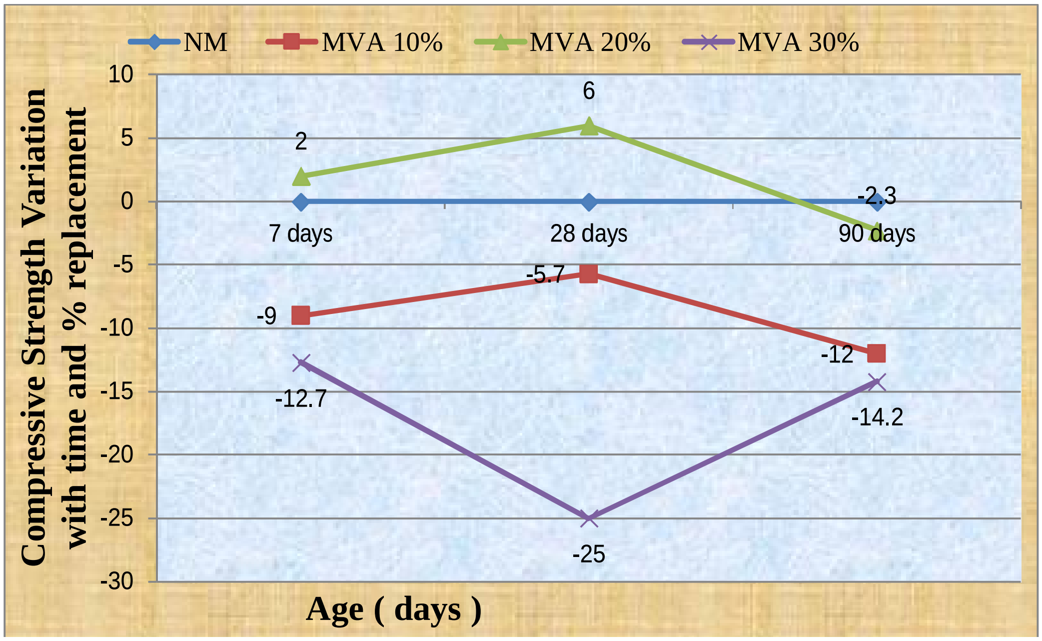
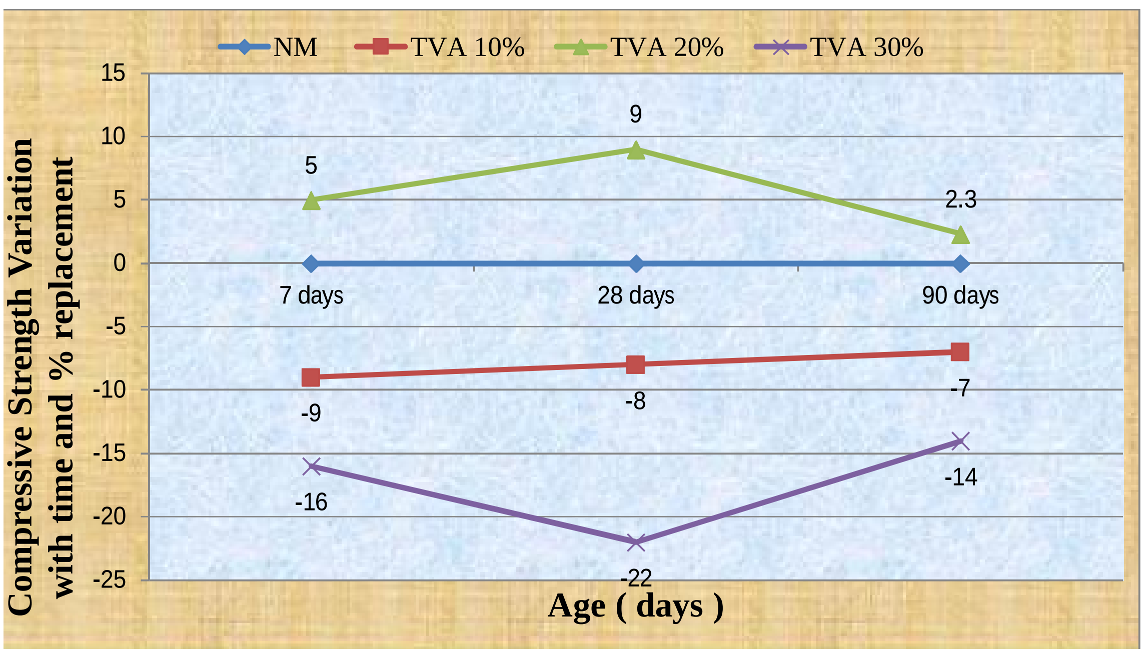


Figure 4.19: **Variation of compressive strength of concrete and NVA in comparison with reference mix**





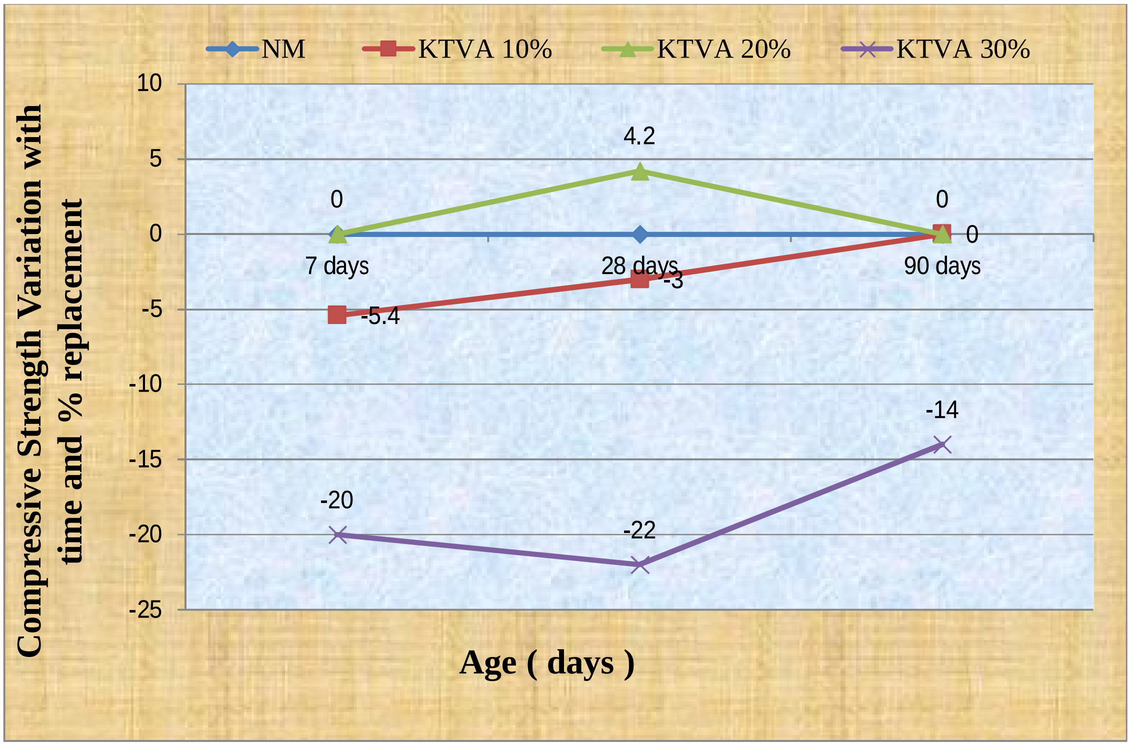


Figure 4.22: **Variation of compressive strength of concrete and KTVA in comparison with reference mix**

4.6 Concrete Hollow Block Compressive Strength Results:

The average compressive strength at 28 days curing of JMVA concrete hollow blocks is presented in Table 4.15, appendix A Table A9. Figure 4.23shows the distribution of compressive strength test result of hollow concrete blocks, where in which coefficient of variation is 12.19, the mean of the samples is 4.31 kN/mm² and the correlation is 0.767. Figure 4.24, show that all blocks with 20% ashes replacement have strengths higher than that of the control mix. It also clears that as percentage of JMVA replacement increases the compressive strength of blocks decreases. The concrete hollow blocks NVA has a higher compressive strength than the other samples. When OPC is replaced with 30% JMVA the compressive strength is less than the control mix but more than the minimum limit of the standard ASTM C-55 which is 3.5N/mm^2.

Table 4.15: Compressive strength of the concrete hollow blocks

Block Designation	% Pozzolana Replacement	Compressive Strength (N/mm²)	Block Density (Kg/m³)	Block Grade	IS Requirement (N/mm²)
(NM)	**0**	**4.4**	**1287**	**B**	

(NVA) (NVA)	20 30	5.3 4.0	1140 1125	B B	3.5 ~ 5.0
(MVA) (MVA)	20 30	4.6 3.9	1218 1172	B B	
(TVA) (TVA)	20 30	4.3 3.7	1234 1187	B B	
(KTVA) (KTVA)	20 30	4.8 3.8	1162 1094	B -	

***(According to standard in table 3.12)**

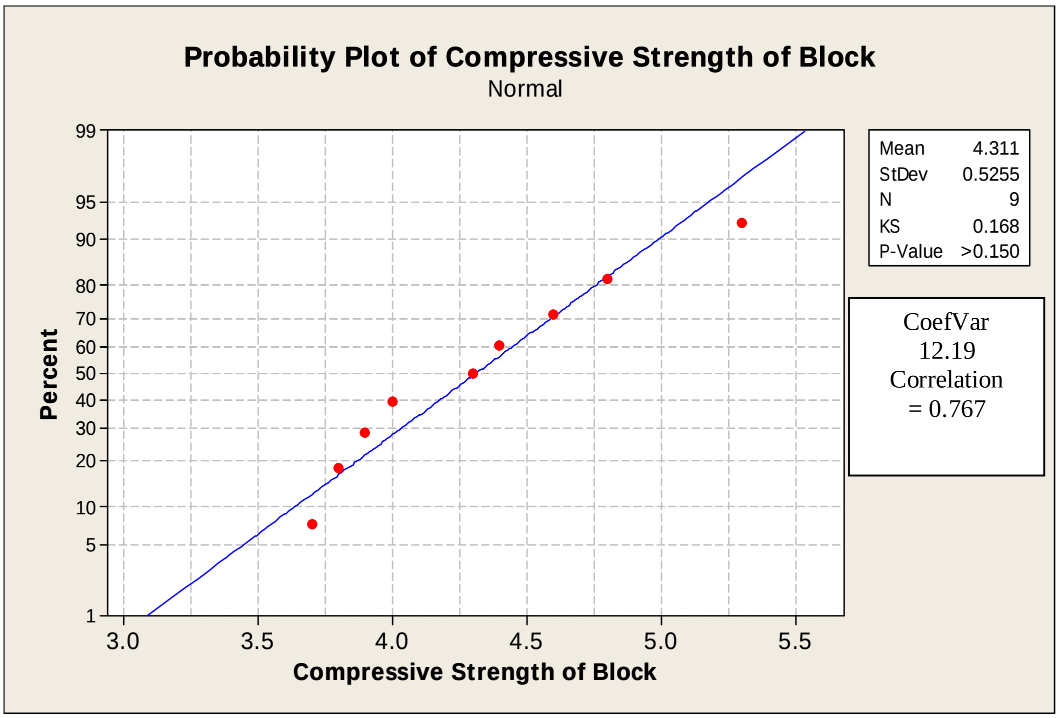


Figure 4.23: Statistic Analysis of compressive strength hollow concrete blocks results

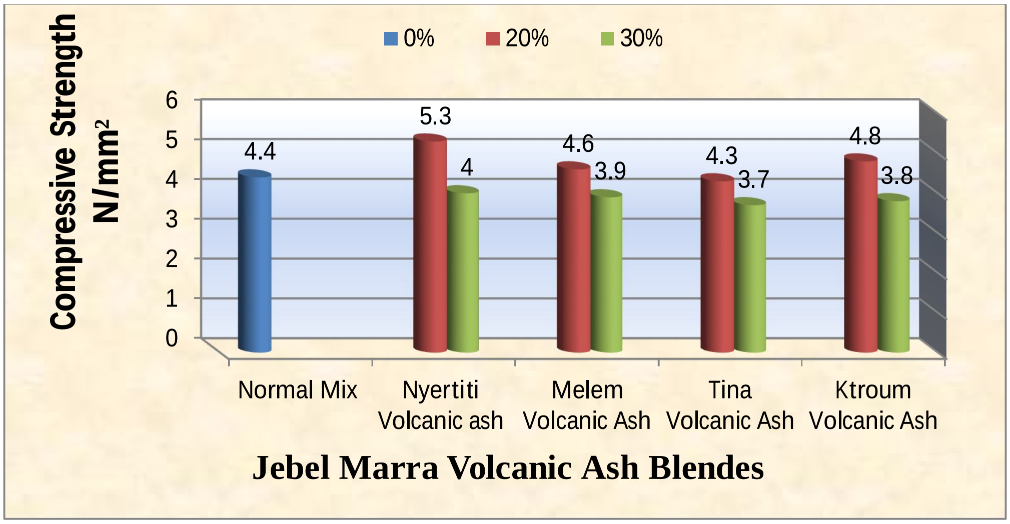


Figure 4.24: Compressive Strength of JMVA Concrete Hollow Blocks

4.7 Effect of JMVA on heat of hydration

The difference in the chemical composition of JMVA and of cement it replaced is a major factor to reduce the heat of hydration in fresh mix. As shown in Table 4.16 and Figure 4.25 the major constituent of JMVA is silica (SiO_2) while that of cement is quicklime (CaO). On mixing the free lime (CaO) liberated from cement hydration reacts with silica to form cementing products like C_3S, C_2S, C_3A ….etc .Heat of hydration - may lead to a microscopic cracks the cement paste, which leads to internal communication gaps and increase permeability. Addition of Pozzolanic materials reduce the heat of hydration as presented in Figure 1, and work to fill internal gaps and pores, which to decrease the permeability.

Table 4.16: JMVA Temperature C° in the fresh mix of hollow block

Replacement	Temperature C°				
	NM	NVA	TVA	MVA	KVA
0%	34	-	-	-	-
20%	-	27	29	29	27
30%	-	25	26	28	26

To show the effect of pozzolanic material addition on reduction of heat of hydration a crude comparative test was carried out on fresh O.P.C and blended cement. A digital thermometer was used to measure temperature of each sample at first 15 min. table 4.16 showed effect of pozzolana type and percentage of cement replacement on heat reduction. Figure 4.28 compares and shows clearly the effect of pozzolana on heat of hydration.

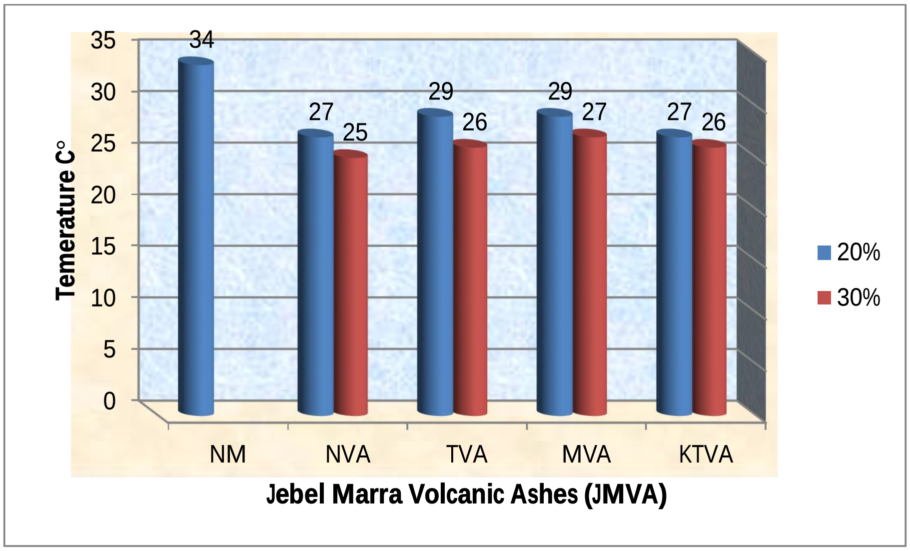


Figure 4.25: Effect of pozzolana on heat of hydration

4.8 Blended Cement:

The specification pertains to five classes of blended cement hydraulic cement for both general and special application, using slag or pozzolana, or both with Portland cement or Portland cement clinker or slag with lime. Table 4.17 shows that the difference between ASTM Requirement and obtained results of the blended cement. See the calculation in Appendix B. B7.

Table 4.17: difference between ASTM C 595 Requirement and obtained results of the blended cement

oxide	% O.P.C Cement	Blended Cements (%)				ASTM Requirement	% Difference
		N	T	KT	M		
AL_2O_3	4.38	7.220	6.742	7.178	6.577	± 2% of cement	3 ~ 13
SiO_2	20.62	24.960	25.198	23.833	23.404	± 3% of cement	1 ~ 7
CaO	62.58	51.762	51.499	53.108	53.472	± 3% of cement	10 ~ 14
SO_3	2.42	2.470	2.420	2.47	2.450	Max 4%	Matching
L.O.I	2.30	2.700	3.400	2.700	3.700	Max 5%	Matching
MgO	2.77	1.008	1.066	1.018	1.142	Max 6%	Matching
Fe_2O_3	3.62	3.544	3.554	3.477	3.561	……….	

From result above it can be seen that there are some difference between the tested blends and ASTM Requirement in the AL, Si and Ca oxides but the difference is not high, it is 3 ~ 13%, 1 ~ 7% and 10 ~ 14% for the oxide respectively. Regarding other oxides (SO_3, MgO) and L.I.O the blended cement matching completely the ASTM requirement. It can be concluded that JMVA can give good blended cements.

4.8.1 Types of blended cement:

In the following lines comparisons were conducted to determine which type of cements are the tested blends are belongs to.

4.8.1.1 Ordinary Portland cement Type I:

Table 4.18 Comparisons between blended cement and cement Type I

Oxide	NBC	TBC	KBC	MBC
Al_2/Fe_2O_3 Not less than 0.66	2.07	2.06	1.89	1.8
Percentage of SO_3 limited by 2.5 when $C_3A \leq 7\%$ and not more than 3.2 when $C_3A > 7\%$	2.47	2.47	2.42	2.45
LSF, limited between (0.66-1.02)	0.62	0.66	0.61	0.68
Loss on ignition, max 4%	2.70	2.7	3.4	3.7
Magnesium Oxide (MgO), max 5%	1.008	1.018	1.066	1.142

4.8.1. 2. Low heat Portland cement Type IV:

Composition:

It contains less C_3S and C_3A percentage and higher percentage of C_2S in comparison with Ordinary Portland cement.

Table 4.19 comparisons between blended cement and cement Type IV

Oxide %	Cement	NBC	TBC	KBC	MBC
C_3S	63	-19	-5.3	-18	3
C_3A	5	13.25	13	11.8	11.4
C_2S	11.3	96	82	96.6	78.08

4.8.1.3: Sulfate – Resisting Portland cement Type V:

Composition:

1. Lower percentage of C_3A and C_4AF.
2. Higher percentage of silicate- in comparison with OPC.
3. C_2S represents a high proportion of the silicate.
4. Max C_3A content by 3.5%, min fineness by 2500cm^2/g.

Table 4.20: Specification for reduced heat cement:

Types of cement	NBC	TBC	KBC	MBC
Type II				

$C_3S + C_3A$ =58%	-6	7.7	-6.2	14.4
Type IV C_3S, max 3.5% C_3A, max 7% C_2S, min 40%	 -19 13.25 96	 -5.3 13 82	 -18 11.8 96.6	 3 11.4 78.08

From calculations and comparisons carried out it can be said that the tested blended cement of JMVA are identified to type I i.e. O.P.C and near to low heat cement type IV with high C_3A content.

4.9 Cement Cost Saving Analysis:

To evaluate the saving in the cost of cement, a typical house of design shown below in Figure 4.26 suggested and analyses to determine the save in cement and hence cost when using blended cement .
The overall saving in this house module is shown in Table 4.21 and 4.22. The saving is about 22% on net.

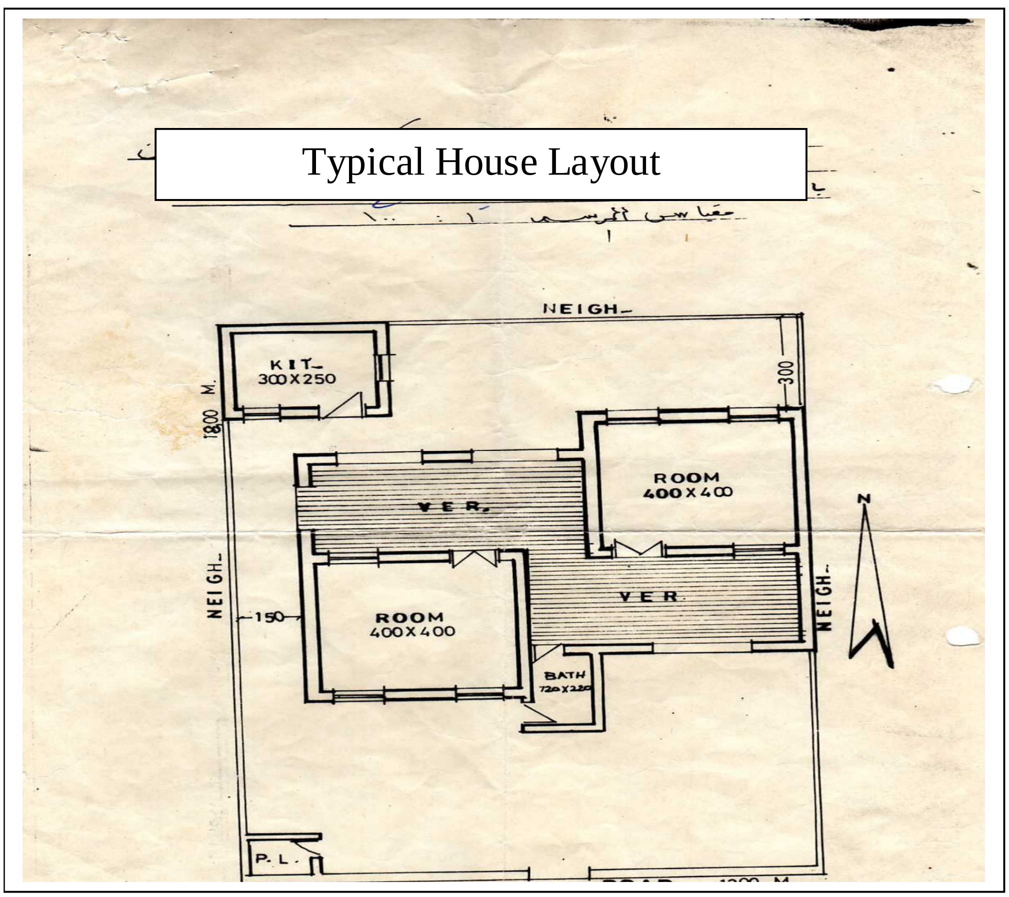


Figure 4.29: Simple Typical House Layout

Table 4.21: Cost Saving when blended cement used to build the house model:

Item	Description	Unit	Qty	Total Qty(ton)	Unit Price(ton)	Total Cost (SD)
1	Block works					
1.1	Blocks laying for 2 rooms using 1:8 cement: sand	m²	128	0.64	2400	1536
1.2	Ditto but for veranda	m²	72	0.4	2400	864
1.3	Ditto but for kitchen and bath room	m²	65	0.3	2400	780
1.4	Ditto but for fence	m²	118	0.59	2400	1416
2	**Plaster Works**					
2.1	Plaster soft 2cm thick , 1:6 c/s for wall internal and external	m²	383	1.9	2400	4656
	Total		766	3.83		9252
	Saving in cement cost (using 30% Pozzolana			1.1		2640

	replacement)					
	Qty of Pozzolana			1.1	600	660
	Net saving in cost of cement using cement with Pozzolana					1980
	Percentage Cost saving					21.4%

Table 4.22: Cost Saving when blended cement is in production of hollow blocks

Item	Description	Unit	Qty	Qty of Cement (ton)	Unit Price(ton)	Total Cost (SD)
1	Hollow block concrete					
1.1	Production of Hollow block concrete for 2 rooms with 1:2.5:3.5 (cement: sand: aggregate)	No	1600	3.2	2400	7680
1.2	Ditto but for veranda	No	905	1.8	2400	4320
1.3	Ditto but for kitchen and bath room	No	820	1.64	2400	3936
1.4	Ditto but for fence	No	1725	3.45	2400	8280
	Total		5050	10.09		24216
	Saving in cement cost (using 30% Pozzolana replacement)			3		7200
	Qty of Pozzolana			3	600	1800
	Net saving in cost of cement using cement and cement with					5400

	Pozzolana					
	Percentage in Cost saving					22.3%

CHAPTER 5

Conclusions and Recommendations

5.1 Conclusions:

The following conclusions can be drawn from literature review, the results of the tests and analysis carried out in this study:

1. Jebel Marra volcanic ashes (JMVA) reduces the heat hydration in concrete thus it can be used in mass concrete structures such as dams, retaining walls, bridge abutments, and rafts where in the rate of dissipation of heat of hydration from the surface is much lower than that generated.
2. The specific gravity values were found to be: 3.15 for OPC, 2.65 for sand, 2.88 for coarse aggregate, 2.59 for NVA, 2.54 for MVA, 2.58 for TVA and 2.61 for KTVA. These satisfy the standard requirements.
3. At 28 days age the strength activity indexes (SAI) of mortar were found to be above 75% for all mixes. The NVA and KTVA produced the highest SAI among the other samples. Thus, 30% JMVA replacement of OPC in mortar can be used safely within standard.
4. Replacement of cement with Pozzolana significantly increased the workability of concrete.

5. The 7-days, 28-days and 90-days compressive strengths at 20% replacement of NVA showed increases of 9%, 10% and 7% respectively compared to the compressive strength of the control mix.
6. Partial replacement of Ordinary Portland Cement with about 20% natural Pozzolana volcanic ash (Jebel Mara) in concrete enhances both workability and strength.
7. Replacement of JMVA retarded the setting time, however this retardation was negligible and it was within the limits as specified, by standard.
8. JMVA can be used to produce blended cement with 20% replacement.
9. The blended cement of JMVA is typical to Type I OPC and close to low heat cement Type IV with high C_3A content.
10. From the economical point of view and for the practical application of low cost blended cement, JMVA is chosen for future implementation of blended cements, since the volcanic ash from Jebel Mara is of great availability, and its utilization does not need any treatment other than grinding to cement fineness. And hence JMVA with 20% and 30% substitution level can be used successfully in mortar,concrete and concrete hollow blocks.
11. The natural Pozzolana volcanic ash collected from Jebel Marra Places can be used as partial replacement of OPC after grinding and calcinations.

5.2 Recommendations

5.2.1 Recommendation Resulting from the Research Finding:

It is recommeanded to:

1. Use 20% NVA replacement of OPC in all types of structural applications.
2. Use up to 30% JMVA replacement of OPC in all mortar uses and hollow blocks production.
3. High strength of OPC is not a requirement for many basic building applications and LPC and blended cements are ideal for use in plasters, mortars, renders and in non-structural concrete such as ground floor slabs.
4. To make full use of the results of this study the researcher suggests training of professionals in cement technology and construction industry.
5. To achieve the above mentioned recommendations there must be coordination between government officials, local authorities, private sector and local communities to insure proper collaboration.

5.2.2 Recommendations for Additional/Future Studies:

It is recommended to:

1. Detailed geological investigations and material testing is required for development and stimulation activity in this area.
2. Study the effect of local lime and Pozzolana on soil stabilization and lime soil interaction.
3. Provide Factories for concrete hollow blocks and mills for natural Pozzolana.
4. In addition to conducted tests on Pozzolanic material, from JMNP its recommended to carry out additional testing on Pozzolanic materials such as: soundness, transverse strength, drying shrinkage, XRD, permeability, and reduction in alkalinity and silica release. These tests will give a comprehensive characterization of any Pozzolana.
5. Investigation of natural Pozzolana from other areas in western Sudan such as Kass, Nyama and Karnawy in Jebel Marra, Jebel Meidob and Kabkabia in Western Sudan OPC price externally high compared to central Sudan.
6. The high increase in workability with replacement without affecting strength indicates the possibity of production of self compacting concrete using Nyertiti volcanic ash (NVA) but this need further investigation.

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Appendix A:

MATERIALS DATA SHEETS

(Chemical & Physical analysis)

Table A1: Chemical Analysis of Jebel Marra

وزارة المعادن
Ministry Of Minerals

MINISTRY OF MINERALS	وزارة المعادن
GEOLGICAL RESEARCH AUTHORTY OF SUDAN	الهيئة العامة للأبحاث الجيولوجية
CHEMICAL LABROTARY	المختبر الكيميائي
Khartoum-NILE STREET, P. BOX 410	الخرطوم – شارع النيل . ص . ب 410

METHODS: XRF — **ENTERY DATE0:05/ 03/ 2015**

RECIPE : AXIOS — **RPORT NO :140**

CLAIBATION : OMNIAN

Lab NO	1429 Nyama	1430 Kotraoum	1431 Kas	1432 Melem	1433 Nyertiti	UNIT
Sender No	mT	ma1	mk	mm	mn	%
Na2O	5.765	5.561	5.973	2.804	4.151	%
MgO	0.926	0.836	0.655	2.276	1.068	%
Al2O3	18.581	19.803	17.306	18.394	16.313	%
SiO2	60.779	60.943	63.473	61.036	64.558	%
P2O5	1.111	0.137	0.084	0.160	0.134	%
SO3	0.051	0.028	0.017	0.024	0.027	%
Cl	0.323	0.075	0.017	0.120	0.261	%
K2O	4.419	3.968	4.329	3.445	5.065	%
CaO	1.473	0.993	0.515	4.063	1.300	%
TiO2	0.402	0.664	0.564	0.693	0.567	%
Cr2O3	0.006	0.010	---	0.021	0.008	%
MnO	0.201	0.218	0.144	0.136	0.201	%
Fe2O3	5.542	6.368	6.695	6.385	5.879	%
Co3O4	---	---	0.009	0.013	---	%
NiO	---	0.006	0.006	0.007	---	%
CuO	0.003	0.003	---	0.007	0.003	%
ZnO	0.018	0.018	0.016	0.014	0.016	%
Ga2O3	0.003	0.005	0.004	0.004	0.004	%
Rb2O	0.019	0.011	0.012	0.013	0.021	%
SrO	0.008	0.018	0.005	0.046	0.014	%

REFRENCE SEN:مني أدم

Chief Chemist
DATE:26/10/2015

الهيئة العامة للأبحاث الجيولوجية

Table A2: Chemical Analysis of Jebel Marrah

وزارة المعادن
Ministry Of Minerals

MINISTRY OF MINERALS
GEOLGICAL RESEARCH AUTHORTY OF SUDAN
CHEMICAL LABROTARY
Khartoum-NILE STREET. P. BOX 410

وزارة المعادن
الهيئة العامة للأبحاث الجيولوجية
المختبر الكيميائي
الخرطوم – شارع النيل . ص . ب 410

METHODS: XRF **ENTERY DATE0:05/ 03/ 2015**

RECIPE : AXIOS **RPORT NO :140**

CLAIBATION : OMNIAN

Lab NO	1429 Nyama	1430 Kotraoum	1431 Kas	1432 Melem	1433 Nyertiti	UNIT
Sender No	mT	ma1	mk	mm	mn	%
Na2O	5.765	5.561	5.973	2.804	4.151	%
MgO	0.926	0.836	0.655	2.276	1.068	%
Al2O3	18.581	19.803	17.306	18.394	16.313	%
SiO2	60.779	60.943	63.473	61.036	64.558	%
P2O5	1.111	0.137	0.084	0.160	0.134	%
SO3	0.051	0.028	0.017	0.024	0.027	%
Cl	0.323	0.075	0.017	0.120	0.261	%
K2O	4.419	3.968	4.329	3.445	5.065	%
CaO	1.473	0.993	0.515	4.063	1.300	%
TiO2	0.402	0.664	0.564	0.693	0.567	%
Cr2O3	0.006	0.010	---	0.021	0.008	%
MnO	0.201	0.218	0.144	0.136	0.201	%
Fe2O3	5.542	6.368	6.695	6.385	5.879	%
Co3O4	---	---	0.009	0.013	---	%
NiO	---	0.006	0.006	0.007	---	%
CuO	0.003	0.003	---	0.007	0.003	%
ZnO	0.018	0.018	0.016	0.014	0.016	%
Ga2O3	0.003	0.005	0.004	0.004	0.004	%
Rb2O	0.019	0.011	0.012	0.013	0.021	%
SrO	0.008	0.018	0.005	0.046	0.014	%

REFRENCE SEN:مني أدم

الهيئة العامة للأبحاث الجيولوجية

Chief Chemist
DATE:26/10/2015

Table A3: Chemical Analysis of Berber Cement

شركة أسمنت بربر المحدودة

Berber Cement Co.Ltd

BERBER CEMENT COMPANY
QUALITY CONTROL DEPARTMENT
Chemical Properties of Dispatched cement
For the Period from January ~ June 2015

SR	MONTH	Particulars																	
		CHEMICAL COMPOSITION %														MODULI			FREE CaO %
		LOI	IR	SiO2	Al2O3	Fe2O3	CaO	MgO	TiO2	Mn2O3	P2O5	Na2O	K2O	SO3	Cl	TOTAL	LSF	SM	AM	
1	JANUARY	2.13	0.43	20.59	4.42	3.66	62.70	2.76	0.33	0.07	0.14	0.30	0.38	2.31	0.00	99.80	0.9365	2.55	1.21	1.49
2	FEBRUARY	2.09	0.37	20.70	4.36	3.60	62.69	2.79	0.31	0.06	0.15	0.27	0.42	2.48	0.00	99.93	0.9316	2.60	1.21	1.57
3	MARCH	1.93	0.52	20.69	4.34	3.63	62.60	2.71	0.31	0.07	0.14	0.26	0.43	2.35	0.00	99.46	0.9419	2.60	1.20	1.70
4	APRIL	2.15	0.61	20.45	4.27	3.60	62.52	2.70	0.30	0.07	0.14	0.26	0.45	2.64	0.00	99.55	0.9389	2.60	1.19	1.78
5	MAY	1.96	0.47	20.63	4.42	3.63	62.43	2.87	0.31	0.07	0.14	0.30	0.40	2.34	0.00	99.50	0.9307	2.57	1.22	1.76
6	JUNE	2.30	0.26	20.64	4.46	3.59	62.55	2.81	0.31	0.08	0.14	0.29	0.39	2.42	0.00	99.98	0.9310	2.56	1.24	1.29
AVERAGE		2.09	0.44	20.62	4.38	3.62	62.58	2.77	0.31	0.07	0.14	0.28	0.41	2.42	0.00	99.70	0.94	2.58	1.21	1.60
MIN		1.93	0.26	20.45	4.27	3.59	62.43	2.70	0.30	0.06	0.14	0.26	0.38	2.31	0.00	99.46	0.9307	2.55	1.19	1.29
MAX		2.30	0.61	20.70	4.46	3.66	62.70	2.87	0.33	0.08	0.15	0.30	0.45	2.64	0.00	99.98	0.9419	2.60	1.24	1.78
STDEV		0.14	0.12	0.09	0.07	0.03	0.10	0.06	0.01	0.01	0.00	0.02	0.02	0.12	0.00	0.23	0.00	0.02	0.02	0.19

Fadl A.Monim Fadl
Act. QC Chief

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Web site: www.berbercement.com - E-mail: info@berbercement.com

Table A4: Physical Analysis (Specific gravity) of Pozzolana

Sudanese Electricity Distribution company Ltd. (SEDC)
Central Laboratory for Technical Services & Calibration (CLTSC)

Kh. North - Kafori - Block (4) - El Shefaa St. - East of Dr. Mahmoud Shareef Power Station
Tel: +249 120344040 - 0123610695 - E-mail: customer@cltsc.gov.sd

Cleint Name: الباحثة منى ادم جمعة

Date: 15/11/2015

Summary of Specific Gravity of Pozzolan Results

Sample ID	Sample Name	Specific Gravity
C186/15/G448	PN	2.591
C186/15/G449	PT	2.577
C186/15/G450	PM	2.538
C186/15/G451	PKT	2.618

NOTE: Ethanol having density 0.789 g/mL at 20±2 C° have been used in the density determination

المعمل المركزي للخدمات الفنية والمعايرة
مدير إدارة المختبرات
التاريخ: 15/11/2015

GEOTECH.LAB.MANAGER:	LABS.TECHNICAL MANAGER:

نسعى لتحقيق ميزة تنافسية بتعزيز إلتزام المختبر المركزي للعلوم والبيئة وأبحاث التربة نحو الشركاء و الزبائن والعاملين والمجتمع من خلال:
النزاهة والاخلاق-المنافع المتبادلة-فريق العمل الفعال-الولاء والثقة-نتائج جيدة, بحوث فعالة, إستشارات وخدمات علمية.

Table A5: Physical Analysis (Specific gravity) of Coarse Aggregate

Sudan University of Science and Technology
College of Engineering
School of Civil Engineering
Soil Laboratory
Sieve Analyses Records

SPECIFIC GRAVITY AND ABSORPTION

Description of Sample No.	Test Number		Average
	1	2	
A weight of oven-dry sample in air (gm)	2500.000	2500.000	
B weight of saturated surface-dry in air (gm)	2509.000	2510.000	
C weight of saturated sample in water (gm)	1644.000	1641.000	
bulk Specific gravity (A/(B-C)	2.890	2.877	2.884
bulk Specific gravity(Saturated surface-dry basis) (B/(B-C)	2.901	2.888	2.894
apparent Specific gravity (A/(A-C)	2.921	2.910	2.915
water absorption 100* (B-A)/A %	0.360	0.400	0.380

Remark:..

....

For:Contractor:..

For Consultant:..

For Client:..

For C. Lab..
26/10
2014

Table A6: Physical Analysis (Specific gravity) of Sand

Sudan University of Science and Technology
College of Engineering
School of Civil Engineering
Soil Laboratory

Sieve Analyses Records

SPECIFIC GRAVITY AND ABSORPTION

Description of Sample No.	Test Number 1	Test Number 2	Average
A weight of oven-dry sample in air (gm)	498.500	499.000	
V volume of flask (mm)	500.000	500.000	
W weight of water added toflask(gm) or volume(mm)	311.500	311.500	
bulk Specific gravity (A/(V-W)	2.645	2.647	2.646
bulk Specific gravity(Saturated surface-dry basis) (500/(V-W)	2.653	2.653	2.653
apparent Specific gravity (A/((V-W)-(500-A))	2.666	2.661	2.664
water apsorption 100* (500-A)/A %	0.301	0.200	0.251

Remark:..

For:Contractor:..........................

For Consultant:..........................

For Client: [illegible]

For C. Lab.......................... 26/10 2014

Table A7: Physical Analysis (Sieve Analyses) of Sand

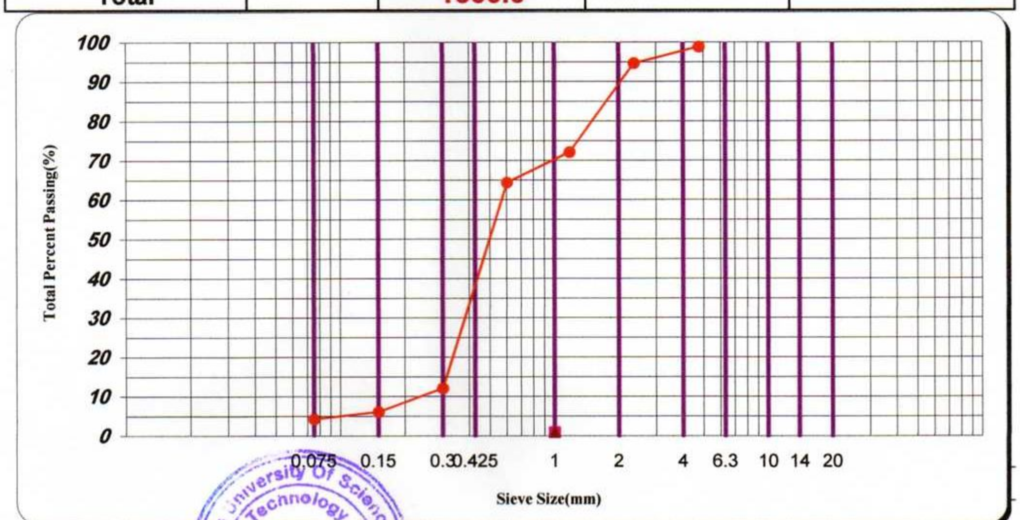
Sudan University of Science and Technology
College of Engineering
School of Civil Engineering
Soil Laboratory

Sieve Analyses Records

AASHTO T-11 and T-27

Material Tested	**Fine Aggregate**		
Location		**Date**	**13-Jul-15**

Sieve(In/No)	Size(mm)	Mass of Retained Sample(g)	% Retained	% Passing
3/8"	9.5	0.0	0.00	100.00
N0 4	4.75	17.0	1.13	98.87
No 8	2.36	62.4	4.16	94.70
No 16	1.18	338.3	22.55	72.15
No 30	0.6	117.1	7.80	64.35
No 50	0.3	783.7	52.24	12.11
No 100	0.15	90.3	6.02	6.08
No 200	0.075	27.8	1.86	4.23
pan		42.6		
Total		1500.0		



For:Contractor:..............................

For Consultant:..............................

For Client:..............................

For C. Lab..............................

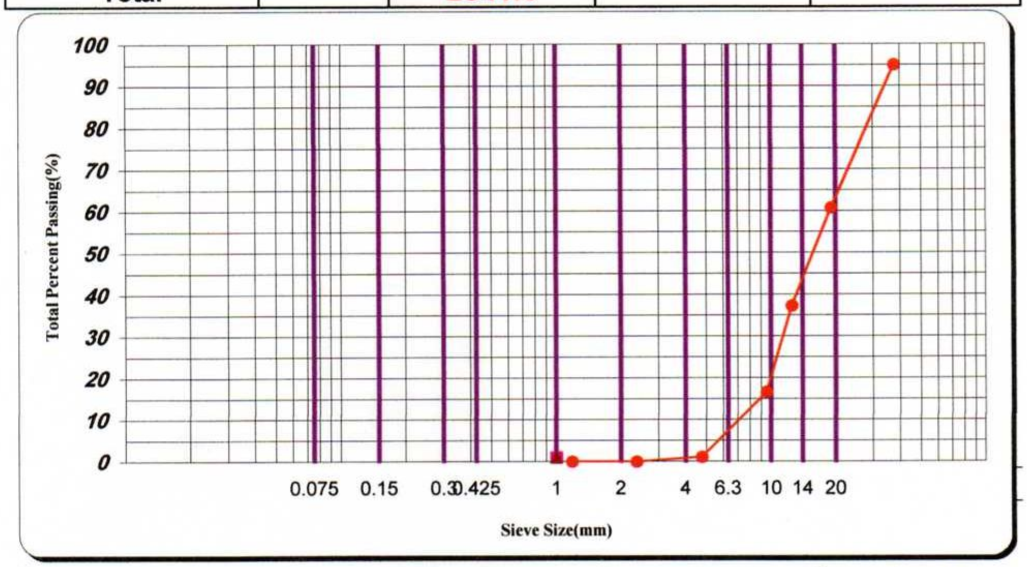
26/10
2014

Table A8: Physical Analysis (Sieve Analyses) of Coarse Aggregate

Sudan University of Science and Technology
College of Engineering
School of Civil Engineering
Soil Laboratory
Sieve Analyses Records
AASHTO T-11 and T-27

Material Tested	**Coerce Aggregate**		
Location		**Date**	**13-Jul-15**

Sieve(In/No)	Size(mm)	Mass of Retained Sample(g)	% Retained	% Passing
2 "	50.0	0.0	0.00	100.00
1 1/2"	37.5	130.0	4.92	95.08
3/4"	19.1	905.2	34.27	60.80
1/2"	12.50	620.5	23.49	37.31
3/8"	9.50	545.1	20.64	16.67
3/16"	4.75	410.0	15.52	1.14
NO 8	2.36	30.0	1.14	0.0
NO 16	1.18	0.0	0.00	0.0
pan	-			
Total		2641.0		



For:
Contractor:...........................

For Client:..........

For
Consultant:...........................

For C. Lab.:..........
26/10
2014

Table A9: Compressive strength of hollow blocks

Materials

Test Engineering Concrete, soil, asphalt test

Date:- 21st/03/2013

Mr. Research supervisor: Prof.Abd El rhman El Zibair

Researcher: Eng/ Mona Adam Jumma

Dear Sir

Subject: Hollow Blocks compressive strength results.

Referring to above subject: the test carry out for "Hollow blocks" strength. The results are shown in table No 10:-

Mortar Code	Curing Age (day)	Compressive strength (N/mm^2)
NM	28	4.4
NVA 20% NVA 30%	28	5.3 4.0
MVA 20% MVA 30%	28	4.6 3.9
TVA 20% TVA 30%	28	4.3 3.7
KTVA 20% KTVA 30%	28	4.8 3.8

Tested by: Eng/

Salaheldeen Ahmed Yousif Eltoum

General Manager

Table A10: UPV Test

Materials

Test Engineering **Concrete , soil , asphalt test**

Date:- 21st/03/2016

Mr. Research Supervisor: Prof. Abd El rhman El Zbair

Researcher :-Eng/Mona Adam Jumma

Dear Sir.

Subject: **The Main UPV of all specimens at 28 days.**

Reference No	Specimen No 1 Reading (μ sec)	Specimen No 2 Reading (μ sec)	Specimen No 3 Reading (μ sec)	Average (Km/ sec)
NM	18.3	20.8	18.7	3.6
NVA	17.2	17.3	18.2	3.9
NVA	17.2	17.6	17.2	4.0
NVA	17.2	17.0	17.5	4.1
MVA	18.2	18,0	18.7	3.82
MVA	18.2	18,0	18.3	3.85
MVA	18.2	18,0	17.8	3.90
TVA	18.7	18.3	19.3	3.70
TVA	18.5	19.2	18.1	3.76
TVA	18.2	19.0	18.0	3.80
KTVA	18.0	18.0	18.5	3.85
KTVA	17.0	17.7	17.5	4.00
KTVA	17.8	17.0	17.7	4.02

Materials

Test Engineering **Concrete , soil , asphalt test**

Tested by: Eng: Salaheldeen Ahmed Yousif Eltoum - General Manager

Table A11: Compressive Strength of Mortar

Materials

Test Engineering **Concrete , soil , asphalt test**

Date:- 21st/03/2016

Mr. Research Supervisor: Prof. Abd El rhman El Zbair

Researcher :-Eng/Mona Adam Jumma

Dear Sir.

Subject: **Compressive strength of Mortar (Pozzolana mixed with OPC) results.**

ample No.	Blending%		Compressive strength (N/mm²) According to B.S1996-EN2005	
	Pozzolana	cement	2 days	28 days
NM	0	100	20.4	40.8
NVA	10	90	20.7	43.5
NVA	20	80	19.4	46.3
NVA	30	70	17.8	43.0
MVA	10	90	18.0	36.0
MVA	20	80	16.0	40.1
MVA	30	70	15,0	37.4
TVA	10	90	20.0	38.0
TVA	20	80	17.0	40.3
TVA	30	70	15.0	37.7
KTVA	10	90	20.0	43.2
KTVA	20	80	18.7	45.2
KTVA	30	70	17.7	42.2

Materials

Test Engineering **Concrete , soil , asphalt test**

Tested by: Eng: Salaheldeen Ahmed Yousif Eltoum -
General Manager

Appendix B

Pozzolana Properties, Uses, Predicting and Standard

Table B1: Chemical analysis of some Pozzolanas in Sudan [3] [4] [33] [85]

	Pozzolana	CaO	MgO	SiO_2	Fe_2O_3	Al_2O_3	Na_2O	K_2O	L.I.O	location
Natu	Diatomite	12.5	0.52	54.3	4	4.7	1.16	1.65	15.4	Gregrieb(Gazeera)

	Obsidian	**0.58**	**0.03**	**75.2**	**1.16**	**6.64**	**1.38**	**1.38**	**5.59**	**Sabaloka (N Khartoum)**
	Natural burnt clay	**3.92**	**1.51**	**59.7**	**8.33**	**8.12**	**0.19**	**0.24**	**12.7**	**Southern Bayouda**
	Volcanic Tuff	**9.65**	**5.31**	**53.7**	**5.56**	**9.39**	**0.76**	**1.17**	**7.80**	**Bayouda**
	Pumice	**7.79**	**6.63**	**51.9**	**9.67**	**10.1**	**1.57**	**1.0**	**11.4**	**Bayouda**
	Volcanic ash	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**Jebelmarrah (S. Darfour)**
	Volcanic ash	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**Miedob (N.Darfour)**
	Volcanic ash	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**Tagabo (N. Darfour)**
	Volcanic ash	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**Gadarif**
	Volcanic ash	**1.8**	**2.7**	**67.4**	**4.66**	**15.6**	**-**	**-**	**9.7**	**Gregrieb(Gazeera**
Artificial Pozzolana	**Kaolin**	**1.2**	**0.2**	**59.4**	**2.4**	**25.5**	**0.5**	**1.1**	**8.9**	**Eastern sudan**
	Kaolin clay	**0.4**	**0.22**	**67.1**	**2.25**	**20.5**	**0.15**	**0.4**	**6.08**	**West of Omdurman**
	Calcined clay	**6.27**	**1.7**	**53.7**	**10.6**	**12.6 3**	**1.35**	**0.95**	**8.86**	**Blue Nile**
	Calcined clay	**5.26**	**2.7**	**51.7**	**10.5**	**14.6**	**1.35**	**0.95**	**9.73**	**Black cotton clay Gadarif**
	bagasse ash	**13.7**	**5.85**	**58.1**	**4.56**	**9.69**	**-**	**-**	**8.66**	**Kinana Sugar Factory**

Table B2 : Maximum Replacement Level of Pozzolanas in Various Countries

Country	Max. allowed replacement, %
Italy	**no limit**
Argentina	**50**
Chile	**50**
China	**50**
Indonesia	**50**

Brazil	**40**
Canada	**40**
Cuba	**40**
Finland	**40**
GDR	**40**
GFR	**40**
Greece	**40**
Korea	**40**
Mexico	**40**
Netherlands	**40**
Peru	**40**
Turkey	**40**
U.S.	**40**
Sudan	**35‡‡**
France	**35**
Japan	**30**
USSR	**30**
Yugoslavia	**30**
India	**25**
Austria	**20**
Belgium	**20**
Hungary	**20**
Poland	**20**
Spain	**20**
Morocco	**15**
Rumania	**15**
South Africa	**15**
Iceland	**10**

Modified after Robert L. 1990.
‡‡Sudanese Standard & Metrology Organization recently allowed replacement %

Table B3 : Pumice and related materials: Estimated World Production (Metric tons), By Country

Country	2007	2008	2009	2010	2011
Algeria, pozzolan	**570,000**	**490,567**	**328,000**	**236,961**	**300,000**
Argentina, pumice	**16,200**	**6,500**	**7,020**	**7,582**	**7,000**
Burkina	**10,000**	**10,000**	**10,000**	**10,000**	**10,000**

Faso					
Cameroon, pozzolan	600,000	600,000	600,000	600,000	600,000
Chile, pumice & pozzolan	1,135,771	1,063,176	919,249	824,049	850,000
Croatia, volcanic tuff	15,085	15,000	15,000	15,000	15,000
Dominica, pumice and volcanic tuff	100,000	100,000	100,000	100,000	100,000
Ecuador: Pozzolan Pumice	 803,502 153,500	 901,379 137,241	 884,773 44,171	 640,620 75,000	 700,000 100,000
Eritrea, pumice	55	60	60	60	60
Ethiopia	22,000	35,000	25,000	35,000	35,000
France, pozzolan & lapilli	250,000	276,000	276,000	276,000	276,000
Greece: Pozzolan, Santorin Pumice	 1,400,000 850,000	 1,059,000 828,000	 830,000 381,000	 900,000 380,000	 850,000 375,000
Guadeloupe, pumice	210,000	210,000	200,000	200,000	210,000
Guatemala, pumice	220,389	393,779	394,955	340,000	150,000
Iceland: Pumice Scoria	100,000 1,000	100,000 1,000	100,000 1,000	100,000 1,000	100,000 1,000
Iran	1,500,000	1,500,000	1,500,000	1,500,000	1,500,000
Italy: Pozzolan Pumice & pumiceous lapilli	4,000,000 20,000	3,000,000 20,000	3,000,000 20,000	3,000,000 20,000	3,000,000 20,000
Jamaica, pozzolan	114,482	124,304	132,470	125,000	125,000
Kosovo, volcanic	NA	39,631	51,769	52,800	52,800

tuff					
Macedonia, volcanic tuff	**80,910**	**103,476**	**113,064**	**113,000**	**113,000**
Martinique, pumice	**130,000**	**130,000**	**130,000**	**130,000**	**130,000**
New Zealand	**354,903**	**174,729**	**159,357**	**118,249**	**120,000**
Philippines **Pumice** **Volcanic tuff**	 **1,912** **16,490**	 **2,063** **17,570**	 **2,064** **18,830**	 **2,274** **19,166**	 **2,300** **19,500**
Saudi Arabia, pozzolan	**784,000**	**810,000**	**800,000**	**915,000**	**950,000**
Slovenia, volcanic tuff	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**
Spain, including Canary Islands	**600,000**	**600,000**	**600,000**	**600,000**	**600,000**
Syria, volcanic tuff	**810,000**	**901,000**	**957,639**	**950,000**	**900,000**
Tanzania, pozzolanic materials	**184,070**	**260,403**	**171,904**	**45,240**	**45,000**
Turkey	**3,995,423**	**3,449,773**	**4,322,543**	**4,000,000**	**4,500,000**
Uganda, pozzolanic materials	**140,000**	**140,000**	**140,000**	**140,000**	**140,000**
U. S., pumice, sold & used by producers	**1,270,000**	**791,000**	**410,000**	**390,000**	**489,000**
Grand total **Of which:**	**20,500,000**	**18,300,000**	**17,700,000**	**16,900,000**	**17,400,000**

Pumice	**2,950,000**	**2,600,000**	**1,670,000**	**1,630,000**	**1,560,000**
Pozzolan	**8,600,000**	**7,390,000**	**6,890,000**	**6,600,000**	**6,710,000**
Scoria	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**
Volcanic tuff	**962,000**	**1,120,000**	**1,200,000**	**1,190,000**	**1,140,000**
Unspecified	**7,990,000**	**7,230,000**	**7,930,000**	**7,480,000**	**8,010,000**

Source: United States Geological Survey Mineral Resources Program http://www.indexmundi.com/en/commodities/minerals/pumice_and_pumicite/pumice_and_pumicite_t4.html

Table B4 : Physical and Chemical Properties of Pozzolana Requirement by Standard Specifications

Requirements	ASTM C 618			Australia AS 1129	Canada CAN-A 23.5	U.K. BS 3892	Japan JIS A6201
	Natural Pozzolana Class N	Fly ash					
		Class F	Class C				
Blaine Fineness (m2/kg), min	-	-	-	None	None	None	2400
Retained on 45-µm (325) sieve, max%	34	34	34	50	34	12.5	None

Strength Activity Index with cement (%) at 7days, min	75	75	75	None	68	85	60
Strength Activity Index with cement (%) at 28 days, min	75	75	75	None	None	None	None
Autoclave expansion (%), maximum	0.8	0.8	0.8	None	0.8	None	None
Dry Shrinkage (%) at 28 days, max.	0.03	0.03	0.03	-	-	-	-
(Fe_2O_3+Al_2O_3+ SiO_2),min.%	70	70	50	None	None	None	None
MgO, max. %	-			None	None	4	None
SO_3, max. %	4	5	5	2.5	5	2.5	None
Loss on ignition, max. %	10	6	6	-	-	-	-
Free moisture, max. %	3.0	3.0	3.0	1.5	3.0	1.5	1.0
Available alkalies as Na_2O, max	1.5%	-	-	None	None	None	None

Table B5: SSB comparisons with burnt bricks and concrete blocks(HABITAT 2009)

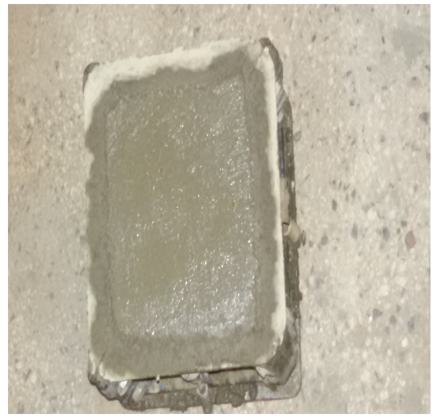
Description	**Stabilized Soil Block(SSB)**	**Burnt bricks**	**Hollow concrete blocks (CB)**
Size	290x140x120 mm	180x90x50 mm	390x190x190 mm
number per square meter	26	216	12.5
number required for a 4m	1,664	13,824	800
Unit Price	$0.36	$0.08	$0.9

cost	$599	$1,105	$720
Cost of cement and sand	$142	$750	$214
construction labor costs	$300	$400	$200
Estimated amount of water	6,000 liters	12,000	6,000 liters
Estimated number of trees	0	14	0
total cost per house	$1041	$2255	$ 1134
Difference in cost to BB	$1214	0	$1121
Percentage in saving	approx. 53.8%		49.7%
comparisson between SSb and CB	93$		
Percentage in cost SSB vs CB	46.2%		50.3%

B6: The Photo Equipment use in the research:

Standard Sieve

Sieve Shaker



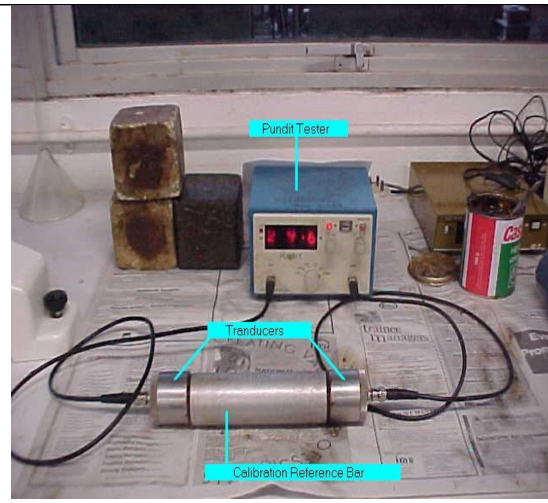
70mmx70mm X70mm mortar.

Casted (150x150x150) mm concrete moulds

Vicat apparatus for Measuring consistencies and setting

Compressive testing machine

Concrete hollow blocks making machine



XRF used for Composition analysis

Ultrasonic used to chemical measure Permeability for mortar

Electric Balance used **for weighting samples.**

Digital thermometer used for measuring temperature.

Slump Cone used the workability.

Apparatus for testing for measure Mortar flow

Compressive testing Machine (Mortar cube)

Through cubical specimen UPV test

B7: Requirement of Tested Blended cement:

Table 1: Blended Cement (Nyrtety) - Chemical Requirements ASTM C 595

oxide	Cement (%)	Blended Cement (%)	Requirement of blended cement
AL_2O_3	4.38	7.220	± 2 from the cement
SiO_2	20.62	24.960	± 3 from the cement
CaO	62.58	51.762	± 3 from the cement
SO_3	2.42	2.470	Max 4%
L.O.I	2.30	2.700	Max 5%
MgO	2.77	1.008	Max 6%
Fe_2O_3	3.62	3.544	……….

Table 2: Blended Cement (Ktroum) - Chemical Requirements ASTM C 595

oxide	Cement (%)	Blended Cement (%)	Requirement of blended cement
AL_2O_3	4.38	7.178	± 2 from the cement
SiO_2	20.62	23.833	± 3 from the cement

CaO	62.58	53.108	± 3 from the cement
SO_3	2.42	2.47	Max 4%
L.O.I	2.3	2.700	Max 5%
MgO	2.77	1.018	Max 6%
Fe_2O_3	3.62	3.477	……….

Table 3: Blended Cement (Tina) - Chemical Requirements ASTM C 595

oxide	Cement (%)	Blended Cement (%)	Requirement of blended cement
AL_2O_3	4.38	6.742	± 2 from the cement
SiO_2	20.62	25.198	± 3 from the cement
CaO	62.58	51.499	± 3 from the cement
SO_3	2.42	2.420	Max 4%
L.O.I	2.3	3.400	Max 5%
MgO	2.77	1.066	Max 6%
Fe_2O_3	3.62	3.554	……….

Table 4: Blended Cement (Melm) - Chemical Requirements ASTM C 595

oxide	Cement (%)	Blended Cement (%)	Requirement of blended cement
AL_2O_3	4.38	6.577	± 2 from the cement
SiO_2	20.62	23.404	± 3 from the cement
CaO	62.58	53.472	± 3 from the cement
SO_3	2.42	2.450	Max 4%
L.O.I	2.3	3.700	Max 5%
MgO	2.77	1.142	Max 6%
Fe_2O_3	3.62	3.561	……….

Blended cement (Nyrtety) Calculation composition:

There are some factors, which are very important to estimate the compressive strength of the cement. These factors are derived from the chemical analysis of the samples:

1. Lime Saturation Factor (LSF)

LSF= CaO -0.7 SO_3/(2.8 SiO_2+1.2 Al_2O_3+0.65 Fe_2O_3)

= 51.762-0.7*2.47/(2.8*24.960+1.2*7.22+0.65*3.544) = **0.62%**

2. Silica Ratio (SR):

SR= SiO_2/ (Al_2O_3+ Fe_2O_3)

= 23.62/(7.22+3.544) = **2.2%**

3. Alumina Ratio (AR): AR= Al_2O_3 / Fe_2O_3

= 7.22/3.544 = **2.03%**

4. Alite: C_3S or Tricalcium Silicate:

C_3S = 4.071 CaO -7.0624 SiO_2-1.4297 Fe_2O_3-6.7187 Al_2O_3

= 4.071 *51.76 -7.0624 *24.96-1.4297 *3.477-6.7187 *7.22= **-19%**

5. Belite: C_2S, or Dicalcium Silicate:

C_2S = 8.6024 SiO_2+ 1.0785 Fe_2O_3+ 5.0683 Al_2O_3- 3.071 CaO

= 8.6024 *24.96+ 1.0785 *3.477+ 5.0683 *7.22- 3.071 *51.76 = **96%**

6. Aluminate Phase: C_3A, or Tricalcium Aluminate:

C_3A = 2.6504 Al_2O_3– 1.6920 Fe_2O_3

= 2.6504 *7.22– 1.6920 *3.544 = **13.13%**

7. Ferrite phase C_4AF, or Tetracalcium Alumino Ferrite:

C_4AF = 3.0432 Fe_2O_3

= 3.0432 *3.544= **10.78%**

Blended cement (Tina) Calculation composition:

There are some factors, which are very important to estimate the compressive strength of the cement. These factors are derived from the chemical analysis of the samples:

1. Lime Saturation Factor (LSF)

LSF= CaO -0.7 SO_3/(2.8 SiO_2+1.2 Al_2O_3+0.65 Fe_2O_3)

= 53.108-0.7*2.47/(2.8*23.833+1.2*7.178+0.65*3.477) = **0.66%**

2. Silica Ratio (SR):

SR= SiO_2/ (Al_2O_3+ Fe_2O_3)

= 23.833/(7.178+3.477) = **2.23%**

3. Alumina Ratio (AR): AR= Al_2O_3 / Fe_2O_3

= 7.178/3.477 = **2.06%**

4. Alite: C_3S or Tricalcium Silicate:

C_3S = 4.071 CaO -7.0624 SiO_2-1.4297 Fe_2O_3-6.7187 Al_2O_3

= 4.071 *53.108 -7.0624 *23.833-1.4297 *3.477-6.7187 *7.178= **-5.3%**

5. Belite: C_2S, or Dicalcium Silicate:

C_2S = 8.6024 SiO_2+ 1.0785 Fe_2O_3+ 5.0683 Al_2O_3- 3.071 CaO

= 8.6024*23.833+ 1.0785 *3.477+ 5.0683 *7.178- 3.071 *53.108 = **82%**

6. Aluminate Phase: C_3A, or Tricalcium Aluminate:

C_3A = 2.6504 Al_2O_3– 1.6920 Fe_2O_3

= 2.6504 *7.178– 1.6920 *3.477 = **13.14%**

7. Ferrite phase C_4AF, or Tetracalcium Alumino Ferrite:

C_4AF = 3.0432 Fe_2O_3

= 3.0432 *3.477= **10.5%**

Blended cement (Ktroum) Calculation composition:

There are some factors, which are very important to estimate the compressive strength of the cement. These factors are derived from the chemical analysis of the samples:

1. Lime Saturation Factor (LSF)

LSF= CaO -0.7 SO_3/(2.8 SiO_2+1.2 Al_2O_3+0.65 Fe_2O_3)

= 51.499-0.7*2.42/(2.8*25.198+1.2*6.742+0.65*3.554) = **0.61%**

2. Silica Ratio (SR):

SR= SiO_2/ (Al_2O_3+ Fe_2O_3)

= 25.198/(6.742+3.554) = **2.45%**

3. Alumina Ratio (AR): AR= Al_2O_3 / Fe_2O_3

= 6.742/3.554 = **1.89%**

4. Alite: C3S or Tricalcium Silicate:

C3S = 4.071 CaO -7.0624 SiO_2-1.4297 Fe_2O_3-6.7187 Al_2O_3

= 4.071 *51.499 -7.0624 *25.198-1.4297 *3.554-6.7187 *6.742**= -18%**

5. Belite: C2S, or Dicalcium Silicate:

C2S = 8.6024 SiO_2+ 1.0785 Fe_2O_3+ 5.0683 Al_2O_3- 3.071 CaO

= 8.6024*25.198+ 1.0785 *3.554+ 5.0683 *6.742**-** 3.071 *51.499 = **96%**

6. Aluminate Phase: C3A, or Tricalcium Aluminate:

C3A = 2.6504 Al_2O_3– 1.6920 Fe_2O_3

= 2.6504 *6.742– 1.6920 *3.554 = **11.8%**

7. Ferrite phase C4AF, or Tetracalcium Alumino Ferrite:

C4AF = 3.0432 Fe_2O_3

= 3.0432 *3.554= **10.8%**

Blended cement (Tina) Calculation composition:

There are some factors, which are very important to estimate the compressive strength of the cement. These factors are derived from the chemical analysis of the samples:

1. Lime Saturation Factor (LSF)

LSF= CaO -0.7 SO_3/(2.8 SiO_2+1.2 Al_2O_3+0.65 Fe_2O_3)

= 53.472-0.7*2.45/(2.8*23.404+1.2*6.577+0.65*3.561) = **0.68%**

2. Silica Ratio (SR):

SR= SiO_2/ (Al_2O_3+ Fe_2O_3)

= 23.404/(6.577+3.561) = **2.3%**

3. Alumina Ratio (AR): AR= Al_2O_3 / Fe_2O_3

= 6.577/3.561 = **1.85%**

4. Alite: C3S or Tricalcium Silicate:

C3S = 4.071 CaO -7.0624 SiO_2-1.4297 Fe_2O_3-6.7187 Al_2O_3

= 4.071 *53.472 -7.0624 *23.404-1.4297 *3.561-6.7187 *6.577**= 3.1%**

5. **Belite: C2S, or Dicalcium Silicate:**

C2S = 8.6024 SiO_2+ 1.0785 Fe_2O_3+ 5.0683 Al_2O_3- 3.071 CaO

= 8.6024*23.404+ 1.0785 *3.561+ 5.0683 *6.577- 3.071 *53.472 = **78%**

6. Aluminate Phase: C3A, or Tricalcium Aluminate:

C_3A = 2.6504 Al_2O_3– 1.6920 Fe_2O_3

= 2.6504 *6.577– 1.6920 *3.561 = **11.4%**

7. Ferrite phase C4AF, or Tetracalcium Alumino Ferrite:

C_4AF = 3.0432 Fe_2O_3

= 3.0432 *3.561= **10.8%**

Table 5: Bogue composition of Blended cement

Material	Bogue Composition (%)						
	C_3S	C_2S	C_3A	C_4AF	LFS	SR	AR
Nyrty B.C	-19	96	13.25	10.5	0.62	2.20	2.07
Tina B.C	-5.3	82	13.13	10.58	0.66	2.23	2.06
ktroum B.C	-18	96.6	11.8	10.8	0.61	2.45	1.89
Melm B.C	3.1	78.08	11.4	10.8	0.68	2.3	1.85

Appendix C

Abstract of Publish Paper

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The Effect of Jebel Marra Natural Pozzolana on the Strength and Permeability of Mortar

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Abstract:
The objective of this study is to find alternative binding materials that can be blended with Ordinary Portland Cement (OPC) to enhance the properties of mortar as well as to reduce the cost. This paper discus the effects of using the natural Pozzolana as the alternative binding material.
Four samples were collected from areas of Jebel Marra Volcanic Ash (JMVA) South Darfur. They were representative samples of volcanic ash, from Nyertity area classified (NVA), from Tina area (TVA), Kotrom area (KTVA) and Melem area (MVA). The study investigated the use of (JMVA) as partial replacement of (OPC) in the production of mortar mixes. Mortar cubes measuring 70mm* 70mm* 70mm were

made from the four different mortar mixes prepared by using (JMVA) to replace 0%,10%, 20% and 30% of (OPC) by mass. The chemical, physical, and mineralogical characteristics of the (JMVA) were first tested. Then the strength and permeability properties of the mixes were examined to determine the effect of these materials on mortar properties compared to control mortar mix. The results of the chemical analysis showed that the sum of oxides of Silica, Alumina and Iron were 86.68%, 86.96%, 86.12% and 87.06% for NVA, MVA, TVA and KTVA respectively.
The permeability of the mortar mixes was evaluated using the Ultrasonic Pluses Velocity (UPV) test at age of 28days, Permeability decreased with an increase in replacement percentage. Mortar specimens were tested for compressive strength at age of 2days and 28 days. The maximum compressive strength at all ages of testing was obtained at 20% replacement. The maximum strengths for the four areas were 46.3, 40.1, 40.3 and 45.2 N/mm² respectively, against 40.8 N/mm² for the control mix. This shows an increase of 13.5% for (NVA) and 11% for (KTVA), with negligible decrease for the two other areas. This is clearly confirmed by the strength activity index (SAI) of mortar results for the four areas. Hence Pozzolana from these areas can be used to partially replace 20% of (OPC) in the production of mortar without compromising strength.

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Partial Replacement of Ordinary Portland Cement (OPC) with Natural Pozzolanas (Jebel Marrah) Volcanic Ash in concrete

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Abstract: Considering the need for low-cost construction materials in the rural areas in Sudan, especially in Darfur, this paper examines ordinary Portland cement (OPC). The use of as a replacement of Jebel Marrah volcanic ash in concrete. The ash is obtained from Jebel Marrah (mountains), west of Sudan. These materials have been chemically and physically characterized. Concrete cubes measuring 150mm*150mm*150mm were made from four different concrete mixes prepared by using pozzolana to replace 0%, 10%, 20% and 30% of OPC by weight. The workability of the fresh concrete mixes were evaluated using the slump test and compacting factor test while compressive strengths of concrete cubes were evaluated at 7, 28, and 90 days. The maximum compressive strength at all ages of testing was obtained at 20% replacement. Workability increased with an increase in replacement percentage and the strength of cement/ash concrete increased with curing period but decreased with increasing ash percentage. The results obtained showed that Pozzolana can be used to partially replace up to 20% of OPC in the production of concrete without compromising strength.

المستخلص- هدفت هذه الدراسة الى إستكشاف مواد بناء قليلة التكلفة كالبوزولانا فى المناطق الريفية فى السودان وخاصة فى ولاية دارفور, وذلك بسبب إرتفاع أسعار الأسمنت البورتلاندى.
كما ركزت الدراسة على إستخدام الرماد البركانى المستخرج من جبل مرة غرب السودان كبديل للأسمنت فى الخرسانة. حيث أكدت النتائج الأولية للتحاليل الكيميائية والفيزيائية مطابقة المواد للمواصفات. لمعرفة درجة فاعلية
البوزولانا تم إعداد أربعة خلطات خرسانية مختلفة, باستخدام مكعبات مقاس mm (150*150*150) بنسب مختلفة 0%, 10%, 20% و 30% من وزن الأسمنت.
تم تحديد قابلية التشغيل للخرسانة الطازجة باستخدام إختبار الهبوط (Slump Test) بينما تم قياس مقاومة ضغط الخرسانة فى 7 يوم, 28 يوم و 90 يوم باستخدام ماكينة الإختبار العالمية (Universal- testing machine).
وقد تم الحصول على أعلى مقاومة فى جميع الأعمار عند إستبدال 20% من الأسمنت, زادت قابلية التشغيل مع زيادة نسبة البوزولانا بينما زادت المقاومة مع زيادة نسبة البوزولانا حتى نسبة 20% ثم انخفضت للنسب الأعلى.
أظهرت النتائج أن البوزولانا (الرماد البركانى) المستخرج من جبل مرة يمكن إستخدامه ليحل محل جزء من الأسمنت بنسبة تصل الى 20% دون تأثير سلبى فى المقاومة.