Preparation of Ethiopian Standard Sand for the Purpose of Construction and Testing

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Abstract

Sand is a naturally produced material resulting from the mechanical and chemical breakdown of rocks. Sand is the most common and loosely packed mineral on the earth's surface. Sand particles mostly range from 0.02 mm to 2.00 mm in diameter. Silica sand is the term used to describe sand that has a very high percentage of silicon dioxide (SiO_2).

In the field of civil engineering, silica sand is used for several purposes like, in construction, in industries for the production of different construction materials. Sand, which is graded according to a specified standard, is used for testing of Portland cement and concrete, in field density determination using sand replacement method, and in water and sewage treatment plants as a filter media.

Due to lack of standard silica sand in Ethiopia, the country is losing high foreign currency by importing standard silica sand from abroad. The purpose of this research is the identification of the different sources of sand in different parts of the country for the purpose of standard sand production.

To achieve the research objective, sand samples for laboratory investigation and field test were collected from North Showa (Jema river valley) and Dire Dawa town.

Visual inspection, index property tests, test for impurities and chemical contents were conducted on both samples. Sand replacement and mortar test were done to check the applicability of the local samples

in field density determination and in testing of Portland cement respectively.

Grain size analysis and impurity test results revealed that both local sand samples cannot be used as standard sand as they are collected directly from their natural places. Thus, inorder to be used as standard sands both samples must be washed, oven dried, sieved and separated to various size fractions and mix each fraction according to the grading requirement.

In all of the test results, the compressive and flexural strength of mortar cubes made with local samples gave lower values compared to that of imported sand. However, a relatively uniform trend was observed both in the compressive and flexural test results between the local samples and the imported one.

The field density test by sand replacement method showed that, both local sand samples gave the same result with the imported Ottawa standard sand in almost all test locations irrespective of the silica content.

Laboratory and field tests conducted on both local sand samples showed that there is a high possibility that both local sand samples can replace the imported standard sand.

Key words

- ***Standard sand****: silica sand, composed of naturally rounded grains of nearly pure quartz, used for preparing mortars in the testing of hydraulic cements.*

- ***CEN Standard sand:*** *natural, siliceous sand consisting mostly of rounded particles of silica content of at least 98%. (CEN means Committee for European Norms). The CEN sand is standard sand used for preparation of mortars in the testing of hydraulic cements by European standard.*

- ***Ottawa standard sand:*** *consists of rounded grains of clear colorless quartz, which have diamond-like hardness, and are pure silica (Silicon Dioxide, SiO_2) uncontaminated by clay, loam, iron compounds, or other foreign substances. The Ottawa sand was chosen by the American Society for Testing and Materials (ASTM) as the standard sand to be used in testing cement and the strength of concrete.*

Chapter One
Introduction, Objectives, and Methodology

1.1 Introduction

Sand is the most common and loosely packed mineral on the earth's surface smaller than gravel and larger than silt and clay. Sand particles mostly range from 0.02 mm to 2.00 mm in diameter. Sand is naturally produced material resulting from the mechanical and chemical breakdown of rocks. Sand accumulates in areas where sediments are transported and deposited such as in desert, beach, and river environments.

The following areas are among the many fields where sand is essential:

- In construction industries for the production of different construction materials
- In concrete technology for testing of Portland cement
- In field density determination using sand replacement method
- In water and sewage treatment plants as a filter media.
- In manufacturing industries for the production of glass and related products
- In agricultural area for different testing purposes

Silica sand is the term used to describe sand that has a very high percentage of silicon dioxide (SiO_2). Silica sand has more diverse fields of use than any other non-metallic minerals mainly because of its common occurrence around the world and its distinctive physical characteristic including hardness, resistant to high temperature, chemical action, and relatively low price.

In industries, silica sand is used for manufacturing sandpaper and is an essential material in glass manufacture, abrasives, polishing powders and heat-resistant materials known as refractories and for the bearings of precision instruments.

This mineral commodity is found abundantly all over the world including Ethiopia. The occurrence of silica sand deposit in Ethiopia has been reported in various localities. Huge amount of silica sand deposits are found in North Shewa of Abay basin around Mugher valley, Haro Genda and Alem Ketema.

The demand of silica sand by different industries like cement, glass, paint, chemical, smelting, etc is increasing from time to time. In order to satisfy their demands, most of these industries are importing silica sand from abroad. However, some like Mugher Cement Factory and Ethio Glass Factory are mining small quantities of silica sand only for their own consumption. The production of silica sand compared to the demand and abundant reserve is insignificant. However, the increasing demand is currently pushing the country to exploit and develop it for potential deposit.

In the field of civil engineering, silica sand is used for several purposes like, in construction, in industries for the production of different construction materials, in concrete technology for testing of Portland cement, in field density determination using sand replacement method, in water and sewage treatment plants as a filter media.

Due to lack of standard silica sand in Ethiopia, the country is forced to import standard sand from abroad. The identification of the different sources of sand in different parts of the country for the purpose of standard sand production is economically very essential and saves the country from high foreign currency loss as well as taking one-step ahead in the development and exploitation of national resources.

The major consumers of standard silica sand in Ethiopia are cement factories and construction materials testing laboratories. According to the present estimates Mugher cement factory, Addis Ababa cement plant, Dere Dawa lime and cement factory and Messebo cement factory consume a total of 40 Kg per day of imported standard sand. The present price of standard sand in the world market is assumed to be 10£ per Kg. Therefore, the factories are forced to spend 400£ per day or 146,000£ per year. Furthermore, a remarkable amount of such sand is also required for field density test by sand replacement method. Therefore, there is a great need to produce standard sand using the locally available natural sand.

1.2 Objectives

Sand, which is graded according to a specified standard, is normally used for the testing of mortars and concrete. In order to check a given mortar or concrete mix against standard values, it is necessary to carry out a similar test with standard sand. This would enable the engineer to determine the quality of the sand used in any mortar or concrete mix for construction purposes. Due to lack of standard sand in Ethiopia, the country is forced to import standard sand from abroad.

The main target of this research is, therefore, to produce standard sand locally through selective sampling and testing, which would serve the mentioned purposes so that it could be used as Ethiopian standard sand that would replace imported standard sand.

1.3 Methodology

Sand samples from different parts of the country were selected for investigation. The standard test procedures stated in any of the standard specifications such as American Society for Testing and Materials (ASTM), British Standard (BS), American State Highways and Transport Officials (ASHTO) and European Standard (EN) were employed.

Tests that are conducted include:

- Visual inspection,
- Index Properties,
- Test for impurities,
- Test for chemical contents,
- Field density measurements using sand replacement method and
- Checking its applicability in testing of Portland cement.

Field density measurement and mortar test on Portland cement were carried out with local sand samples and the results are compared with test results obtained using imported sand. The results obtained are evaluated and those samples, which fulfill the requirements, are recommended to be used as Ethiopian standard sand. Proposals are made for the improvement of the appropriate sand quarries, so as to fulfill the major requirements so that standard sand could be produced from identified sources.

All the required tests are carried out at A.A.U Faculty of Technology, Ethiopian Standards Authority, Addis Ababa Cement Plant, and Ethiopian Geological Survey laboratories.

Chapter Two
Literature Review

2.1 General

Sand is a naturally produced material resulting from the mechanical and chemical breakdown of rocks. Sand is the most common and loosely packed mineral on the earth's surface. Smaller than gravel and larger than silt and clay, sand particles mostly range from 0.02 mm to 2.00 mm in diameter. Sand accumulates in areas where sediments are transported and deposited, in areas such as desert, beach, and river environments, [10].

The most common component of sand is quartz. Quartz is a mineral that is abundant, hard, nearly insoluble in water, and resistant to chemical decay. Other sands are made of silicates such as feldspar. The quartz sands usually contain a small quantity of feldspar and white mica. Yellow, brown, and red sands contain iron compounds, [5]. Red desert sands are usually made of quartz coated with iron oxides. The best field indicators of quartz are crystal system, hardness, fracture, color, luster, etc, [10].

2.2. Back ground and uses of silica sand

Silica sand is the term used to describe sand that has a very high percentage of silicon dioxide (SiO_2) which is an essential material in glass manufacture, in certain chemical and metallurgical processes, and in many manufactured products as filler material, [12].

One of the first industries to use silica sand was glass industry. At least 4,000 years ago, long before iron was smelted, glass making was already known craft. Although the place and data of the first manufactured glass are not known, specimen of the glass are from Babylon (2600 BC) and from Egypt (2500 BC), where the industry was well established by about 1500 BC. Many varieties of glass were known during the Roman times. Little is known of the glass making method used in Europe from the fall of the Rome until the 10th century, when stared glass was produced in Venice. After this, Venice remained the leader in fine glassware for the next 4 or 5 centuries. In the 17th century, a process for casting glass was invented in France, and later, England began to make flint glass, marking the beginning of modern glass technology. Glass making was apparently the first industry to be transplanted from Europe to North America, first to Mexico and later to British colonies to USA in 1608, [13].

Silica sand has more diverse fields of use than any other non-metallic minerals mainly because of its common occurrence around the world and its distinctive physical characteristic including hardness, resistant to high temperature, chemical action, and relatively low price.

Silica sand is important in ceramics, chemicals, and fillers for rubber and plastics. It is also utilized as a flux in smelting and chemical production, as filer media, and in many other uses.

The following are some of the commercial applications of silica sand:

I. **In construction industry**

a) Silica bricks and tiles-Silica sand is used to manufacture silica brick and tiles used in furnace linings and beds.

b) Filter-Silica sand is used extensively in filtering municipal water supply, industrial uses, swimming pools and in sewage treatment plants.

c) Testing sand – Silica sand used to determine the strength of cement in accordance with standard specification and determine in place density of soil during dam and highway construction, [14].

II. **In glass industry**

Silica sand has a wide range of use in a significant number of glass industries for manufacturing, [15]

- Glass containers
- Flat glass (sheet glass), safety glass
- Pressed and blown glass, fiber glass
- Specialty glasses (optical glass and industrial glass)

III. **In metallurgy and abrasives**

Silica sand is used as fluxing agent for basic oxides in various smelting operations and as a source of silicon for ferrosilicon manufacture. Sand as a fluxing agent is used in smelting foundry of ferrous and nonferrous mineral. In the process of ore smelting it reacts with various impurities in the ore and produces a slag. The slag is drawn off with the impurities, leaving a more refined metal behind.

2.3 Commercially Available Standard Sand

2.3.1 Ottawa standard sand

The Ottawa quartz sand consists of rounded grains of clear colorless quartz, which have diamond-like hardness, and are pure silica (Silicon Dioxide, SiO_2) uncontaminated by clay, loam, iron compounds, or other foreign substances, [11].

The Ottawa sand was chosen by the American Society for Testing and Materials (ASTM) as the standard sand to be used in testing cement and the strength of concrete, [8]. The Ottawa sand consists of single mineral quartz. It is a naturally occurring very homogeneous, inorganic material formed because of geological processes. This sediment has a definite chemical composition (SiO_2) and an ordered atomic arrangement in its mineral, [11]. It is obtained from the St. Peter Sandstone which is a sedimentary rock built of grains of sand held together by a natural cement. It is found in a massive formation from 40*m* to 80*m* in thickness that outcrops along the Fox Rivers near Ottawa, in Illinois, [11]. The Ottawa sand should meet the grading requirements which is described in Table 2.1

Table 2.1 Grading requirements of Ottawa sand

Square mesh size (mm)	**Cumulative passing** (%)
1.18	100
0.6	96-100
0.425	65-75
0.3	20-30
0.15	0-4

2.3.2 CEN standard sand

CEN (Committee for European Norms) Standard sand is natural, siliceous sand consisting mostly of rounded particles of silica content of at least 98%. The sand is thoroughly washed, dried and accurately graded before being put into 1350g packs ± 5g. The sand packs are placed onto waterproof, film shrink-wrapped pallets, [3].

The Requirements of CEN standard sand mainly focuses on particle size distribution and moisture content.

i) Particle size distribution

The particle size distribution should lie within the limits defined in Table 2.2.

Table 2.2 Grading requirements of the CEN reference sand

Square mesh size (mm)	**Cumulative Retained** (%)
2.00	0
1.60	2-12
1.00	28-38
0.50	62-72
0.16	82-92
0.08	99-100

ii) Moisture content

The Moisture content should be less than 0.2% determined as the loss of mass of a representative sample of sand after 2 hours drying at 105 ^{o}C to 110 ^{o}C and expressed as a percentage by mass of the dried sample.

Chapter Three

Test Results and Discussion of Test Results

3.1 Sampling, Sample Preparation & Description

Even though the country has abundant sand deposits, [4] due to financial limitations and time constraints sand samples are taken from two sites located at the Central and Eastern Ethiopia. The sand samples for laboratory investigation and field test were collected from North Showa (Jema river valley) and Dire Dawa town. Sand sample taken from North Showa is designated as sample NS and that of Dire Dawa is designated as sample DD.

The sample taken from Dire Dawa was collected from the riverbed that crosses the town. The North Showa sample is taken from natural sand deposit. The sampling area is located in the Amhara Regional National State of North Shoa at Haro Genda locality. Haro Genda is located 200 Km north east of Addis Ababa.

To conduct the different laboratory as well as field tests, some 200 Kg of sand samples was collected in bulk randomly from respective sites. From the visual inspection of the sand samples it was observed that the color of sample DD is brown while that of sample NS is white. Before conducting index property tests, the clay content was determined for both samples and it was found out that they have high clay content. Therefore, all index properties, physical and chemical composition tests were conducted on washed and oven-dried sand sample.

For mortar testing, both local sand samples were thoroughly washed, oven dried and sieved to separate each size fraction. According to CEN grading requirement sand retained in each sieve was mixed and then put into 1350g ± 5g plastic bags. The sand passing ASTM Sieve No. 20 and retained on Sieve No.30 is used for field density test for both local sand samples and the result was compared with Ottawa 20-30 sand.

The standard test procedures stated in any of the standard specifications such as American Society for Testing and Materials (ASTM), [2], British Standard (BS), [3], American State Highways and Transport Officials (ASHTO), [1] and European Standard (EN), [3] were employed. Some of the tests conducted include visual inspection, index properties, test for organic impurities, mineralogical analysis, and field density measurements using sand replacement method and checking its applicability in testing of Portland cement.

3.2 Index Property Tests

3.2.1 Grain size analysis

Grain size analysis, which is among the oldest of soil tests, is widely used in engineering classifications of soils. The purpose of this test is to determine the distributions of grain sizes in a given soil sample. Listed in Table 3-1 and 3-2 are the results of grain size analysis performed on sand sample NS and sand sample DD respectively. Grain size distribution curves of these two sand samples are shown in Figs. 3.1 and 3.2.

Table 3.1 Grain size analysis result of sample NS

Sieve size (mm)	**Weight retained** (gm)	**Percentage retained** (%)	**Cumulative percentage retained** (%)
4.75	1.23	0.25	0.25
2.36	4.43	0.90	1.15
1.18	27.80	5.63	6.77
0.6	133.07	26.93	33.70
0.3	221.57	44.84	78.54
0.15	93.30	18.88	97.42
0.075	12.73	2.58	100.00
Sum	494.13	100.00	-

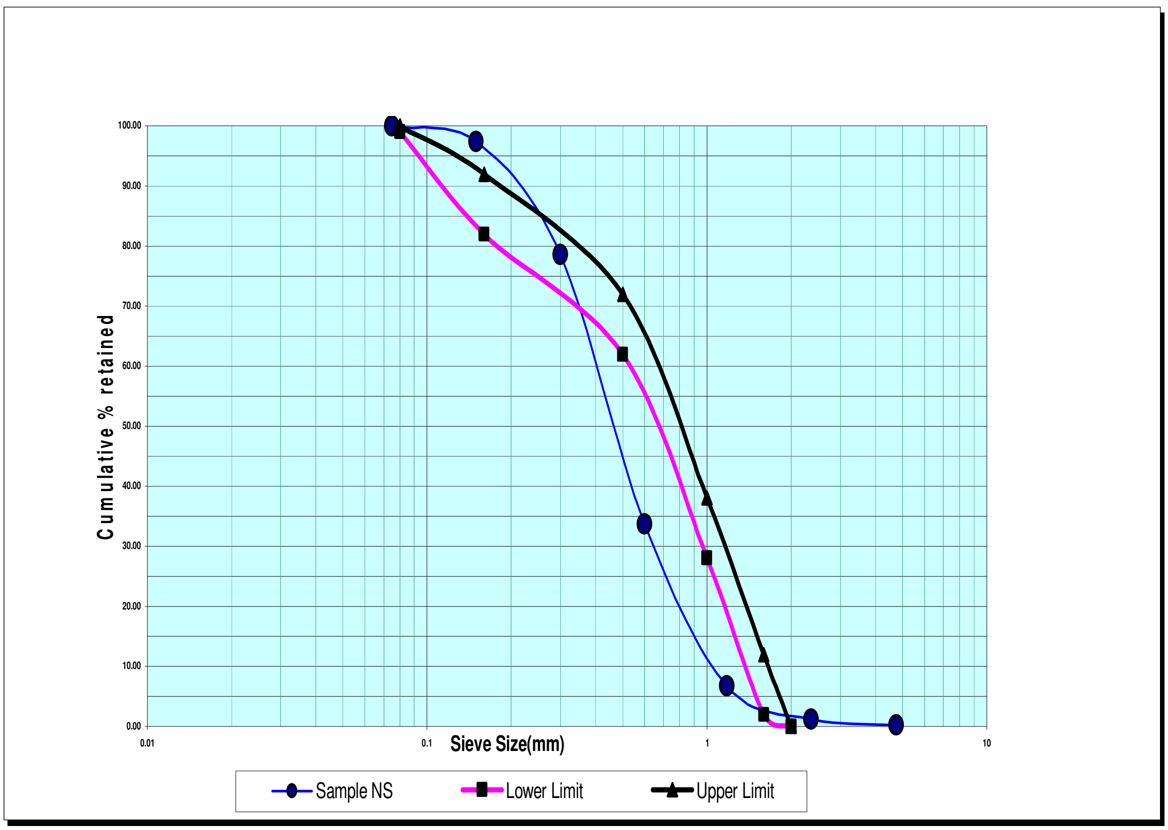

Fig.3.1 Particle size distribution curve of sample NS compared against CEN specification limit

Table 3.2 Grain sieve analysis result of sample DD

Sieve size (mm)	**Weight retained** (gm)	**Percentage retained** (%)	**Cumulative percentage retained** (%)	**CEN Specification Limit** (Cumulative % retained)
2	117	23.45	23.45	0
1.6	38.5	7.72	31.16	2-12
1	135	27.05	58.22	28-38
0.5	160	32.06	90.28	62-72
0.16	47.5	9.52	99.80	82-92
0.08	1	0.20	100.00	99-100
Sum	499	100	-	-

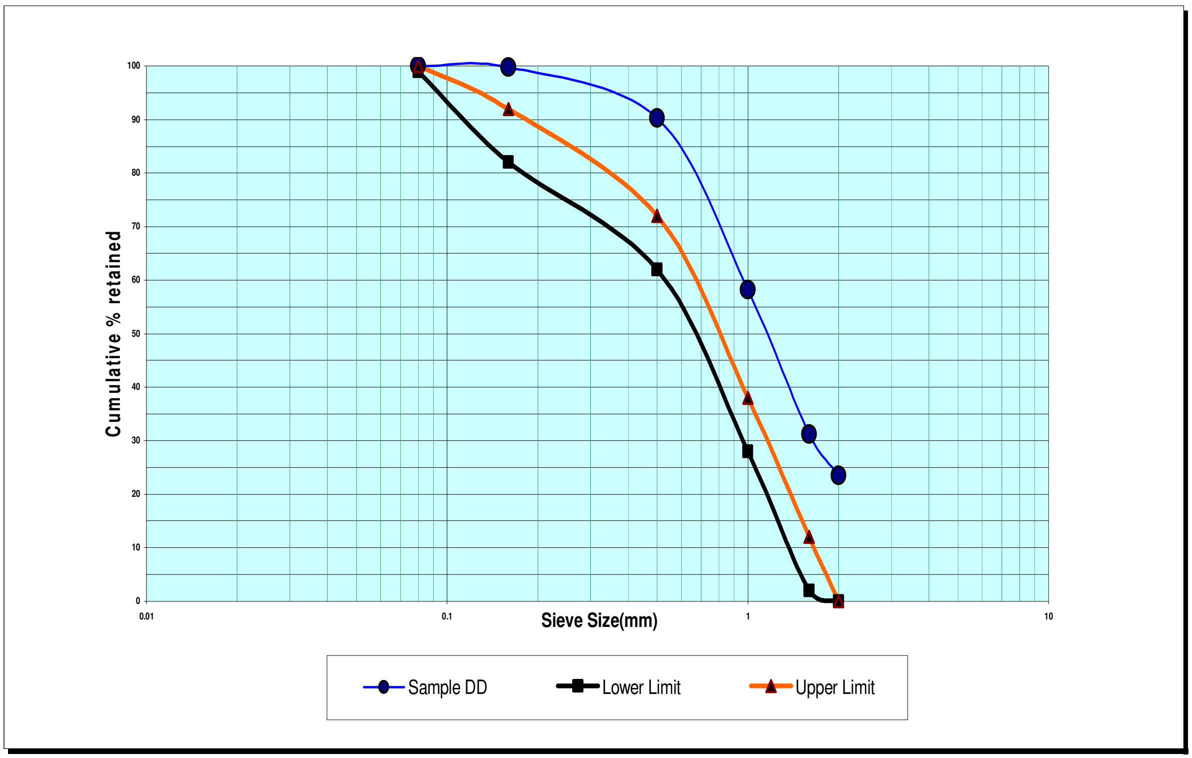

Fig.3.2 Particle size distribution curve of sample DD compared against CEN specification limit.

As it can be seen from Figs. 3.1 and 3.2 the particle size distribution of the sands under investigation are out of the CEN specification range. This indicates that both local sand samples cannot be used directly in their natural state.

Therefore, in this research both sand samples were thoroughly washed and sieved to separate each size fraction and graded accordingly before being put into 1350g packs ± 5g for mortar testing. (See Fig.3.3)

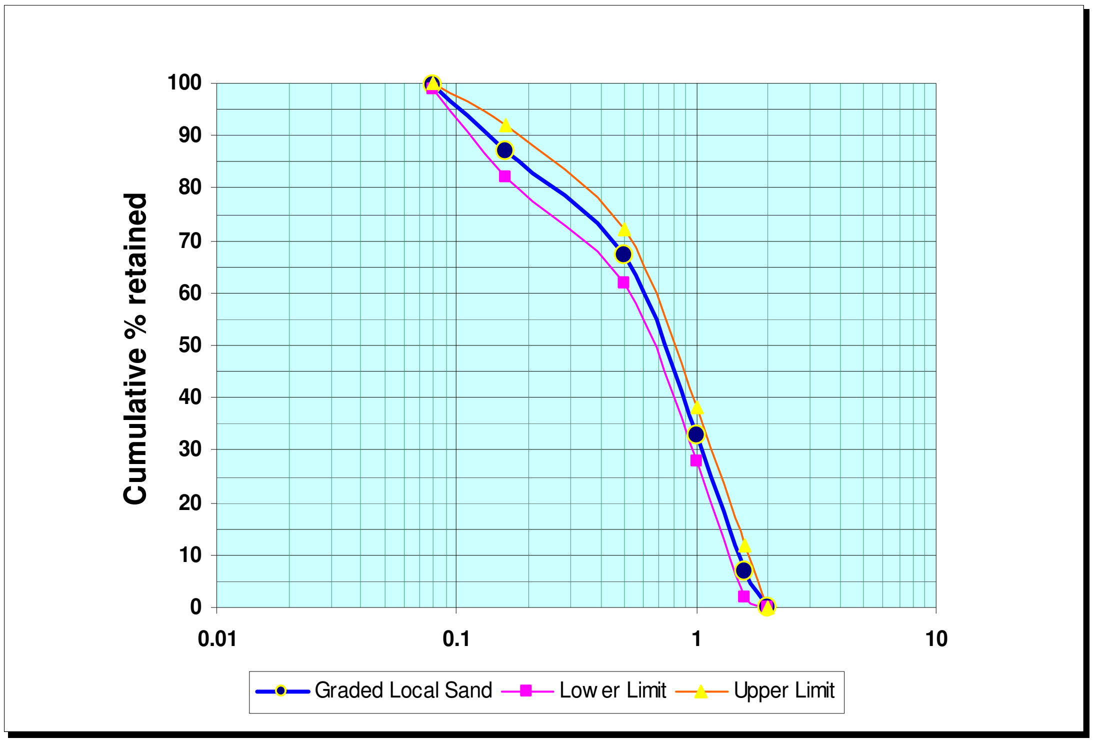

Fig. 3.3 Particle size distribution curve of graded local sand according to CEN specification limit.

3.2.2 Specific gravity

Specific gravity of a soil is defined as the ratio of the weight in air of a given volume of soil particles to the weight in air of an equal volume of distilled water at stated temperature.

Specific gravity was determined in the laboratory according to ASTM D854-92, [2] from the weight of pycnometer filled with distilled water at a test temperature of 20^{o}C and pycnometer filled with distilled water plus 25 gm of oven-dried sand in it. Listed in Table 3-3 are the results of specific gravity test performed on sand sample NS and sample DD.

Table 3.3 Specific gravity test result of sand sample NS and sample DD

Description	**Type of Sand**			
	Sample NS		**Sample DD**	
Determination No.	1	2	1	2
Mass of pycnometer+ sand+ water,M_{pws}	176.1	175.1	178.9	175.8
Temperature, T_x (^oc)	20	20	20	20
Mass of pycnometer+ water at T_x, M_{pw}	160.5	159.5	163.4	160.3
Mass of sand, M_s	25	25	25	25
Conversion factor, K	1	1	1	1
Specific gravity of soil, G_s	2.66	2.66	2.63	2.63
Average value of G_s	**2.66**		**2.63**	

The specific gravity is 2.66 and 2.63 for sample NS and sample DD respectively. The specific gravity values some how reflects the silica content of the sand i.e. the higher the silica content the higher the specific gravity.

3.3 Physical Property Tests

3.3.1 Clay content

Any sand that is supposed to be used as standard sand should be free from clay and organic impurities. The impurities in the sand affect the bond between the cement paste and the sand surface and hence decrease the strength of the mortar. From the result of clay content test, which is presented in Table 3.4, it is clearly observed that, both samples contain relatively high clay content, which is greater than 1%. Since this much clay content is unacceptable the sand samples obtained from their natural sources must be washed to remove the clay properly before making any comparison test with the imported sand.

A colorimetric (organic impurity) test was also conducted on both local sand samples and the result revealed that the samples are free from organic matter, which is an acceptable requirement for standard sand. In this research, therefore, all the index properties, physical and chemical composition tests were conducted on washed and oven-dried local sand samples.

Table 3.4 Result of clay content test of Sample NS and Sample DD

Description	**Type of Sand**			
	Sample NS		**Sample DD**	
Determination No.	1	2	1	2
Mass of sand before washing, M_1	500	500	500	500
Mass of sand after washing, M_2	494.2	493.1	493.7	492.8
Clay content, %	1.16	1.38	1.26	1.44
Average value, %	**1.27**		**1.35**	

3.3.2 Unit weight

Unit weight of sand is the weight of the sand divided by the total volume occupied by it. The total volume includes the volume of sand particles and the volume of voids. In other words, it is the amount of material that can be placed in a container of unit volume. The amount may vary, depending on the method used to fill the container, grading and shape of particle. The normal range of unit weight is from 1200 to 1700 Kg/m^3. Listed in Table 3.5 is the results of unit weight test performed on sand sample NS and sample DD. According to the results obtained the unit weight of both local sand samples are within the normal range.

Table 3.5 Result of unit weight test of Sample NS and Sample DD

Description	**Type of Sand**			
	Sample NS		**Sample DD**	
Determination No.	1	2	1	2
Mass of cylinder, (gm)	454.1	454.1	454.1	454.1
Volume of cylinder, (cc)	1618.3	1618.3	1618.3	1618.3
Mass of cylinder+ sand, (gm)	2842.1	2835.2	2585.3	2586.4
Unit weight, (Kg/m^3)	1,476	1,471	1,317	1,317
Average value, (Kg/m^3)	**1,474**		**1,317**	

3.4 Mineralogical Composition

Mineralogical analysis has been carried out in the Ethiopian Geological survey laboratory on both samples designated as Sample NS and Sample DD. The composition was found as shown in Table 3.6.

Table 3.6 Chemical compositions of Sample NS and Sample DD

Mineral Oxides	**Composition in Percent (%)**	
	Sample NS	**Sample DD**
Silicon dioxide, SiO_2	99.09	75.89
Aluminum oxide, Al_2O_3	0.34	13.14
Iron oxide, Fe_2O_3	0.34	0.83
Calcium oxide, CaO	0.01	2.00
Magnesium oxide, MgO	0.04	0.03
Sodium oxide, Na_2O	0.01	3.70
Potassium oxide, K_2O	0.01	4.02
Manganese oxide. MnO	0.02	0.02
Titanium oxide, TiO_2	0.05	0.05

Phosphorous oxide, P_2O_5	0.01	0.01
Loss on ignition (L.O.I)	0.48	0.99

Any sand that is going to be used as a standard testing sand in accordance with CEN standards should have a silica content of at least 98%. One can see clearly from Table 3.6 that sample NS satisfies the chemical requirement but sand sample DD does not. Even though, sample DD does not satisfy the chemical requirement; the test was proceeded to observe the effect of silica content on mortar strength.

3.5 Mortar Test

3.5.1 General

As it was mentioned earlier, the main target of this research is to prepare a standard testing sand through selective sampling and testing of local sand samples, which could be used as Ethiopian standard sand that would replace imported sand which is used mainly for testing purpose.

3.5.2 Test procedure

To check the applicability of the local sand samples for mortar testing comparison tests were conducted on the two local sand samples designated as Sample NS, collected from North Showa, Sample DD, collected from Dire Dawa and imported CEN standard sand.

The test method comprises the determination of the compressive and flexural strength of prismatic test specimens 40mmx40mmx160mm in size, [3]. The specimens are cast from a batch of plastic mortar containing one part by mass of cement and three parts by mass of standard or local sand with a water/cement ratio of 0.5. Each batch for three test specimens consist of (450±2) gm of cement, (1350±5) gm of sand and (225±1) gm of water. The cement used to prepare the mortar is Portland pozzolana cement produced by Addis Ababa Cement Plant. The mortar is prepared by mechanical (see Fig. 3.8) mixing and is compacted using a standard jolting apparatus (see Fig 3.8). The specimens are stored in a moist atmosphere (see Fig.3.11) for about 24h and then the demoulded specimens (see Fig. 3.13) are stored under water until time of testing. At the age of seven days, the specimens are taken from their wet storage, broken in flexure (see Fig 3.16) into two halves and each half tested for strength in compression.

Six packs of Sample NS of which 18 mortar prisms were casted, six packs of sample DD of which 18 mortar prisms were casted. In addition, twelve packs of imported CEN sand were used to cast 36 mortar prisms to compare the compressive and flexural strength of this material with the local material.

3.5.3 Determination of flexural strength of mortar prisms

The prism was placed in the testing machine with one side face on the supporting rollers with its longitudinal axis normal to the supports (see Fig.3.16). The load is applied vertically by means of the loading roller to opposite side face of the prism and increased smoothly at the rate of (50±10) N/s until failure. The broken half prisms that were tested for flexure kept damp until tested for compression. The Flexural strength R_f is calculated in N/mm^2 from equation 3.1.

$$R_f = 1.5 \times \frac{F_f \times L}{b^3} \quad \text{.................. (Eq.3.1)}$$

Where:

R_f = flexural strength, in Newtons per square millimeter

b = side of the square section of the prism, in millimeters

F_f = applied load to the middle of the prism at fracture, in Newtons

L = distance between the supports, in millimeters.

The flexural strength test results obtained are described in Table 3.7 and 3.8 for sample NS and Sample DD respectively. Based on the results obtained a graph is plotted to observe and compare the flexural strengths of the mortar prisms using local and imported sand. The comparison graphs are shown in Fig 3.4 and Fig 3.5.

Table 3.7 Summary of Flexural Strength Test Result of Sample NS

Sample No.	**Flexural Strength** (N/mm^2)	
	Sample NS	**CEN Sand**
12	4.28	4.16
13	4.30	4.33
14	4.34	4.59
15	4.43	4.80
16	5.51	5.61
17	5.65	5.63
Average	**4.75**	**4.85**

Table 3.8 Summary of Flexural Strength Test Result of Sample DD

Sample No.	**Flexural Strength** (N/mm^2)	
	Sample DD	**CEN Sand**
22	4.39	4.49
23	4.41	4.51
24	4.76	4.91
25	4.84	5.26
26	4.97	5.30
27	5.11	5.35
Average	**4.75**	**4.97**

In all of the test results, the flexural strength of mortar cubes made with local samples gave lower values compared to that of imported sand. However, a relatively uniform trend was observed in the flexural test results between the local samples and the imported one as shown in Figs 3.4 and 3.5.

$$y = -34.38x^2 + 303.74x - 666.07 \qquad \text{(Eq.3.2)}$$

$$y = -0.8026x^2 + 8.8811x - 19.044 \qquad \text{(Eq 3.3)}$$

Based on the seventh day flexural strength values, a mathematical relationship is established between the local sand samples and imported sand as (Eq.3.2) for sample NS and (Eq.3.3) for sample DD. Where x is flexural strength value obtained by local sand sample and y is its CEN equivalent value.

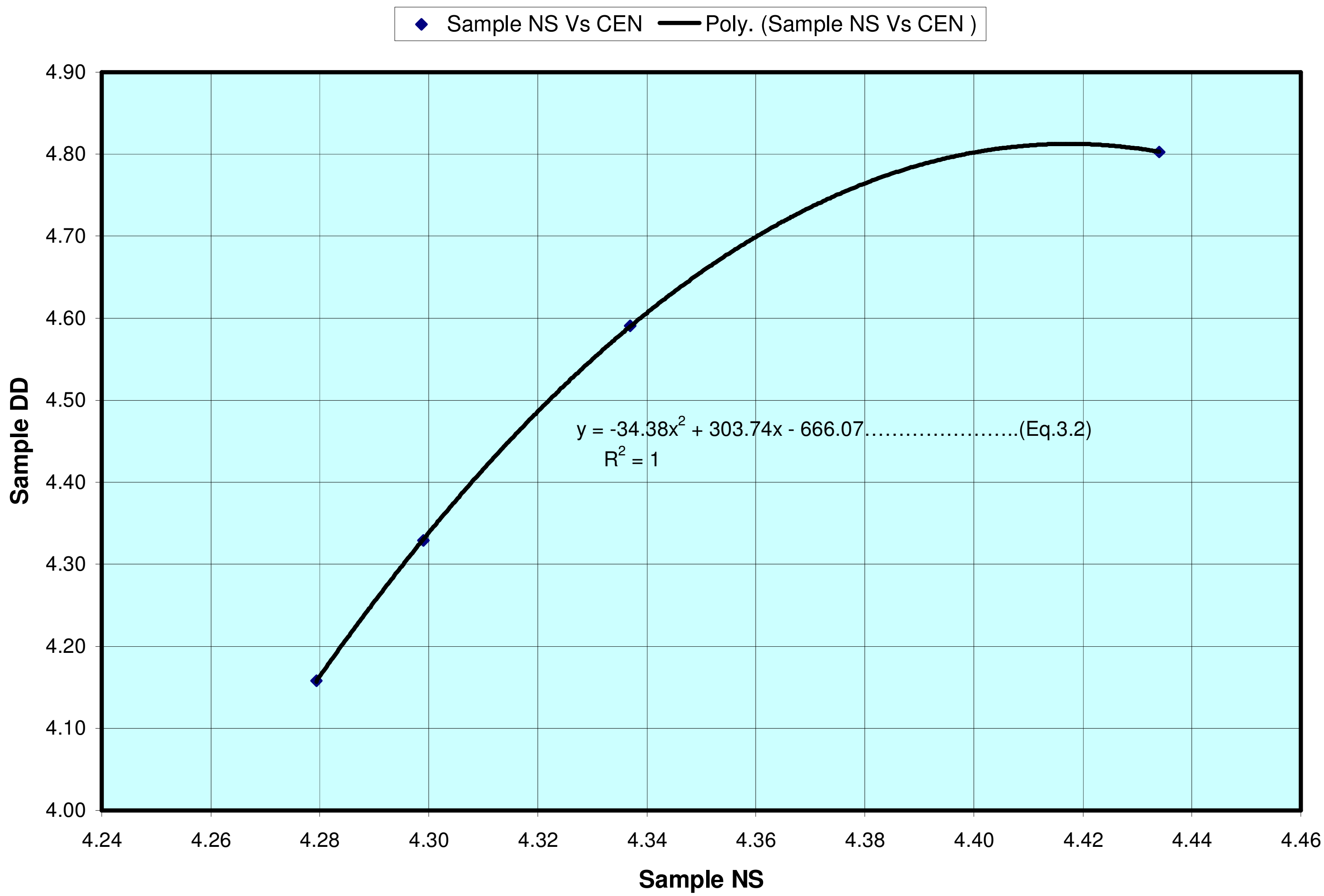

Fig 3.4 A plot of Flexural StrengthTest Results Obtained Using Sample NS and CEN Sand

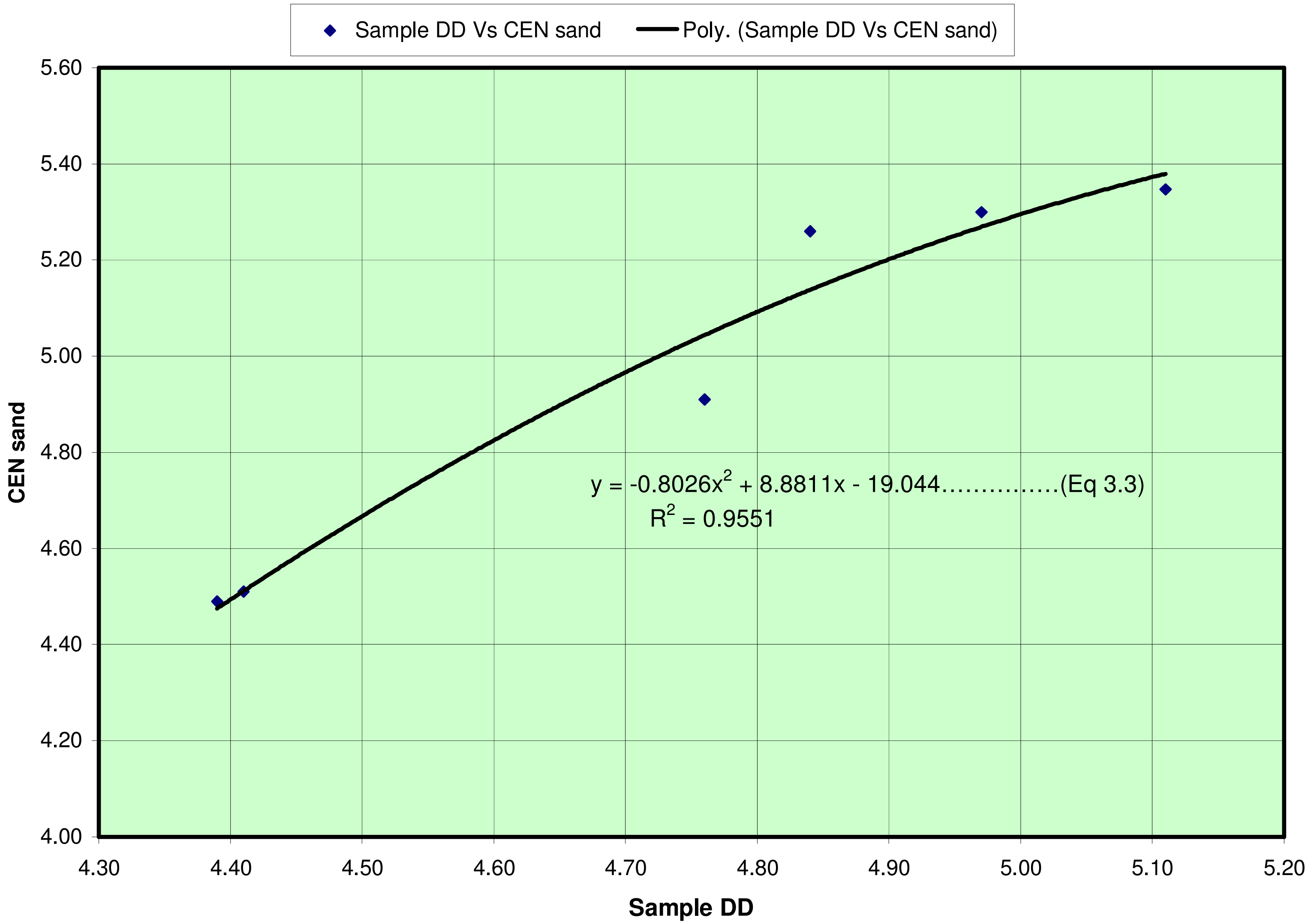

Fig 3.5 A Plot of Flexural Strength Test Results Obtained Using Sample DD and CEN Sand

3.5.4 Determination of compressive strength

The prism halves that were left after the flexural strength test were again used to perform the compressive strength test. The test was conducted on the smooth side of the faces by means of the compression test equipment (See Fig.3.17). The load increment is at a smoothly at the rate of 2400±200 N/s over the entire load application until failure in fracture.

The compressive strength is R_c calculate in N/mm^2 from equation 3.4.

$$R_c = \frac{F_c}{A} \text{ .... (Eq.3.4)}$$

Where:

R_c = compressive strength, in Newtons per square millimeter;

F_c = maximum load at fracture, in Newtons

A=1600=40mmx40mm is the area of the auxiliary plates, in square millimeters.

If one test result within the six determinations varies by more than ±10% from the mean of the six, this result will be discarded. During analysis, the mean of the result of the five remaining results will be taken. However, if a further result within these five determinations varies more than ±10% from their mean, the set of results will totally be discarded, [3]. Compressive strength test were carried out and the results obtained are stated in Table 3.9 and 3.10 for sample NS and Sample DD respectively. In addition, a graph is plotted to compare the compressive strengths of the mortar prisms using local and imported sand. These graphs are shown in Fig 3.6 and Fig 3.7.

Table 3.9 Summary of Compressive Strength Test Result of Sample NS

Sample No.	**Compressive Strength** (N/mm^2)	
	Sample NS	**CEN Sand**
12	10.08	11.08
13	10.60	11.59
14	11.56	13.47
15	11.97	14.08
16	12.52	14.38
17	13.22	14.65
Average	**11.66**	**13.21**

Table 3.10 Summary of Compressive Strength Test Result of Sample DD

Sample No.	**Compressive Strength** (N/mm^2)	
	Sample DD	**CEN Sand**
22	14.02	14.02
23	14.19	14.25
24	14.21	14.62
25	14.33	16.12
26	14.38	16.21
27	15.19	17.32
Average	**14.39**	**15.04**

In all of the test results, the compressive strength of mortar cubes made with local samples gave lower values compared to that of imported sand. However, a relatively uniform trend was observed in the compressive test results between the local samples and the imported one, as shown in Figs 3.6 and 3.7.

$$y = -0.3043x^2 + 8.309x - 41.952 \quad \text{(.Eq.3.5)}$$

$$y = 19.776x^2 - 556.03x + 3922.3 \quad \text{(Eq. 3.6)}$$

Based on the seventh day compressive strength values, a mathematical relationship is established between the local sand samples and imported sand as (Eq.3.5) for sample NS and (Eq.3.6) for sample DD. Where x is compressive strength value obtained by local sand sample and y is its CEN equivalent value.

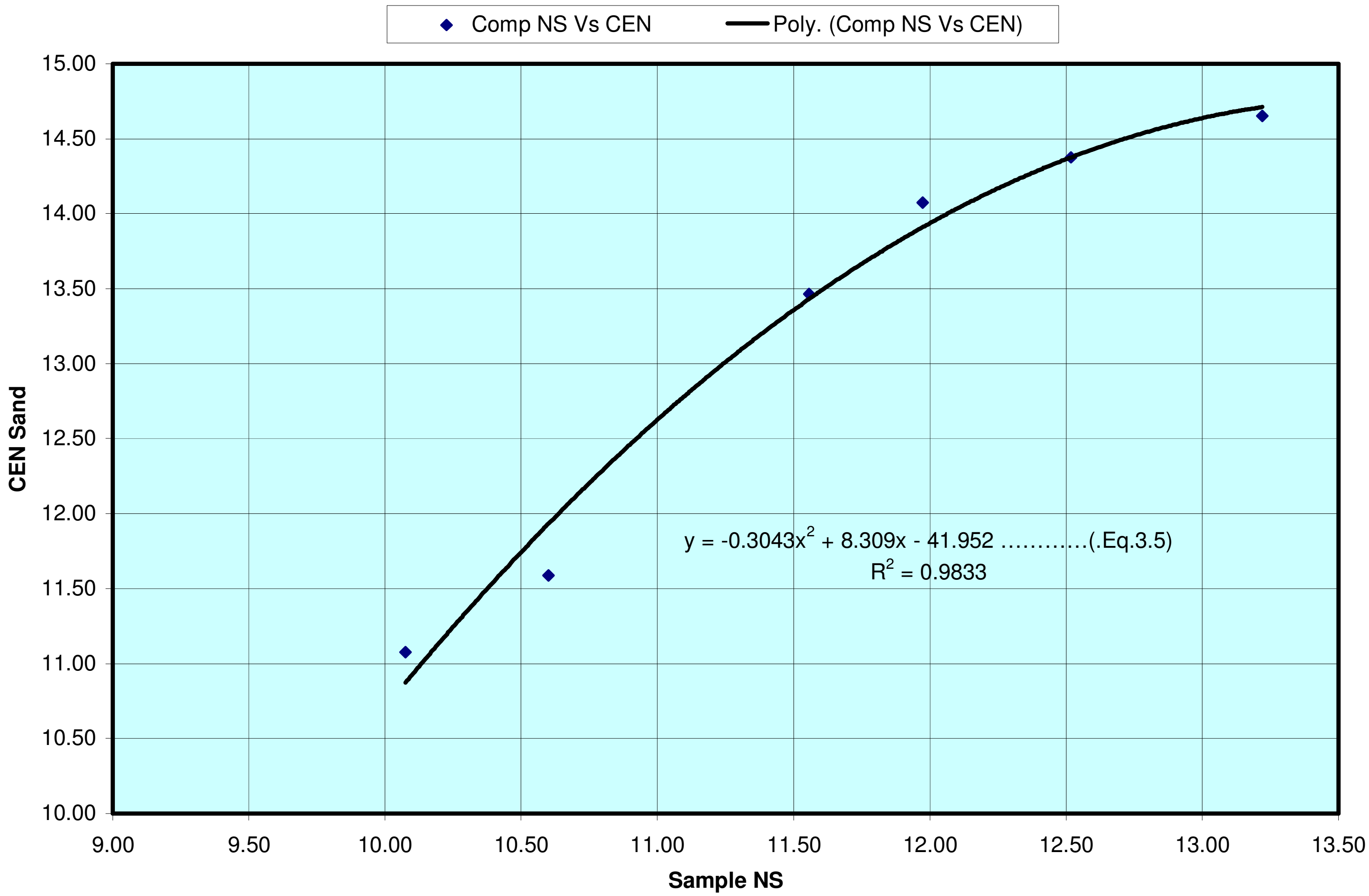

Fig 3.6 A Plot of Compressive Strength Test Results Obtained Using Sample NS and CEN Sand

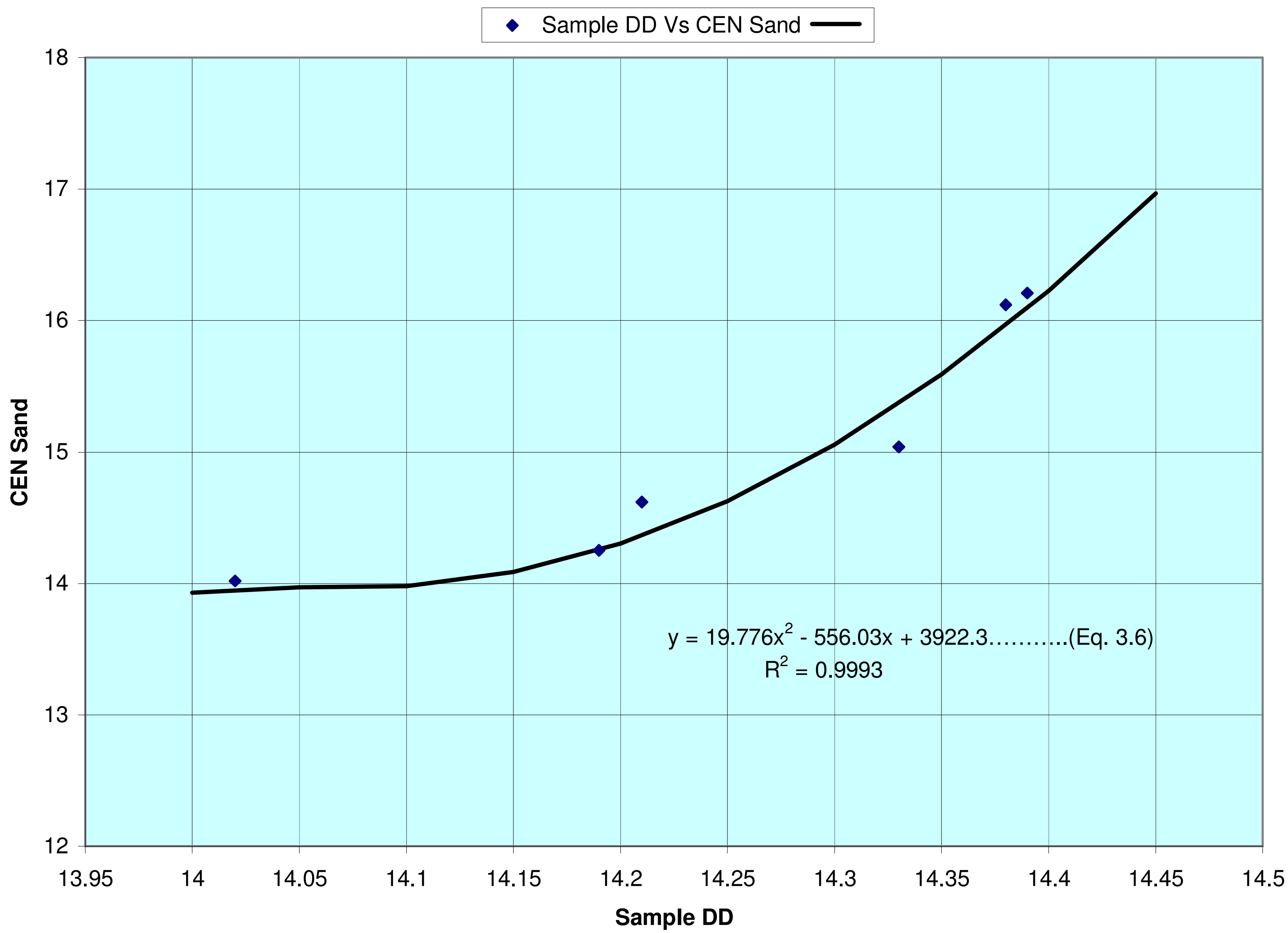

Fig 3.7A Plot of Compressive Strength Results Obtained Using Sample DD and CEN sand

Fig 3.8 Mechanical mortar mixer

Fig 3.9 Standard (compacting) jolting apparatus

Fig 3.10 Preparation of mortar prisms

Fig 3.11 Moist cabinet for storage of the specimens

Fig 3.12 Mortar prisms in the mould

Fig 3.13 Demoulded mortar prisms

Fig 3.14 Multifunctional mortar testing machine

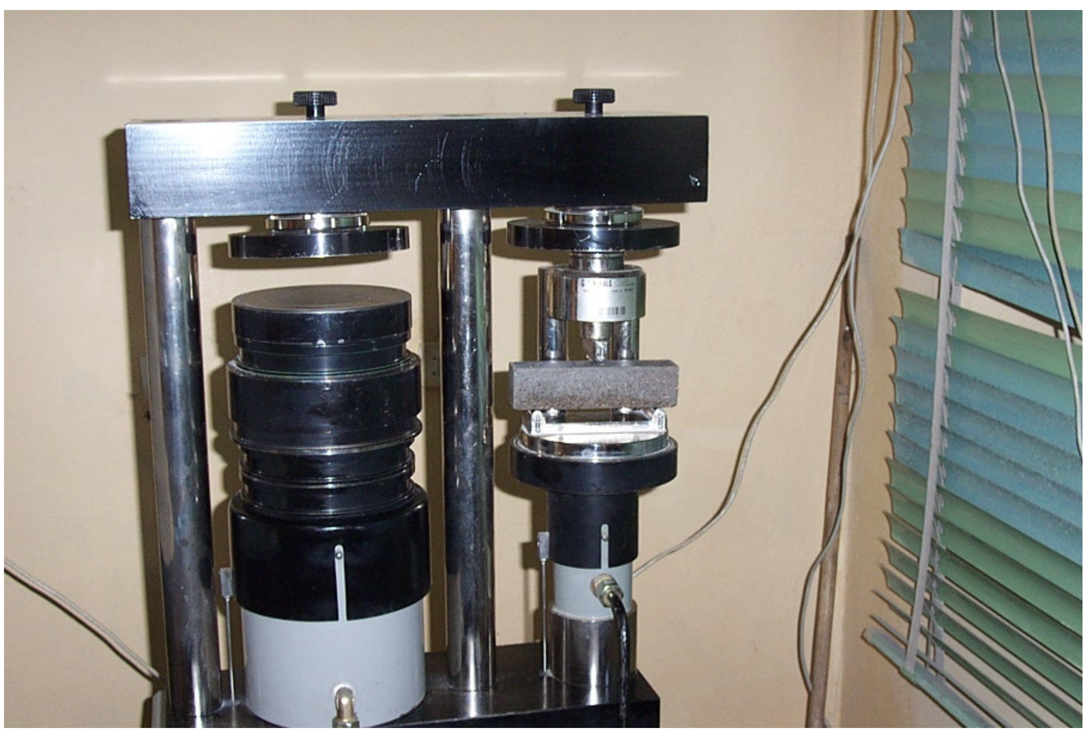

Fig 3.15 Mortar prism mounted on testing machine to be tested for flexure

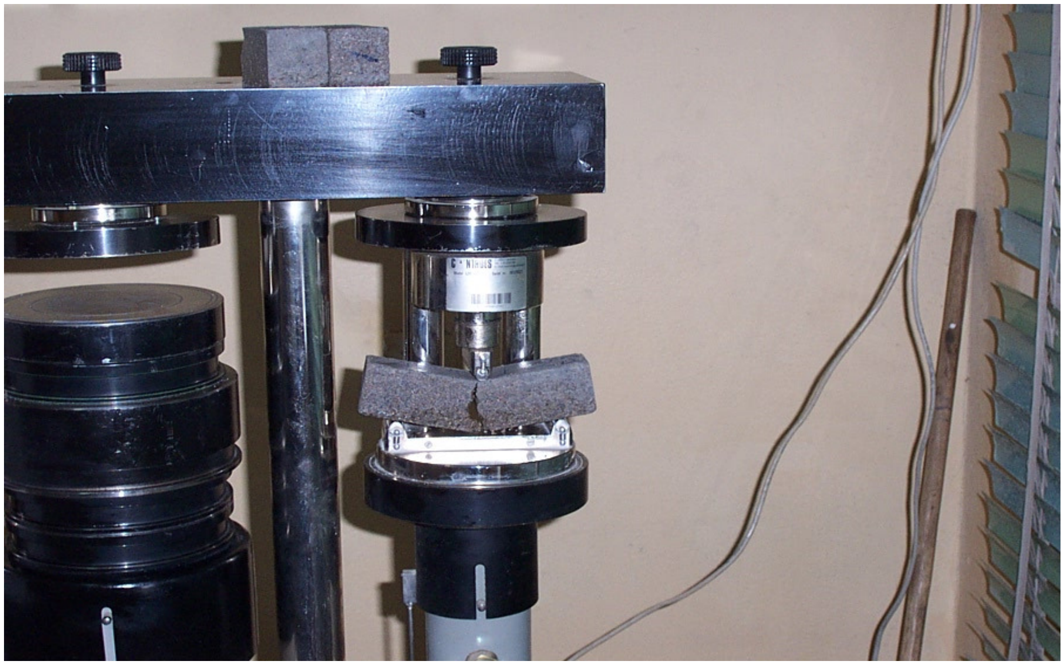

Fig 3.16 Mortar prism tested for flexure

Fig 3.17 Mortar prism tested for compression

3.6 In place Density of Soil by Sand Replacement Method

3.6.1 General

The in place density of natural soil is needed for compaction control, for the determination of bearing capacity of soils, stability analysis of slopes, determination of pressures on underlying strata for the calculation of settlement and the design of underground structures. Sand replacement test is a quality control test, when compaction is required, especially during embankment and pavement construction.

By conducting sand replacement test, it is possible to determine the field density of the soil. As moisture content of soils is likely to vary from time to time, it is clear that the field density could also vary as well. Therefore, it is required to report the test result in terms of dry density. Equation 3.7 shows the relationship that can be established between the dry densities with known moisture content.

$$\gamma_d = \frac{\gamma_b}{(1+\omega)} \qquad \text{.................. (Eq.3.7)}$$

Where:

γ_d=Dry density

γ_b=Bulk density

ω= Water content

3.6.2 Test procedure and results

In order to see the applicability of local sands for the determination of in-place density determination, several tests were conducted according to AASHTO T-191, [1] at different places using the selected sands and Ottawa sand. Before the test was conducted, the sand-pouring cylinder (bottle) was calibrated for the weight of sand filling the cone portion of the sand-pouring cylinder (M_{sc}). In addition, the densities of sand Sample NS, Sample DD and Ottawa sand was determined. The results obtained are tabulated in Table 3.12.

Table 3.11 Calibration of sand pouring cylinder

Description	**Type of Sand**		
	Sample NS	**Sample DD**	**Ottawa sand**
Mass of sand in the cone (gm)	1609	1421	1616
Density (Kg/m^3)	1474	1317	1519

In this research, the in-place density test was carried out on a road project that was under construction by Addis Ababa City Roads Authority. Eight test holes were dug into the soil, and the dry densities of the soil were determined using the local sand samples, and the imported Ottawa sand. The results obtained are presented in appendix B in table format.

The in place densities of the eight test locations are summarized and presented in Table 3.12 for ease of comparison. In addition, a graph is plotted to establish a mathematical relationship between the local samples and imported standard Ottawa sand. These graphs are shown in Fig 3.19 and Fig 3.20 with their corresponding equations.

Table 3.12 Summary of field density (in gm/cc) obtained using sample NS, sample DD and Ottawa sand

Test location	***Type of sand***		
	Sample NS	**Sample DD**	**Ottawa Sand**
1	1.3026	1.3032	1.3577
2	1.3590	1.3408	1.3625
3	1.8380	1.8538	1.8625
4	1.8754	1.8714	1.8963
5	1.8340	1.8562	1.8451
6	1.4983	1.4595	1.4661
7	1.7769	1.7246	1.7613
8	1.3672	1.3800	1.3768

Fig 3.18 In-place density determination using sand replacement method

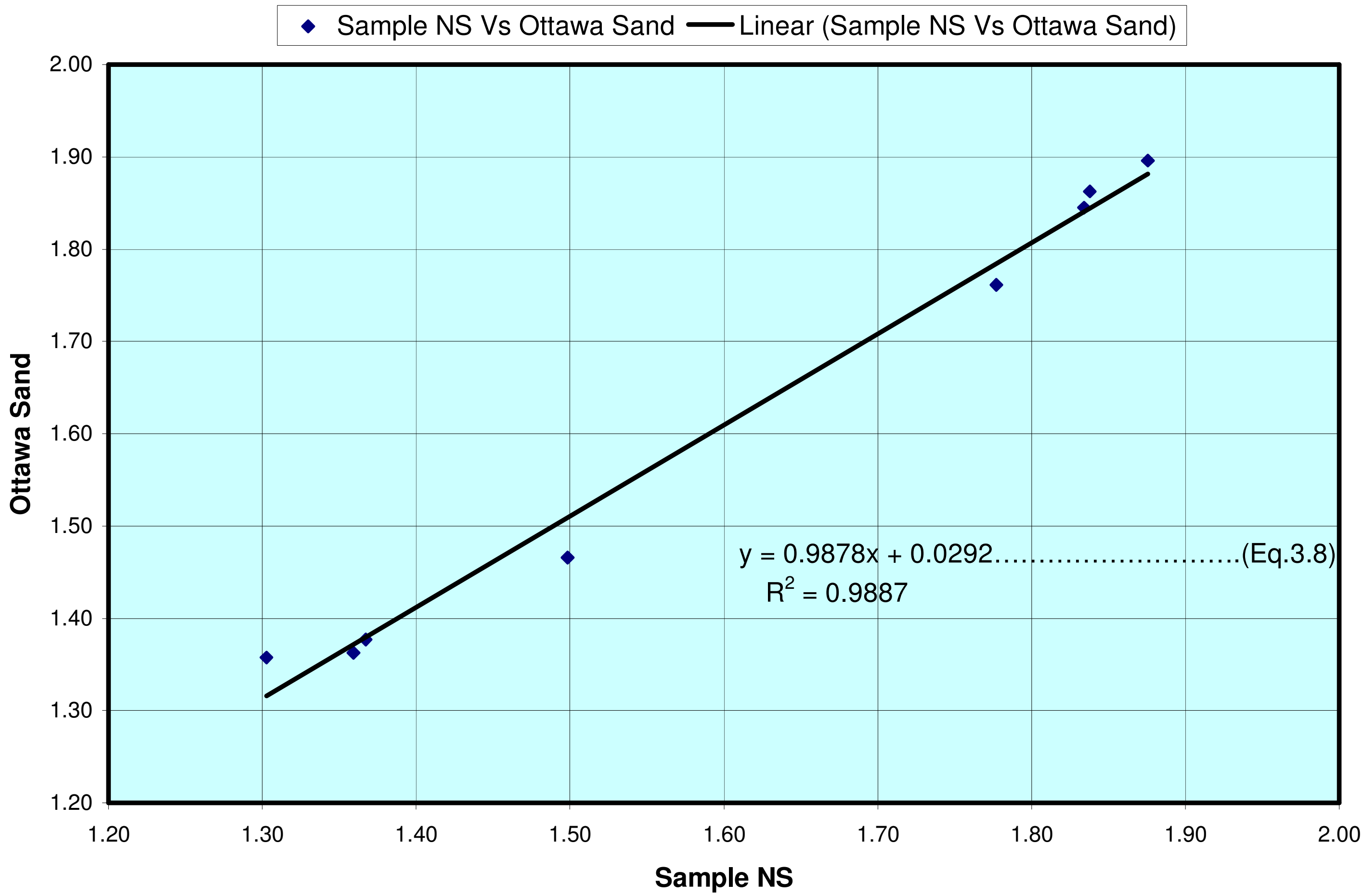

Fig 3.19 A Plot of Field Density Results Obtained Using Sample NS and Ottawa Sand

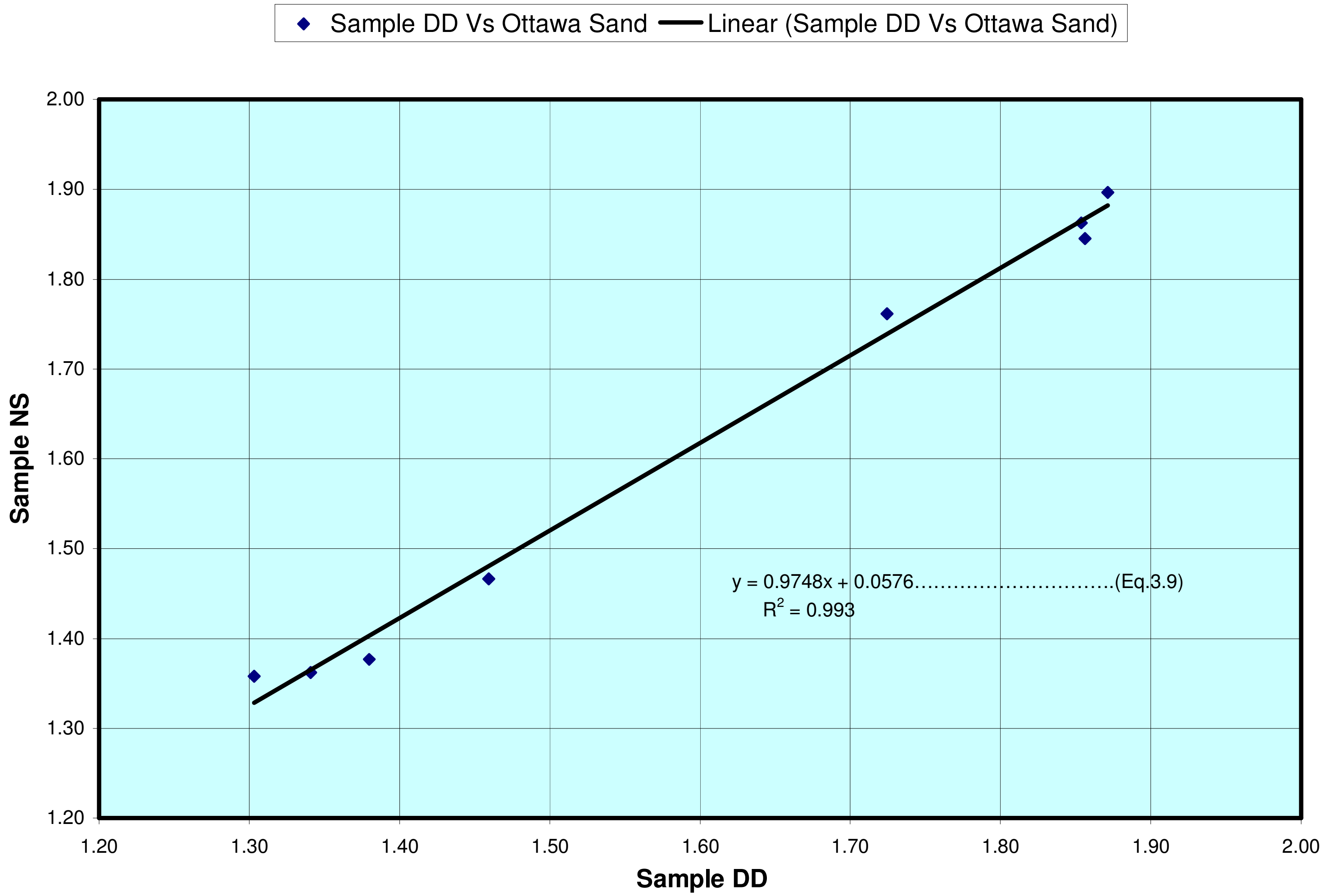

Fig 3.20 A Plot of Field Density Results Obtained Usinmg Sample DD and Otawa Sand

A comparative analysis of the test results obtained showed clearly that the field densities obtained using local sand samples and imported Ottawa sand are similar at all test locations. Therefore, it is obvious that it is possible to replace the imported sand by both local sand samples in field density tests.

Chapter Four

Conclusions and Recommendations

4.1 Conclusions

The major goal of this research, as it was mentioned in chapter one, is to prepare a standard testing sand through selective sampling and testing of local sand, which could be used as Ethiopian standard sand that would replace imported sand which is used mainly for testing purpose.

Based on grain size analysis and impurity test results it appears that both local sand samples are not comparable with CEN standard sand be used as Ethiopian standard sand as they are taken directly from their natural places. Thus, in order to be used as standard sand both local sand samples must be washed, oven dried, sieved and separated to various size fractions. Each size fraction is then remixed according to the grading requirement stated by CEN.

The comparison test made between the local and imported sand in compression and flexure has revealed that, there is a uniform trend between the local and imported standard sand. This correlation can be defined by equations 3.2 and 3.3 for flexural strength and equations 3.5 and 3.6 for compressive strength. Hence, one can convert the test result obtained using local sand to its CEN equivalent value by using these equations.

The fact that the sand to be used for mortar testing should contain high silica content is that the sand grains must remain intact while the bond between the cement paste and the grains broke during testing. From the results of flexure and compression test, it can be concluded that the effect of silicon dioxide content has little effect on flexural and compressive strength of mortar prisms.

Field density tests revealed that both local sand samples gave relatively similar result with the imported Ottawa standard sand in almost all test locations irrespective of the silica content. Therefore, it can be concluded that both local sand samples can replace the imported standard Ottawa sand.

4.2 Recommendations for Future Work

The present work has attempted to prepare Ethiopian standard sand by taking local sand samples. However, due to financial constraints and time limitations the present research work did not cover detail laboratory investigation on the behavior of local sand. In view of this, it would be desirable to consider the following recommendations and comments to obtain a better result.

1. Even though, the country is endowed with abundant sand deposits due to financial limitations and time constraints sand samples taken from two sites located at the Central and Eastern Ethiopia are investigated. A better result would be obtained by taking sand samples from several other sites.

2. Twelve packs of imported CEN sand were used to cast 36 mortar prisms to compare the compressive and flexural strength of

mortar made with local sand. Due to the high cost of CEN sand, it was not possible to cast more cubes to get a better result. A better result would have been obtained if more prisms were casted.

3. Due to time constraints, comparison test was made on the seventh day strength. Since the cement used for mortar test was Portland pozzolana cement which has low early strength. A better result would be obtained if the 28-day result were compared.

Appendix A

(Test Results of Mortar Prisms)

Table A.1 Flexural strength of mortar prisms NS 12 and CEN 12

Prism No.	Flexural Strength (N/mm2)	
	NS-12	**CEN-12**
1	4.746	5.156
2	5.775	5.552
3	6.005	6.176
Average	**5.509**	**5.628**

Table A.2 Compressive strength of mortar prisms NS 12 and CEN 12

Prism halves No.	Compressive Strength (N/mm2)	
	NS-12	**CEN-12**
1	10.21	11.93
2	10.59	13.51
3	12.26	14.26
4	12.71	14.46
5	13.99	15.03
6	15.35	15.26
Average	**12.52**	**14.08**

Table A.3 Flexural strength of mortar prisms NS 13 and CEN 13

Prism No.	Flexural Strength (N/mm2)	
	NS-13	**CEN-13**
1	5.534	5.388
2	5.639	5.627
3	5.775	5.801
Average	**5.649**	**5.605**

Table A.4 Compressive strength of prisms NS 13 and CEN 13

Prism halves No.	Compressive Strength (N/mm2)	
	NS-13	**CEN-13**
1	12.41	12.01
2	12.71	13.88
3	12.85	14.36
4	13.12	15.16
5	13.56	16.01

6	14.65	16.5
Average	**13.22**	**14.65**

Table A.5 Flexural strength of mortar prisms NS 14 and CEN 14

Prism No.	Flexural Strength (N/mm2)	
	NS-14	**CEN-14**
1	4.038	4.193
2	4.227	4.35
3	4.573	4.444
Average	**4.279**	**4.329**

Table A.6 Compressive strength of mortar prisms NS 14 and CEN 14

Prism halves No.	Compressive Strength (N/mm2)	
	NS-14	**CEN-14**
1	8.68	10.03
2	8.74	10.61
3	9.19	10.81
4	10.11	11.19
5	11.62	11.64
6	12.11	12.18
Average	**10.08**	**11.08**

Table A.7 Flexural strength of mortar prisms NS 15 and CEN 15

Prism No.	Flexural Strength (N/mm2)	
	NS-15	**CEN-15**
1	5.639	5.388
2	5.534	5.801
3	5.775	5.627
Average	**5.649**	**5.605**

Table A.8 Compressive strength of mortar prisms NS 15 and CEN 15

Prism halves No.	Compressive Strength (N/mm2)	
	NS-15	**CEN-15**
1	7.09	10.51
2	9.18	10.69
3	10.86	11.2
4	11.37	11.89

5	11.89	12.43
6	11.22	12.81
Average	**10.27**	**11.59**

Table A.9 Flexural strength of mortar prisms NS 16 and CEN 16

Prism No.	Flexural Strength (N/mm2)	
	NS-16	**CEN-16**
1	4.155	3.991
2	4.247	4.845
3	4.608	4.936
Average	**4.337**	**4.591**

Table A.10 Compressive strength of mortar prisms NS 16 and CEN 16

Prism halves No.	Compressive Strength (N/mm2)	
	NS-16	**CEN-16**
1	11.35	12.21
2	11.18	13.4
3	11.21	13.67
4	11.87	14.68
5	12.47	15.26
6	13.76	17.04
Average	**11.97**	**14.38**

Table A.11 Flexural strength of mortar prisms NS 17 and CEN 17

Prism No.	Flexural Strength (N/mm2)	
	NS-17	**CEN-17**
1	4.324	4.395
2	4.451	4.723
3	4.528	5.292
Average	**4.434**	**4.803**

Table A.12 Compressive strength of mortar prisms NS 17 and CEN 17

Prism halves No.	Compressive Strength (N/mm2)	
	NS-17	**CEN-17**

1	10.84	12.01
2	10.28	12.05
3	11.73	12.7
4	11.76	13.32
5	11.81	14.99
6	12.92	15.72
Average	**11.56**	**13.47**

Table A.13 Flexural strength of mortar prisms DD 22 and CEN 22

Prism No.	Flexural Strength (N/mm2)	
	DD-22	**CEN-22**
1	4.741	5.201
2	4.77	5.409
3	5.018	5.43
Average	**4.843**	**5.347**

Table A.14 Compressive strength of mortar prisms DD 22 and CEN 22

Prism halves No.	Compressive Strength (N/mm2)	
	DD-22	**CEN-22**
1	13.03	14.96
2	15.35	17.31
3	14.59	17.31
4	14.87	17.86
5	16.13	18.03
6	17.14	18.42
Average	**15.19**	**17.32**

Table A.15 Flexural strength of mortar prisms DD 23 and CEN 23

Prism No.	Flexural Strength (N/mm2)	
	DD-23	**CEN-23**
1	4.026	4.995
2	4.153	5.142
3	5.048	5.752
Average	**4.409**	**5.296**

Table A.16 Compressive strength of mortar prisms DD 23 and CEN 23

Prism halves No.	Compressive Strength (N/mm2)	
	DD-23	**CEN-23**
1	13.71	14.96
2	13.86	15.04
3	14.26	16.34
4	14.31	16.86
5	14.38	17.16
6	14.59	16.91
Average	**14.19**	**16.21**

Table A.17 Flexural strength of mortar prisms DD 24 and CEN 24

Prism No.	Flexural Strength (N/mm2)	
	DD-24	**CEN-24**
1	4.842	5.071
2	4.967	5.473
3	5.114	5.241
Average	**4.974**	**5.262**

Table A.18 Compressive strength of prisms DD 24 and CEN 24

Prism halves No.	Compressive Strength (N/mm2)	
	DD-24	**CEN-24**
1	13.06	15.18
2	13.47	15.25
3	13.53	15.75
4	14.07	15.96
5	15.13	16.57
6	17.03	17.99
Average	**14.38**	**16.12**

Table A.19 Flexural strength of mortar prisms DD 25 and CEN 25

Prism No.	Flexural Strength (N/mm2)	
	DD-25	**CEN-25**
1	4.641	3.888
2	5.018	4.282
3	5.677	5.365
Average	**5.112**	**4.512**

Table A.20 Compressive strength of mortar prisms DD 25 and CEN 25

Prism halves No.	Compressive Strength (N/mm2)	
	DD-25	**CEN-25**
1	13.89	12.53
2	13.99	12.64
3	14.42	14.44
4	14.48	14.59
5	14.56	15.47
6	14.61	15.82
Average	**14.33**	**14.25**

Table A.21 Flexural strength of mortar prisms DD 26 and CEN 26

Prism No.	Flexural Strength (N/mm2)	
	DD-26	**CEN-26**
1	4.132	3.185
2	4.172	4.823
3	4.861	5.456
Average	**4.388**	**4.488**

Table A.22 Compressive strength of mortar prisms DD 26 and CEN 26

Prism halves No.	Compressive Strength (N/mm2)	
	DD-26	**CEN-26**
1	12.44	10.14
2	13.46	12.55
3	14.46	14.08
4	14.63	14.18
5	15.01	14.645
6	15.28	14.76
Average	**14.21**	**14.04**

Table A.23 Flexural strength of mortar prisms DD 27 and CEN 27

Prism No.	Flexural Strength (N/mm2)	
	DD-27	**CEN-27**
1	4.172	4.866
2	4.961	4.922
3	5.132	4.927
Average	**4.755**	**4.905**

Table A.24 Compressive strength of mortar prisms DD 27and CEN 27

Prism halves No.	Compressive Strength (N/mm2)	
	DD-27	**CEN-27**
1	12.57	12.31
2	13.17	13.36
3	13.99	13.76
4	14.55	14.51
5	14.61	16.61
6	15.22	17.15
Average	**14.02**	**14.62**

Appendix B

(In-place Density Results)

Table B.1 In-place densities of test locations 1 and 2

	Test location		1			2		
	Type of sand		**Sample NS**	**Sample DD**	**Ottawa Sand**	**Sample NS**	**Sample DD**	**Ottawa Sand**
Determination of Bulk Density	Mass of wet soil, M_{ws}	gm	2345	2345	2345	2831	2831	2831
	Initial mass of sand in the bottle, M_{sbi}	gm	6000	7000	7000	6000	7000	7000
	Final mass of sand in the bottle, M_{sbf}	gm	2399	3758	3368	2075	3439	2955
	Mass of sand in hole and cone, M_{shc}	gm	3601	3242	3632	3925	3561	4045
	Mass of sand in cone, M_{sc}	gm	1562	1421	1616	1562	1421	1616
	Mass of sand in hole, Msh	gm	2039	1821	2016	2363	2140	2429
	Density of sand, D_s	gm/cc	1.474	1.317	1.519	1.474	1.317	1.519
	Volume of sand in hole, V_{sh}	cc	1383.31	1382.69	1327.19	1603.12	1624.91	1599.08
	Bulk density of wet soil, D_{bulk}	gm/cc	1.6952	1.6960	1.7669	1.7659	1.7423	1.7704
Determination of Moisture Content	Container No.		155	155	155	173	173	173
	Mass of wet soil+ container	gm	81	81	81	98	98	98
	Mass of dry soil+ container	gm	70	70	70	83	83	83
	Mass of water	gm	11	11	11	15	15	15
	Mass of container	gm	33.5	33.5	33.5	32.9	32.9	32.9
	Mass of dry soil	gm	36.5	36.5	36.5	50.1	50.1	50.1
	Moisture content	%	30.14	30.14	30.14	29.94	29.94	29.94
	Dry density of soil	gm/cc	***1.3026***	***1.3032***	***1.3577***	***1.3590***	***1.3408***	***1.3625***

Table B.2 In-place densities of test locations 3 and 4

	Test location		3			4		
	Type of sand		**Sample NS**	**Sample DD**	**Ottawa Sand**	**Sample NS**	**Sample DD**	**Ottawa Sand**
Determination of Bulk Density	Mass of wet soil, M_{ws}	gm	2868	2868	2868	2657	2657	2657
	Initial mass of sand in the bottle, M_{sbi}	gm	6000	7000	7000	6000	7000	7000
	Final mass of sand in the bottle, M_{sbf}	gm	2271	3701	3228	2460	3850	3380
	Mass of sand in hole and cone, M_{shc}	gm	3729	3299	3772	3540	3150	3620
	Mass of sand in cone, M_{sc}	gm	1609	1421	1616	1609	1421	1652
	Mass of sand in hole, Msh	gm	2120	1878	2156	1931	1729	1968
	Density of sand, D_s	gm/cc	1.474	1.317	1.519	1.474	1.317	1.519
	Volume of sand in hole, V_{sh}	cc	1438.26	1425.97	1419.35	1310.04	1312.83	1295.59
	Bulk density of wet soil, D_{bulk}	gm/cc	1.9941	2.0113	2.0206	2.0282	2.0239	2.0508
Determination of Moisture Content	Container No.		117	117	117	98	98	98
	Mass of wet soil+ container	gm	84	84	84	86	86	86
	Mass of dry soil+ container	gm	80	80	80	82	82	82
	Mass of water	gm	4	4	4	4	4	4
	Mass of container	gm	32.9	32.9	32.9	32.9	32.9	32.9
	Mass of dry soil	gm	47.1	47.1	47.1	49.1	49.1	49.1
	Moisture content	%	8.49	8.49	8.49	8.15	8.15	8.15
	Dry density of soil	gm/cc	***1.8380***	***1.8538***	***1.8625***	***1.8754***	***1.8714***	***1.8963***

Table B.3 In-place densities of test locations 5 and 6

	Test location		5			6		
	Type of sand		**Sample NS**	**Sample DD**	**Ottawa Sand**	**Sample NS**	**Sample DD**	**Ottawa Sand**
Determination of Bulk Density	Mass of wet soil, M_{ws}	gm	2425	2425	2425	2935	2935	2935
	Initial mass of sand in the bottle, M_{sbi}	gm	6000	7000	7000	6000	7000	7000
	Final mass of sand in the bottle, M_{sbf}	gm	2629	3982	3495	2105	3439	2927
	Mass of sand in hole and cone, M_{shc}	gm	3371	3018	3505	3895	3561	4073
	Mass of sand in cone, M_{sc}	gm	1562	1421	1652	1562	1421	1616
	Mass of sand in hole, M_{sh}	gm	1809	1597	1853	2333	2140	2457
	Density of sand, D_s	gm/cc	1.474	1.317	1.519	1.474	1.317	1.519
	Volume of sand in hole, V_{sh}	cc	1227.27	1212.60	1219.88	1582.77	1624.91	1617.51
	Bulk density of wet soil, D_{bulk}	gm/cc	1.9759	1.9998	1.9879	1.8543	1.8063	1.8145
Determination of Moisture Content	Container No.		157	157	157	169	169	169
	Mass of wet soil+ container	gm	89	89	89	95	95	95
	Mass of dry soil+ container	gm	85	85	85	83	83	83
	Mass of water	gm	4	4	4	12	12	12
	Mass of container	gm	33.3	33.3	33.3	32.5	32.5	32.5
	Mass of dry soil	gm	51.7	51.7	51.7	50.5	50.5	50.5
	Moisture content	%	7.74	7.74	7.74	23.76	23.76	23.76
	Dry density of soil	gm/cc	***1.8340***	***1.8562***	***1.8451***	***1.4983***	***1.4595***	***1.4661***

Table B.4 In-place density of test locations 7 and 8

	Test location		7			8		
	Type of sand		**Sample NS**	**Sample DD**	**Ottawa Sand**	**Sample NS**	**Sample DD**	**Ottawa Sand**
Determination of Bulk Density	Mass of wet soil, M_{ws}	gm	2749	2749	2749	2335	2335	2335
	Initial mass of sand in the bottle, M_{sbi}	gm	6000	7000	7000	6000	7000	7000
	Final mass of sand in the bottle, M_{sbf}	gm	2498	3793	3367	2172	3573	3065
	Mass of sand in hole and cone, M_{shc}	gm	3502	3207	3633	3828	3427	3935
	Mass of sand in cone, M_{sc}	gm	1562	1421	1616	1562	1421	1616
	Mass of sand in hole, M_{sh}	gm	1940	1786	2017	2266	2006	2319
	Density of sand, D_s	gm/cc	1.474	1.317	1.519	1.474	1.317	1.519
	Volume of sand in hole, V_{sh}	cc	1316.15	1356.11	1327.85	1537.31	1523.16	1526.66
	Bulk density of wet soil, D_{bulk}	gm/cc	2.0887	2.0271	2.0703	1.5189	1.5330	1.5295
Determination of Moisture Content	Container No.		112	112	112	89	89	89
	Mass of wet soil+ container	gm	87	87	87	92	92	92
	Mass of dry soil+ container	gm	79	79	79	86	86	86
	Mass of water	gm	8	8	8	6	6	6
	Mass of container	gm	33.4	33.4	33.4	31.9	31.9	31.9
	Mass of dry soil	gm	45.6	45.6	45.6	54.1	54.1	54.1
	Moisture content	%	17.54	17.54	17.54	11.09	11.09	11.09
	Dry density of soil	gm/cc	***1.7769***	***1.7246***	***1.7613***	***1.3672***	***1.3800***	***1.3768***

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