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Effects of Sand Quality on Strength Properties of Concrete: A Case Study on Nairobi City County and Its Environs

by

Hannah Nyambara Ngugi

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Declaration

This thesis is my original work and has not been submitted to any other university for examination.

Signature: .... Date: ....

Hannah Nyambara Ngugi

This thesis report has been submitted for examination with our approval as University Supervisors.

Signature: .... Date: ....

Prof. Raphael N. Mutuku (Jomo Kenyatta University of Agriculture and Technology)

Signature: .... Date: ....

Prof. Zachary A. Gariy (Jomo Kenyatta University of Agriculture and Technology)

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Dedication

This study is dedicated to my husband, my parents, brothers and sisters whose encouragement and inspirations has seen me this far in pursuit of knowledge.

Abstract

Collapse of buildings in Kenya and other nations has been on the increase and has resulted to loss of lives, inflicted injuries and led to huge loss of investment for developers. In a span of 8 years, fourteen buildings collapsed in Kenya, half of them occurring in Nairobi City County and its environs. Past researches identify the major causes of buildings failure as dependent on the quality of building materials used, workmanship employed in the concrete mix proportioning, construction methodology, defective designs and non-compliance with specifications. Information on the quality of commercial building sands being used in concrete making in Nairobi and their effect on strength properties of concrete was lacking. Non-destructive testing (NDT) methods such Schmidt rebound hammer as present a convenient way of assessing the quality of concrete both in the field and in laboratory thus promoting sustainable development.

The objective of this research was to establish the level of silt and clay content and organic impurities found in building sand being used in Nairobi City County and its environs and the effect of these impurities on the compressive and bond strength of concrete. 27 sand samples were collected from 8 main supply points in Nairobi City County and its environs. Laboratory tests carried out included examination for particle texture and shapes, sieve analysis, specific gravity, chemical tests, testing for silt and clay content and organic impurities, cube testing for compressive strength using universal testing machine and rebound hammer and pull out test.

The results of the investigation showed that majority of building sand being supplied in Nairobi City County and its environs exceed the allowable limits for silt and clay content and organic impurities as set out in BS 882, IS and ASTM standards. With regard to compressive strength, 38% of the concrete cubes made from sand with varying sand impurities failed to meet the expected design strength of $25N/mm^2$ at the age of 28 days. Linear regression and correlation showed that presence of silt and clay content and organic impurities contribute to reduction in cube strength and bond strength between concrete and reinforcement by 44% and 56.8% respectively. It is concluded that the allowable maximum amount of silt and clay content organic impurities are 4.8% and 0.106 ohms respectively beyond which concrete is likely to fail. Increase in workability led to significant decrease in cube strength. Particles shapes and texture had implication on the resulting compressive strength. Testing of quality of sand for every construction project is recommended as well as policy formulation to this effect. There was close correlation between NDT and DT (destructive testing) results implying use of rebound hammer for monitoring of concrete is convenient, cheaper and the testing element is not damaged during testing.

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Abbreviations

ASMT	-	American Society for Materials Testing
BS	-	British Standard
DT	-	Destructive tests
EN	-	Euro codes
GDP	-	Gross Domestic Product
IAEA	-	International Atomic Energy Agency
ICRAF	-	World Agroforestry Centre
ICT	-	Information, Communication and Technology
IS	-	Indian Standard
JKUAT	-	Jomo Kenyatta University of Agriculture and Technology
LDPSA	-	Laser Diffraction and Particle Size Analysis
NaCl	-	Sodium Chloride
NaOH	-	Sodium Hydroxide
PAU	-	Pan African University
PPE	-	Personal Protective Equipment
NDT	-	Non-Destructive Testing
NDTs	-	Non-Destructive Tests
TXRF	-	Total X-ray fluorescence

CHAPTER 1: INTRODUCTION

1.1 General Introduction

This chapter presents background information on quality of construction materials specifically on building sand. It further covers the sustainable development approach in relation to the effect of sand quality on the strength characteristics of structural concrete, for longer lifespan of buildings and increased return on investment. Findings on the main causes of buildings failure based on past researches are also discussed in this section. These causes include quality of building sand, quality of coarse aggregates, workmanship, quality of steel reinforcement and concrete mix proportioning.

1.2 Background on Quality of Construction Materials

Quality assurance of building materials is very essential in order to build strong, durable and cost effective structures (Savitha, 2012). When construction is planned, building materials should be selected to fulfill the functions expected from them. Careful selection of environmentally sustainable building materials is one of the easiest ways for construction professionals to begin incorporating sustainable design principles in buildings. Kim and Rigdon (1998) emphasize that a "cradle-to-grave" analysis of building products right from the gathering of raw materials to their ultimate disposal, provides a better understanding of the long-term costs of materials. The long term costs are paid not only by the client but also by the owner, the occupants and the environment. High quality construction materials result in structures with long life span hence better return on investment for developers and long-term cost efficiency.

Collapse of buildings in Kenya and other nations has been on the increase in the last 10 years and has resulted to loss of lives, inflicted injuries and led to huge loss of investment for developers. In a span of 8 years, fourteen buildings have been reported to have collapsed in Kenya, half of them occurring in Nairobi City County and its environs (see details in Appendix 1). Building industry is a dynamic industry where all manners of local and foreign materials, professionals and equipment co-habit in order to achieve quality buildings of high standard (Ayodeji, 2011).

To prevent failure of buildings, careful selection of construction materials including building sands is paramount to ensure they meet the set construction standards. Good quality building sands should be free from high clayey, silts and organic materials. Impurities in sand impact negatively on compressive strength as well as bond strength between steel reinforcement and concrete and may cause failure of buildings.

Further, structural elements deteriorate over time due to various factors such as age, poor workmanship, and lack or inadequate maintenance. It is therefore important to assess the structural integrity of hardened concrete using non-destructive tests for quality assurance, to inform the maintenance schedule as well as to determine the repairs required (IAEA, 2002). Although rebound hammer is one of the most popular nondestructive testing methods used to investigate concrete due to its relatively low cost and simple operating procedures, it is still not commonly used in developing countries thus need to be promoted (Snell, 2012 and IAEA, 2002). This could be due to lack of understanding in interpretation of results. The rebound hammer is also one of the easiest pieces of equipment to misuse thus many people do not trust the rebound test results (Snell, 2012). For it to be used to determine surface hardness, engineering judgment and the specified test procedure should be followed. Improper use may happens when someone attempts to solely use the rebound values obtained and the correlation chart provided by the equipment producer to determine the compressive strength of the concrete (Cemex, 2013). ASTM C805 requires that for each test area, ten readings be obtained, with no two tests being closer to one another than one inch. A reading differing from the average of the ten readings by more than six units should be discarded. Also, if two readings differ from the average by six units or more, the operator should discard the entire set of readings and take ten new readings within the test area.

1.2.1 Sustainable Development of Buildings

Sustainable development is defined as a process of developing (land, cities, business, communities, lifestyles, etc) that meets the needs of the present without compromising the ability of future generations to meet their own needs (United Nations, 1987). The global community is yearning for sustainable engineering practices and design, and social equity in the consumption of resources, hence engineers have to embrace sustainability and practice environmental stewardship by accepting green design and life-cycle cost-benefit analyses.

Engineers are now required to use new, environmentally-friendly technologies to improve the quality of life in urban environments (Oyawa, 2013). Horvath (1999) further affirms that the construction industry has not done enough to reduce its environmental footprint. Poor quality materials lower the lifespan of buildings thus making investment uneconomical for investors.

Construction is the single biggest industry in the developed world such as United Kingdom, at around 13% of GDP (Adams *et al,* 2011), with arguably the greatest environmental impact. Further Wibowo (2009) further states construction industry's contribution to the economy ranges from 7% to 10% for highly developed economies and around 3% to 6% for underdeveloped economies. The construction process and buildings use not only consume the most energy of all sectors in most developed countries and create the most CO_2 emissions, they also create the largest volume of waste, use most non-energy related resources, and are responsible for most of the pollution.

To reduce the total amount of materials consumed and their environmental impact, there is need to make more efficient use of existing materials and minimize the amount of waste. Use of materials with least environmental impact while considering both operational and whole lifecycle performance of materials and designs as well as design and build for de-construction, re-use, adaptation, modification and recycling are critical for sustainable development of infrastructures (Horvath, 1999). Use of good quality building sands improve both operational and lifecycle performance of buildings by preventing frequent repairs and ensuring building's long lifespan thus reducing overall investment cost. Non-destructive testing of materials is useful in order to evaluate the structural integrity of buildings with the aim of informing the structures that require repair, demolition or de-construction. This research seeks to find the correlation between compressive strength obtained using rebound hammer (NDT) and universal compressive machine (DT) and to assess NDT's reliability.

1.2.2 Buildings Failure and Causes of Collapse of Buildings

Collapse of buildings essentially indicates the structural failure of a building or failure to adequately transmit both imposed and non-imposed loading to the ground evenly. This can also mean the inability of the ground to carry or resist the loadings from the building where the loadings surpass the allowable loading of the ground causing uneven settlement of the building (Machuki, 2012). A loss of bond between the concrete and reinforcement could lead to failure of the structure (Johnson, 2010). It is unlikely that concrete structural failure will be caused by a single factor. A major factor combined with other secondary factors such as rainfall, sudden fluctuation of temperatures, uploading of formwork and reinforcements and placing of concrete will lead to devastation consequences (Shyh-Chyang, 2007). This research focuses only on the silt and clay content and organic impurities as a contributing factor towards determination of compressive and bond strength of concrete.

Various researches have investigated causes of failure of buildings from different perspectives. Oleyede *et al* (2010) argues that the main challenge in handling collapsed buildings is that individuals differ on the professional to blame for the major cause of the collapse of a building. While several studies (Oleyede *et al*, 2010; Dimuna, 2010; Ayodeji, 2011; and Ayuba *et al*, 2012 indicate that use of poor quality materials and use of incompetent professionals are major causes of building failure in Nigeria, Mathenge (2012) suggests that unethical issues and corruption has contributed to collapse of buildings and infrastructures in Kenya. Specifically, incompetent artisans, poor workmanship, weak site supervision and incompetent contractors and non-enforcement of existing laws are found as major cause of collapse of buildings in Nigeria (Oleyede *et al*, 2010). Poor concrete mixes can also contribute to buildings collapse (McWilliams and Griffin, 2013). Lack of recognition of professionalism by the wider society, refusal to pay for professional services and attitude of contractors led to poor quality constructions that are prone to collapsing and are unsafe for human occupancy (Dimuna, 2010).

Figure 1: Collapsed Matigari building near Mathare North, Nairobi
Source: http://www.a4architect.com

In the view of building collapse in Nigeria, Windapo and Rotimi (2012) assert that construction approach does not consider sustainable development principles thus contributing to under performance of buildings. By use of moment correlation coefficient and linear regression analysis to generate a model, Ayodeji (2011) adds that design error, natural phenomenon and excessive loading contributed to buildings collapse in Nigeria. In addition to design error, Olusola *et al* (2011) argues that technical factors such as site production and faulty foundation designs as well as non-technical factors such as lack of site-trade training and corruption lead to building collapse.

Figure 2: Collapsed building in Kiambu town

Source: habarizanyumbani.jambonewspot.com

Machuki (2012) assessed the causes of collapse of buildings in Mombasa Island in Kenya and found that materials used in construction, professionals engaged in the building industry, the building procedure, the developers and the municipal council in Mombasa Island contribute immensely towards the collapse of buildings in Mombasa County. Johnson (2010) concludes that a loss of bond between the concrete and reinforcement could lead to failure of the structure. Impurities in building sands may lead to weak bond between steel reinforcement and concrete and overall reduce the concrete strength leading for failure.

1.3 Problem Statement

Although there has been a robust growth in housing development in Kenya in the last 10 years, demand for housing is very high especially in urban area due to the growing urban population. Provision of housing facilities for residential, commercial, educational institutions and health facilities remains a key focus as provision of infrastructures is engraved in the economic pillar of Kenya's Vision 2030.

As the rush to provide these much needed buildings and houses continue to rise collapse of buildings in Kenya is on the increase and this is expected to continue as the construction industry continues to experience robust growth, unless something is done about it. This collapse of buildings had led to and may continue to lead to injuries, deaths and loss of investment for developers. This is likely to lead to loss in economy, loss of breadwinners and unemployment. Use of poor quality construction materials result in poor quality building structures and may cause structures failure and has been shown to be one of the likely causes of the failure (Dimuna , 2010 and Ayodeji, 2011).

Sand is one of the critical input materials in the concrete for construction. It is this perspective that its quality can have impact on the concrete quality. Clayey, silt and organic materials found in sands for concrete making result in reduced compressive strength of the resultant concrete. Further, impurities in building sands contribute to weak bond strength by allowing slip of reinforcement due to reduced friction and mechanical interlocking. Although many studies carried out have shown that use of poor quality materials is one of the major contributing factors to collapse of buildings, testing of impurities in building sands has not been carried out to establish their impact on the overall concrete performance and its relationship to concrete failure. Consequences of failure of buildings include frequent repairs and higher cost of maintenance. Non-destructive tests are useful methods for assessing strength characteristics for in-situ concrete. Regular building inspections and monitoring promote repairs and rehabilitation as opposed to demolitions and reconstruction that result use of large volumes of natural resources and generates large volumes of waste to the environment.

It is therefore important to determine the comparative compressive strength characteristics of concrete made from building sands sourced from the existing supply points in Nairobi City County and its environs and well as assess bond strength between steel reinforcement and concrete made from the currently used commercial building sands. Assessment of the accuracy of NDT using rebound hammer in comparison to cube strength testing is paramount to promote their use in regular monitoring and inspection of building to determine their structural integrity during their service life.

1.4 Research Questions

i. What is the amount of impurity in building sands being used in Nairobi City County and its environs?

ii. What is the effect of impurities on the physical and strength properties of concrete made using building sands in Nairobi City County and its environs in comparison to control concrete made using clean river sand?

iii. What is the bond strength between steel reinforcement and concrete made using the currently used building sands in Nairobi City County and its environs in comparison to control concrete made using clean river sand?

1.5 Research Objectives

1.5.1 Overall Objective

To assess the effects of sand quality on the strength properties of concrete made using commercial building sand sourced from Nairobi City County and its environs.

1.5.2 Specific Objectives

1. To determine amount of impurities in building sands obtained from the existing sources in Nairobi City County and its environs.
2. To determine the compressive strength of concrete made of building sands sourced from the current supply points in Nairobi City County and its environs and compare non-destructive testing and destructive strength assessment methods.
3. To examine the bonding strength between steel reinforcement and concrete made from building sands sourced from Nairobi City County and its environs.

1.6 Justification

Building sand containing clays and other impurities weakens the bond strength between concrete and reinforcement. There lacks information on the quality of building sands being used in Nairobi City County and its environs.

Quality of concrete is dependent on the quality of ingredients used in concrete production. This research helps in assessing the quality of building sand being used within Nairobi City County and its environs by determining the amount of silt and clay content and organic impurities present and assessing the role they play in determination of compressive and bond strength of concrete. It further examines the correlation between use of NDTs and DT method to assess their relationship and ease of use.

The research outputs are very useful to construction professional by providing information on the level of level of silt and clay content and organic impurities found in building sand being supplied in Nairobi City County and its environs. The maximum allowable level of these impurities have been determined beyond which concrete is likely to fail in compressive force and pull out force application. This is of importance to structural designers to ensure that sand samples from every construction project is tested and designs make provision for strength reduction as a result of presence of silt and clay content and organic impurities to avoid failure of buildings. In addition rebound hammer was also used to assess the concrete cubes strength in comparison with results obtained using the universal testing machine. The close correlation between the two methods indicate that use of NDTs such as rebound hammer present a convenient method for strength determination. It is a relatively accurate and suitable method for assessing the strength of in-situ concrete for quality assurance and preventing collapse of buildings in the construction industry.

1.7 Scope and Limitations

Contextually, the study focused on the quality of concrete made using building sands sourced within Nairobi City County and its environs and the results were compared with control sample made using clean river sand. Geographically, the study was conducted in Nairobi City County and its environs. Sand samples were be sourced from the main supply points in Nairobi namely; Njiru, Mlolongo, Kitengela, Kawangare, Dagoreti Corner, Kariobangi, Kiambu and Thika areas.

Figure 3: Map showing eight main sand supply points at the entry roads to Nairobi City county and environs

Source: Google earth, January 2014

Preparation of concrete cubes, casting and testing were conducted in JKUAT civil engineering laboratory. Further, pull out testing was carried out at the University of Nairobi concrete laboratory while chemical analysis of sand concrete was done at ICRAF diagnostic laboratory, Gigiri.

As a result to budget and time constrains sand samples were sourced from the supply points in Nairobi City County and its environs. As a result of this limitation samples could not be collected from the actual source (river beds, pits, sea etc) for comparison. Further the current Kenyan standard for aggregates does not specify the minimum level of silt and clay and organic impurities allowable in sand used for concrete production. As a result British, Indian and American standards were used in this research.

CHAPTER 2: LITERATURE REVIEW

2.1 General Introduction

This section presents concrete as a construction material and its' constituents. It further covers the conceptual framework on concrete bonding, bond strength and building sands. The section also contains description of both destructive and non-destructive testing of concrete together with use of both Rebound hammer and Windsor probe test as convenient tools for inspection of quality of buildings both in the field and in the laboratory.

2.2 Materials and Their Importance in Concrete Structures

Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space between the aggregate particles and glues them together in presence of water through the hydration process. Janotka (2000) affirms that Portland cement is a hydraulic cement that hardens in water to form a water-resistant compound. The hydration products act as binder to hold the aggregates together to form concrete. The name Portland cement comes from the fact that the colour and quality of the resulting concrete are similar to Portland stone, a kind of limestone found in England. Tricalciumisilicate (C3S) is the major cementitious component of Portland cement. The hydration reaction is represented by the following chemical equation (1) below. In cement nomenclature the hydration reaction equation is given by equation (2) below. The products formed are a calcium silicate hydrate known as C-S-H and calcium hydroxide (Janotka, 2000).

$$2Ca_3SiO_5 + 6H_2O \rightarrow Ca_3Si_2O_7.3H_2O + 3Ca\,(OH)_2 \;\ldots\ldots\ldots\ldots\ldots \; (1)$$

$$2C_3S + 6\,H \rightarrow C_3S_2H_3 + 3CH \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (2)$$

Concrete is a versatile materials used for construction of infrastructures such as buildings, dams, roads, bridges among others. Concrete is the most widely used construction material in the world (Henderson, 2006). Essentially concrete consist of cement, fine aggregates, coarse aggregates, water and any admixtures. Admixtures are added to provide specific characteristic such as air-entraining admixtures, plasticizers and quick hardening (Caltrans, 2010). Fine aggregates such as sands are carefully selected to fill in the gaps between coarse aggregates such as crushed stones. Generally crushed aggregates consist of angular particles having a rough surface texture resulting in concrete with lower workability but higher strength compared to similar mix with uncrushed aggregates (Teychenne *et al*, 1993).

Concrete is the most inexpensive and the most readily available material. Its cost of production is low compared with other engineered construction materials. It can be formed into different desired shapes and sizes right at the construction site. Careful selection and grading of aggregates is important to concrete because a good grading will reduce the cement content and void in concrete and thus produce economical and better concrete (Quiroga and Fowler, 2004). Impurities in fine aggregates such as sands affect the overall performance of concrete (Olanitori and Olotuah, 2005).

Adherence with the quality standards specified by various organizations (e.g. British Standards, ASTM), is required to ensure appropriate structural strength is achieved to adequately designed structural loading. Olanitori and Olotuah (2005) tested the effects of clayey impurities found in building sands as well as their effects on concrete's crushing strength. Upon testing of ten samples collected in various locations in Akure Metropolis, Nigeria they found that strength reduction was as high as 70% of the 20N/mm^2 cube strength at day 28. From their research they concluded that the permissible clay content should be 3.4% and 8% is allowed by the Nigerian standard organization. Investigation of the silt and clayey content in building sands used in Kenya is paramount to assess if they play a significant role frequent collapse of buildings in Nairobi City County and its environs and also to devise a possible solution to this problem.

2.3 Concrete - Steel Bonding

Bond strength is a measure of the transfer of load between the concrete and the reinforcement. Bond strength theory is the basis behind the equations below used in design of reinforced concrete structures in BS 8110 (Johnson, 2010).

$$f_{cd} = 0.67\, f_{cu}/\gamma_m \qquad \text{……………………………………} \; (3)$$

where f_{cd} = design compressive strength of concrete

f_{cu} = characteristic cube compressive strength at 28 days

γ_m = materials safety factors

ACI (2003) defines bond force as the force that tends to move a reinforcing bar parallel to its length with respect to the surrounding concrete. Bond strength thus represents the maximum bond force that may be sustained by a bar. Anchored length, bonded length, and embedded length are used interchangeably to represent the length of a bar over which bond force acts. In most cases, this is the distance between the point of maximum force in the bar and the end of the bar.

Bond strength is influenced by bar geometries, concrete properties, the presence of confinement around the bar, as well as surface conditions of the bar (ACI 2003 and Johnson, 2010). A loss of bond between the concrete and reinforcement could lead to failure of the structure. For example, in a reinforced concrete beam, steel reinforcement carries tensile loads as concrete is weak in tension and not capable of carrying itself due to the low tensile capacity of concrete. The concrete carries the compressive loads while the steel reinforcement carries the tensile loads. Therefore reinforcement must be well bonded to the concrete in order for these forces to transfer from one material to the other to provide equilibrium for the member. If this bond fails, the reinforcement will slip from the beam, nullifying the ability to transfer the tension forces from the concrete to the steel leading to concrete failure (Johnson, 2010).

Hadi (2008) emphasizes that for reinforced concrete to function effectively as a composite material it is necessary for the reinforcing steel to be bonded to the surrounding concrete. The bond ensures that there is little or no slip of the steel relative to the concrete and the means by which stress is transferred across the steel-concrete. Bond resistance is made up of chemical adhesion, friction and mechanical interlock between the bar and surrounding concrete. In the plain or round bars on the other hand, only the first two of these components contribute to the bond strength. In the deformed or twisted bars, the surface protrusions or ribs interlocking with and bearing against the concrete key formed between the ribs contribute more positively to bond strength, and it is the major reason for their superior bond effectiveness compared to round bars. Bond stress is higher near the end of the bar that is being loaded and lower at the other end of the bar (Kahl, 2002).

By use of high strength concrete and high strength reinforcing bars, Hadi (2008) observed three modes of pull out failures namely; pull out, splitting and steel rapture failures. See illustration in Figure 4. He noted that pullout failure mode occurred when the concrete cover provided adequate confinement, thus preventing a splitting failure of the test specimen. Splitting failure mode was characterized by splitting of the concrete specimen in a brittle mode of failure. Both transverse and longitudinal cracks were observed at failure. Steel rapture occurred when steel reinforcement just cut upon loading.

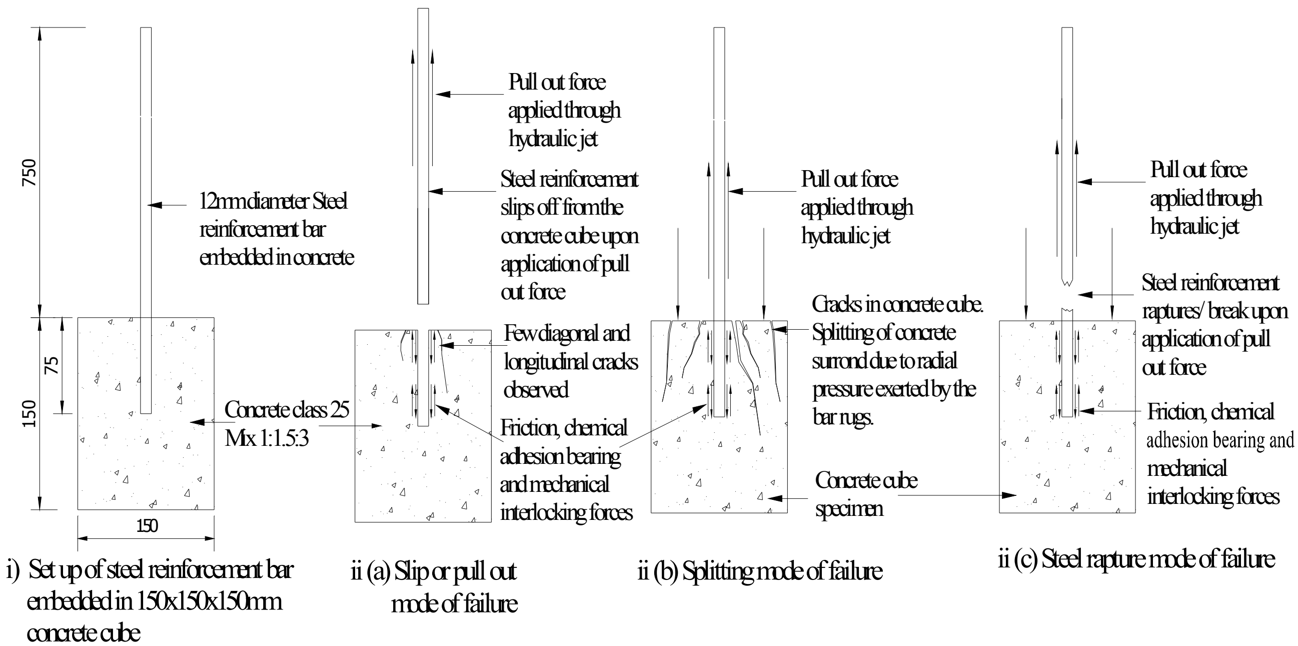

Figure 4: Modes of bond failure between concrete and steel reinforcement bar

Different kinds of building sands used in Nairobi contain varying clay content and other impurities. With use of building sands containing adulterous materials including clay, and silt little is known about how these impurities impact on the bond strength between a reinforcement bar and concrete, and thus the behavior of the reinforced concrete overall.

Concrete splitting as mode of failure indicates that the resisting frictional force between concrete and reinforcement is higher than the pulling force thus indicating stronger bond strength. Steel rapture mode of failure implies that the bond strength between concrete and reinforcement bar was much lower than the resisting stress in the reinforcement bar. Bar slip mode of failure implies that a weak bond between concrete and reinforcement bar as a result of reduced resistance at the bond between concrete and reinforcement bar.

2.4 Buildings Sands

2.4.1 Introduction

Concrete aggregates can be broadly classified into three namely; heavy weight, normal weight and light weight aggregates. They can further be classified as natural or artificial aggregates (Orchard, 1979). Sand is one of the normal weight natural fine aggregates for concrete production.

Sand occur as natural product of rock disintegration and may occur as huge and thick deposits called pits sands, as riverbed deposits and as marine or beach sands (Mutuku, 2013; Orchard, 1979). Pure sand, mainly qartz (SiO_2) which is quite hard with hardness of up to 7 using Mohs' hardness scale, is resistant to all types of chemical deterioration and grain sizes vary between 2mm to 1/16mm. Building sands vary in shape, size and purity depending on their mode of formation. Rounded shaped river, sea and windblown sand is as result of water wearing and attrition forces while irregular shaped land and dug sands and gravels is as result of naturally irregular and partly action of attrition (Orchard, 1979).

Sand may be classified as argillaceous, siliceous or calcareous, according to its composition. It is procured from pits, shores of rivers, sea-shores, or by grinding sandstones. It is chiefly used for production of mortar, concrete and plaster. Pit sand has an angular grain, and a porous, rough surface, which makes it good for mortar, but it often contains clay and similar impurities. River sand is not so sharp or angular in its grit, the grains having been rounded and polished by attrition. It is commonly fine and white, and therefore suited for plastering. Sea sand also is deficient in sharpness and grit from the same cause. It contains alkaline salts, which attract moisture and cause permanent damp and efflorescence (Orchard, 1979).

Sand found to contain impurities, such as clay and loam should be washed by being well stirred in a wooden trough having a current of water flowing through it which carries off the impurities. It is sometimes washed by machinery, such as an Archimedean screw revolving and carrying up the sand, while a stream of water flows down through it. In examination of sands, clean sand should leave no stain when rubbed between the moist hands. Salts can be detected by the taste, and the size and sharpness of the grains can be judged of by the eye.

2.4.2 Building Sand Quality

2.4.2.1 Silt Content Test of Sand

The maximum quantity of silt in sand shall not exceed 8% according to the Nigerian standard organization (Olanitori and Olotuah, 2005). Both ASTM C 117(1995) and Hong Kong's Construction standard (2013) give an allowable limit of 10% for silt and clay content in sand. On the other hand British Standard BS 882 and Indian Standard (1970) states that the percentage of clay and fine silts must not exceed 4% by weight for sand for use in concrete production (Harrison and Bloodworth, 1994). Fine aggregate containing more than allowable percentage of silt shall be washed so as to bring the silt content within allowable limits. According to Singh *et al* (2006) and Anosike (2011) as a thumb rule, the total amount of deleterious materials in a given aggregates should not exceed 5%.

The methods of determining the content of these deleterious materials are prescribed by IS 383(1970), BS 882 (1992), ASTM C 117 (1995) and ASTM C40 (2004). These include determination of contents organic impurities, clay, or any deleterious material or excessive fillers of sizes smaller than No. 100 sieve. This research also seeks to establish the minimum allowable limits of silt and clay and organic impurities for concrete production based on the tested samples.

2.4.2.2 Grading of Sand

On the basis of particle size, fine aggregate is graded into three zones (JKUAT Lab Manual) as illustrated in Table 1 below. Where the grading falls outside the limits of any particular grading zone of sieves, other than 600 micron IS sieve (equivalent to mesh no. 25 BS standard or no. 30 ASTM standard), by a total amount not exceeding 5 percent, it shall be regarded as falling within that grading zone.

Table 1: Grading of fine aggregate

IS Sieve Designation	Percentage passing for				Where as
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV	Zone I: Coarse sand Zone II: Normal sand Zone III: Fine sand Zone IV: very fine sand
10mm	100	100	100	100	
4.75mm	90 – 100	90 – 100	90 – 100	90 – 100	
2.36mm	60 – 95	75 – 100	85 – 100	95 – 100	
1.18 mm	30 – 70	55 – 90	75 – 100	90 – 100	
600 micron	15 – 34	35 – 59	60 – 79	80 – 100	
300 microns	5 – 20	8 – 30	12 – 40	15 – 50	
150 microns	0 – 10	0 – 10	0 – 10	0 – 15	

Source: IS: 383 (1970)

Indian standard (IS 383, 1970) recommends that fine aggregates conforming to Grading zone IV should not be used in reinforced concrete unless tests have been made to ascertain the suitability of proposed mix proportions. It further emphasis that as the fine aggregate grading becomes progressively finer, that is from zones I to IV, the ratio of fine aggregates to coarse aggregate ratio should be progressively reduced.

2.4.2.3 Deleterious Materials in Sand

Sand shall not contain any harmful impurities such as iron, pyrites, alkalis, salts, coal or other organic impurities, mica, shale or similar laminated materials, soft fragments, sea shale in such form or in such quantities as to affect adversely the hardening, strength or durability of the mortar (Mishra, 2012). The maximum quantities of clay, fine silt, fine dust and organic impurities in the sand / marble dust shall not exceed the following limits:

(a) Clay, fine silt and fine dust when determined in accordance within not more than 5% by mass in Indian's IS 383, natural sand or crushed gravel sand and crushed stone sand. Both ASTM C 117 (1995) and IS (1970) give an allowable limit of 10% for silt and clay content in sand while BS 882 (1989) gives a limit of 4% by weight (British Geological Survey, 1994).

(b) Organic impurities when determined in colour of the liquid shall be lighter in accordance with IS 383 and ASTM C87 (1995).

In some instances, sands are mixed with impurities during transportation thus deteriorating its quality and this affects the strength of constructed structures. In some regions, many sand quarries contain high clay content and often large amount of dusts and care is taken to ensure manufactured sands are free from these impurities (Mutuku, 2012). Fine aggregates may contain sufficient harmful matter (such as humic acid) to interfere with setting or rate of hardening of cement thus that being its chief deleterious effect (Orchard, 1976).

Orchard (1979) argues that sands from pits are usually washed to free them from clay and silts but if the pit is flooded and the material is excavated under water, then washing can be avoided. Sands from the sea shore are washed off chlorides that cause corrosion of reinforcement if concrete is porous and becomes damp. Many sands from pits, rivers and sea shore may contain large volume of calcium carbonate. This has no harmful chemical effect when it is up to 20% by volume as long as adequate cube strength is obtained (Orchard, 1979). Granite rocks are most commonly used coarse aggregates for concrete production.

Aggregates must be relatively clean for use in concrete making. Vegetation, soft particles, clay lumps, excess dust and vegetable matter may affect performance by quickly degrading, which causes a loss of structural support and/or prevents binder-aggregate bonding. American Society for Materials Testing (ASTM) C33 / C33M standards specify the requirements for grading and quality of fine and coarse aggregate for use in concrete. Fine aggregate may include natural sand, manufactured sand, or a combination both. The standard recommends that for quality concrete, fine aggregates should be free of injurious amounts of organic impurities (ASTM C33, 2006). Usually, fine aggregate for use in concrete are subjected to wetting or extended exposure to humid atmosphere, or contact with moist ground should not be chemically reactive to alkalis in the cement to avoid excessive expansion of mortar or concrete.

2.4.2.4 Bulking of Fine Aggregates

The volume of fine aggregates such as sand is at minimum when sand is absolutely dry or when it is completely inundated/flooded. Bulking or increase in volume of fine aggregates may range from 20% to 30% depending on moisture content and degree of fineness in grading. The finer the aggregates, the greater the percentage by which the material bulks

(Orchard, 1979). Therefore concrete mix design should consider the moisture content and related bulking of sand to ensure that correct volume of ingredients are used in concrete production.

2.4.3 Coarse Aggregates in Concrete

Coarse aggregate is also an important input in concrete production together with sand. Coarse aggregate may consist of gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, crushed hydraulic-cement concrete, or a combination of more than one material. The sampling and test methods include grading and fineness modulus test, organic impurities test, effect of organic impurities on strength test, soundness test, clay lumps and friable particles test, coal and lignite test, bulk density of slag test, abrasion of coarse aggregate test, reactive aggregate test, freezing and thawing test, and chert test method (ASTM C33/C33M, 2006).

2.4.3.1 Coarse Aggregates Quality

ASTM D2419 – 09 (2006) on Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate assigns an empirical value to the relative amount, fineness, and character of claylike material present in the test specimen. A minimum sand equivalent value is usually specified to limit the permissible quantity of claylike fines in an aggregate. This method provides a rapid field method for determining changes in the quality of aggregates during production or placement.

2.4.3.2 Improvement of Aggregates by Processing

Many regions have inferior aggregates being locally available in abundant supply. Unsatisfactory aggregates are lighter and softer than suitable quality ones. Lighter fractions may be removed by (a) placing aggregates in a liquid of such specific gravity that light fractions float while heavy fractions sink where such liquid may include suspensions of magnetite and ferro-silicon ground to fine powder, or (b) retarding settling of aggregates in water and this can be effected by upwards pulsation in water caused by either pneumatically or mechanically by a diaphragm (Orchard, 1979).

On the other hand, soft materials may be removed by (a) breaking them up in a mill crusher or (b) by allowing aggregates to fall on inclined hard steel plates where hard particles rebound a greater distance than soft ones (Orchard, 1979). Normal-weight aggregates include sands, natural gravels and rocks, crushed or uncrushed and some manufactured aggregates such as crushed iron blast-furnace slag, and their density ranges from 2000 to 2600kg/m^3. Lightweight aggregates are defined as those having a density less than 1,950 kg/m^3. They are used to produce concrete of substantially lower unit mass than that made from dense aggregates and include materials such as scoria, a porous rock of volcanic origin, pumice, and manufactured materials such as foamed iron blast furnace slag and expanded clays and shales. Density of heavy weight aggregates ranges from 3000 to 5000kg/m^3 (New Zealand)

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2.4.4 Amount of Clayey and Silty Material in Aggregates

British Standard (BS 882, 1989) details the method of determining the amount of clayey and silt materials in aggregates. Fine silts can be usually taken as material below 20 microns in size. According to British Standard BS 882, the percentage of clay and fine silts must not exceed 3, 10 and 1 percent by weight respectively for sand or crushed gravel sand, crushed stone sand, and coarse aggregates (Orchard, 1976).

The American test designation ASTM C142 consists of sieving out clayey material, after having first broken down all lumps with unaided fingers, and then expressing the loss in weight as percentage of original weight.

2.5 Concrete Strength Tests

2.5.1 Destructive Tests

2.5.1.1 Introduction

The methods used in the diagnostic testing of building structures are divided into destructive test (DT), semi-destructive test (SDT) and non-destructive test (NDT) methods. Destructive tests can be applied to both samples and natural-scale structural elements where both are destroyed in the tests. For this reason only a few representative samples or natural-scale elements are subjected to such tests. Semi-destructive tests are also applied to samples and full elements and structures and they involve a small (usually superficial) intrusion into the structure of the material, resulting in local loss of service properties and requiring repair. In non-destructive testing there is no such intrusion applied to natural-scale elements and structures hence NDTs can be applied to the same elements and structures many times and at different times and therefore such methods are suitable for the diagnostic testing of building structures during both their erection and the many years of their service life (Hoła and Schabowicz, 2010).

In destructive testing, tests are carried out to the specimen's failure, in order to understand a specimen's structural performance or material behaviour under different loads. These tests are generally much easier to carry out, yield more information, and are easier to interpret than NDT (Gamidi, 2009). Destructive testing is most suitable, and economic, for objects which will be mass-produced, as the cost of destroying a small number of specimens is negligible. It is usually not economical to do destructive testing where only one or very few items are to be produced such as in the case of a building. Pull out test and compressive strength testing using cube's crushing machine are examples of destructive tests since the specimen (concrete and/or reinforcement) are destroyed in the process.

2.5.1.2 Pull Out Test

A pullout test is one of the NDTs and it measures the force required to pull a specially shaped steel rod or disc out of the hardened concrete into which it has been cast. Since structural concrete is often used with steel, the bond strength between the two materials is of importance (Neville, 1981). The bond arises primarily from friction and adhesion between concrete and steel but may also be affected by shrinkage of concrete relative to steel. Neville (1981) concluded that the bond is related to quality of concrete and bond strength is approximately proportional to compressive strength of up to 20MPa. For higher strengths, increase in bond strength becomes progressively smaller and eventually negligible.

ASTM C900 (2006) standards describes the test method used for determination of the pullout strength of hardened concrete by measuring the force required to pull an embedded metal insert or reinforcement and the attached concrete fragment from a concrete test specimen or structure. The insert reinforcement is either cast into fresh concrete or installed in hardened concrete. Upon pulling of the rod, concrete fails in tension and to shear and the force is quoted in kilo newtons (Orchard 1979, Neville, 1981).

Pullout tests may be used to determine whether the in-place strength of concrete has reached a specified level so that post-tensioning may proceed, formwork and shores may be removed or structure may be put into service. It may further be used to estimate the strength of concrete in existing constructions (ASTM C900, 2006). EN 12350-1 to 12350-7 and EN 12390-1 to 12390-11 provide basis on testing of hardened concrete. According to Neville and Brooks (2004), Penetration test can be considered almost non-destructive as the damage is only local and it is possible to re-test in the vicinity. Pull out tests presents a suitable method for determination of the bond strength between reinforcement bar embedded in concrete and the surrounding concrete.

2.5.2 Non-Destructive Methods of Evaluation of Concrete Strength

2.5.2.1 Introduction

Non-destructive testing (NDT) is a form of testing carried out on various construction members and materials without causing any permanent damage to them. As NDT is used in concrete, it can also be used very effectively for other building members and materials (Patil and Patil, 2008). NDT is primarily carried out for quality control, identification of problems, and assessment of existing condition for retrofitting, and quality assurance or concrete repair (Saleem et al, 2012, Gamidi, 2009). The best NDT methods do not alter the material and result in superficial local damage. Evaluation of concrete properties is of great interest and may aim at detecting altered areas, controlling the concrete quality or estimating its compressive strength (Hannachi and Guetteche, 2012).

2.5.2.2 Schmidt Rebound Hammer Test

The Schmidt rebound hammer BS EN12504-2 (2012) is one of the oldest and best known surface hardness tester methods. It is used to indirectly assess concrete strength thus comparing the concrete in various parts of a structure or different structures. The hammer weighs about 1.8 kg and is suitable for use both in a laboratory and in the field. Its main components are; the outer body, the plunger, the hammer mass, and the main spring. It also has a latching mechanism that locks the hammer mass to the plunger rod and a sliding rider that measures the rebound of the hammer mass (see Figure 5). The rebound distance is measured on a scale marked from 10 to 100. The rebound or bounce back of an elastic mass depends on the hardness of the surface against which its mass strikes (Hannachi and Guetteche, 2012).

Although there is little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer, empirical correlations within limits have been established between strength properties and the rebound number (IAEA, 2002).The rebound hammer presents a convenient on-site strength testing method because it can be used in the horizontal, vertically overhead, vertically downward positions or any intermediate angle provided the hammer is perpendicular to the surface under test. Rebound hammer test is sensitive to the presence of aggregates and of voids underneath the plunger hence it is necessary to take 10 to 12 readings over the area to be tested (Neville and Brooks, 2004).

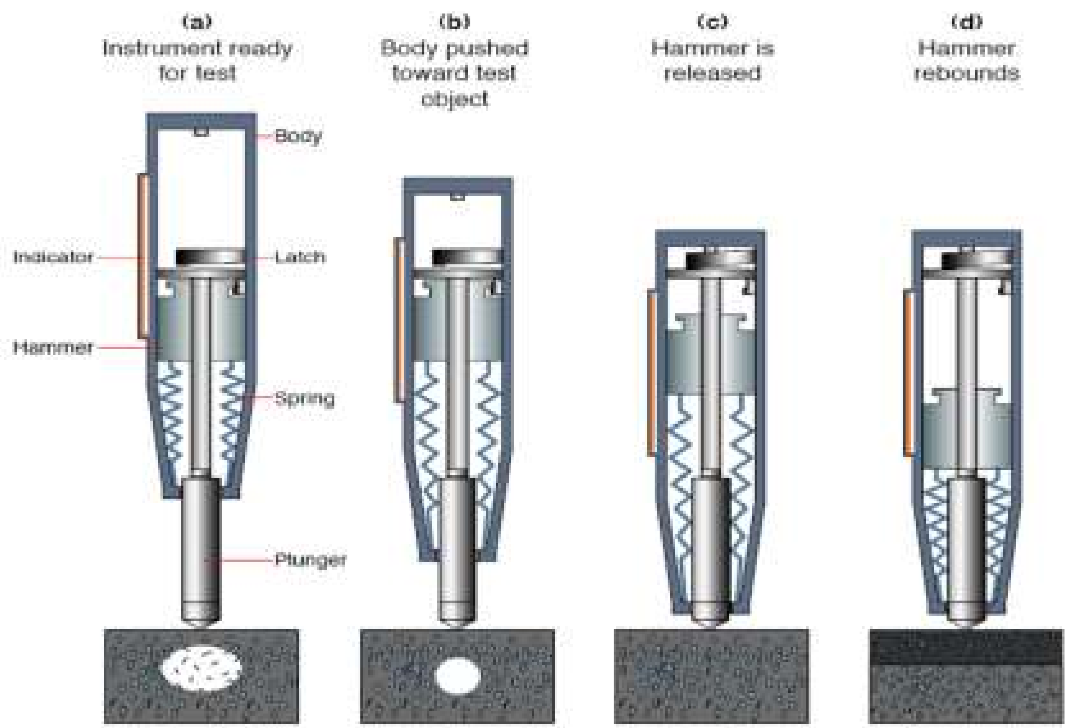


Figure 5: Schmidt rebound hammer

Source: http://www.engineersdaily.com/2011/04/rebound-hammer-test.html

Nucera and Pucinotti (2009) explain that although rebound hammer is a simple tools for compressive strength testing, it is necessary to build a suitable correlation curve. The rebound hammer test described in ASTM C805, EN12504-2012 and in BS 1881 (1983) are significantly influenced by several factors such as:

a) smoothness of test surface;
b) size, shape, and rigidity of the specimens;
c) age of the specimen;
d) surface and internal moisture conditions of the concrete;
e) type of coarse aggregate and type of cement;
f) carbonation of concrete surface

Care is taken in the use and positioning of rebound hammer to ensure accurate results is obtained (Hannachi and Guetteche, 2012). The rebound hammer test is also referred as Impact hammer test or Sclerometer test and is based on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges (Neville and Brooks, 2004). This research uses rebound hammer for assessing surface hardness as indicated by rebound number and compressive strength of concrete.

2.5.2.3 Windsor Probe Test

It is also called Penetration Resistance test and is used to measure the surface hardness hence used in determination of strength of the surface and near surface layers of the concrete. Like the rebound hammer, the Windsor probe is a hardness tester (Crawford, 1997). Research shows that the probe penetration relates to some property of the concrete below the surface and within limits, it is possible to develop empirical correlations between strength properties and the penetration of the probe. The Windsor probe uses a powder-activated driver to fire a hardened-alloy steel probe into the concrete specimen (see Figure 6 overleaf. The exposed length of the probe indicates a measure of the penetration resistance of concrete. The standard test procedure is described in ASTM C-803.In absence of rebound hammer, use of Windsor probe test is recommended for inspection of structural strength in concrete.

Figure 6: Windsor HP probe system

Source: Construction Materials Testing Equipment, http://www.humboldtmfg.com

2.6 Summary of Literature Review

Use of poor quality construction materials result in poor quality structures and may cause structural failure leading to injuries, deaths and loss of investment for developers. Past researches identify the major causes of failure of buildings as use of poor quality building materials used (sand, coarse aggregates, steel reinforcement, water), workmanship employed in the concrete mix proportioning and construction methodology, defective designs and non-compliance with specifications or standards (Machuki, 2012; Oleyede *et al*, 2010; Dimuna, 2010; Ayodeji, 2011; Ayuba *et al*, 2012 and Dahiru et al, 2010). However, isolated assessment of the impacts of presence of silt and clay content and organic impurities in building sand used for concrete production has not been carried out. Barbosa and Filho (2013) assessed the bond strength using steel reinforcement of various diameters and concluded that bond stress increases with increase in bar diameter. Johnson (2010) assessed the bond strength of corrosion resistant steel reinforcement in concrete and concluded that increased relative rib area results in an increase in bond strength and that Epoxy coating decreases the initial bond strength of reinforcement.

Impurities in buildings sand contribute to weak bond strength by allowing slip of reinforcement due to reduced friction and mechanical interlocking between concrete and reinforcement. It is therefore necessary to carry out this research in order to establish the amount of impurities found in the building sands and their relationship to the overall concrete compressive strength as well as the bonding between concrete and steel reinforcement.

Use of non-destructive testing methods such as Schmidt Rebound Hammer and Windsor Probe Test methods for inspection of buildings is not common. All buildings need periodic inspection without exception and rebound hammer is a useful inspection tool.

2.7 Conceptual Framework

Designs of concrete members are based on the fundamental assumption that exist the effective bond linking concrete and steel when the structural member is loaded. The behaviour of reinforced concrete elements depends on the steel-concrete bond and the strength capacity of these elements is directly related with the bond (Barbosa and Filho, 2013). For a reinforced concrete member to act as per design there must be no slipping between concrete and the steel reinforcement. Figure 7 below shows the strength formation process for reinforced concrete. In this research independent variables (IV) were quality parameters of cement, coarse aggregates and water and sand which are dependent on level of impurities. No other admixtures were used in test concrete production. The quality of a parameter of concrete compressive strength and bond strength and are dependent variables.

while sand was the dependent variable (DV). Sand samples were sourced from various supply point and contained varying levels of impurities.

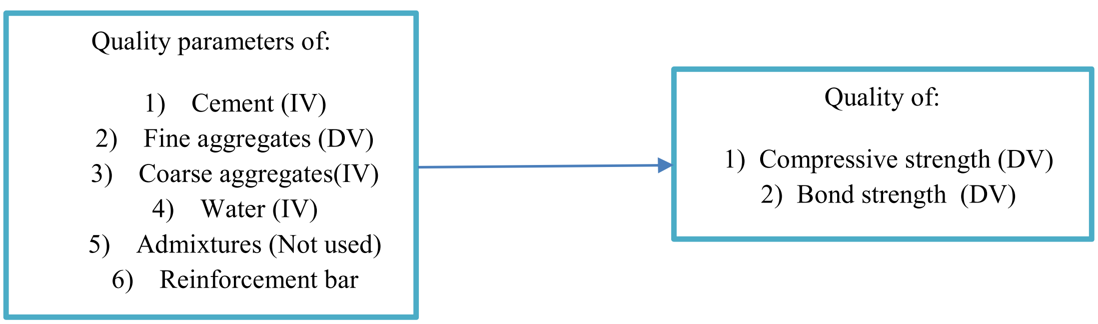


Figure 7: Dependent and independent variables

The transfer of axial force from the reinforcement steel bar to the surrounding concrete is produced from the development of tangential stress components along the contact surface (Albarwary and Haido, 2013). The bond stress acts parallel to the bar along the concrete interface. For the reinforced concrete material, it is necessary to create suitable bond between steel bars and surrounding concrete. Bond ensures that there is little or no slip of the steel bars relative to the concrete and the means by which stress is transferred across the steel-concrete (Hadi 2008). Bond strength is defined by chemical adhesion, friction and mechanical interlock between the bar deformations and the surrounding concrete. Poor bond strength between steel reinforcing bar and concrete results in concrete failure.

The concrete compression strength and the concrete tension strength are the main parameters that influence the anchorage length and the transmission of the tensions concentrated on the reinforcement bar ribs (Barbosa and Filho, 2013). Other factors that influence the bond stress are: surface roughness of the bars and/or irregularities (increase the bond), diameter of the bars (one increase of the bar diameter reduces the maximum bond stress), type and disposition of the ribs.

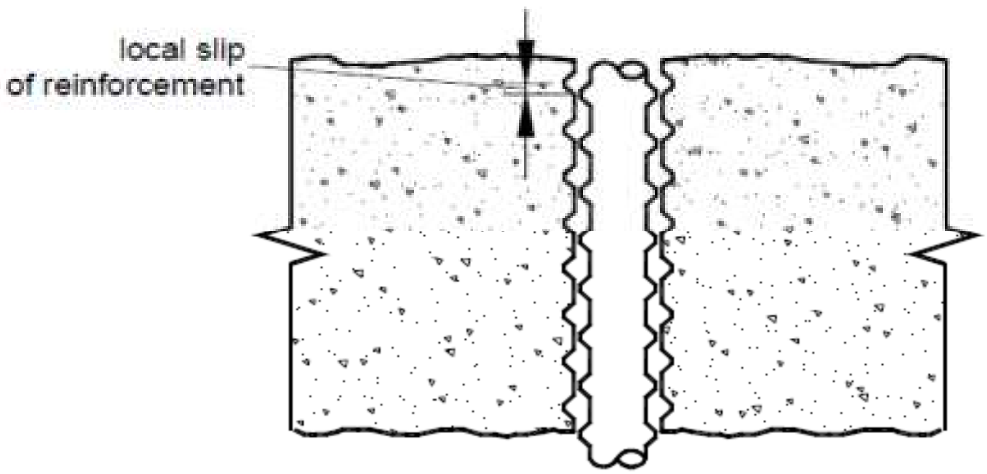


Figure 8: Local bond failure showing slip of reinforcement

Source: http://faculty.washington.edu/lowes/dissertation

Presence of impurities in construction materials may affect performance of concrete by quickly degrading, which causes a loss of structural support and/or prevents binder-aggregate bonding. ASTM C33 (2006) and BS 882 (1989) standards recommends that for quality concrete, fine aggregates should be free of injurious amounts of organic impurities. ASTM D2419 (2009) on Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate assigns an empirical value to the relative amount, fineness, and character of claylike material present in the concrete test specimen. A minimum sand equivalent value is usually specified to limit the permissible quantity of claylike fines in an aggregate. This method provides a rapid field method for determining changes in the quality of aggregates during production or placement of concrete.

CHAPTER 3: METHODOLOGY

3.1 Research Approach

The research employed laboratory experimental methods. This entailed collection of sand samples from eight main sand supply points in Nairobi City County and its environs namely Njiru, Mlolongo, Kitengela, Kawangare, Dagoretti Corner, Kariobangi, Kiambu and Thika. Reconnaissance survey was carried out to establish and map out the existing supply points. Sand samples were labeled based on their point collection where NR , ML, KT, KW, DC, KB, KBU and TK were used to represent samples sourced from Njiru, Mlolongo, Kitengela, Kawangare, Dagoretti Corner, Kariobangi, Kiambu and Thika respectively. A digit number was further given to represent the sample number as collected from each supply point e.g. NR1, NR1, NR3 was used to label sample 1, sample 2 and sample 3 respectively sourced from Njiru area. Two sand samples CL1 and CL2 were washed and used as control samples. From each supply point, 50kg the selected sand samples were procured for grading and testing. A total of twenty six samples were collected.

Graded coarse aggregates comprising of crushed stones of maximum size 20mm was sourced from a quarry in Mlolongo while ordinary Portland cement grade 32.5 and 12mm diameter twisted steel reinforcement bars were sourced from local manufacturers in Juja, Kenya. Clean portable water from Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya was used. Thus sand was maintained as the only concrete production input with varying quality that could impact on the strength of concrete. The other independent variables, coarse aggregates, cement and water were made to be of same quality such that the dependent variable namely concrete quality parameters, compressive and bond strengths could only be affected by the sand quality and levels of impurities.

3.2 Materials and Equipment

The following materials and equipment were used in carrying out the research:

i. Compressive strength testing machine and steel concrete moulds
ii. Pull out testing machine
iii. Schmidt rebound concrete hammer

iv. Ingredients: Sands samples from eight supply points, crushed stones, Portland cement, water and reinforcement bar
v. PPE tools (Apron, helmet, gloves, safety shoes, cylinders, labels, rubber bands)
vi. Chemicals: Tannic acid, sodium hydroxide and sodium chloride
vii. Laptop and internet connectivity
viii. Printing and photocopying papers
ix. TXRF and LDPSA equipment at ICRAF soil diagnostic laboratory for chemical analysis

3.3 Methods

3.3.1 Reconnaissance Survey

Reconnaissance survey was carried out to establish and map out the main sand supply points in Nairobi City County and its environs. This entailed field visit to familiarize with the existing sand supply points within Nairobi City County and its environs. Camera, note book and pen were used during reconnaissance survey and the outputs comprised of a list of supply points with brief description of location, and photographs/plates. A map of sand supply points where sand was sourced is shown in Figure 9 below. The eight sources are indicate by yellow pin points.

Figure 9: Map of sand supply points where sand was sourced

Source: Google Earth, January 2014

3.3.2 Determination of Particle Shape Texture and Specific Gravity

After sand samples were sun-dried, they were subjected to physical examination to determine the particle shapes and surface texture. Particle shapes were classified as rounded or irregular/angular while surface texture was classified as smooth or rough texture. Determination of specific gravity of sand samples was carried out using pycnometer glass vessel as detailed in IS (1970) equivalent to ASTM D854 (2014) for aggregates less than 10mm diameter. Specific gravity for saturated and wet sand, apparent specific gravity and absorption rate for 27 samples were determined and comparison with clean control sample done.

3.3.3 Grading of Sand Samples

Upon completion of reconnaissance survey, sand samples were then sourced from the identified supply point within Nairobi City County and its environs. From each supply point, a heap of about 50kg was procured from each sand sample for grading and testing. In the laboratory, sieve analysis was carried out on the sand samples to determine the degree of fineness. Percentage passing and retained was analyzed and grading curved plotted for comparison. In order to determine samples with more-or-less similar characteristics, sand samples were group based on their degree of fineness as indicated by percentage passing the 600 microns standard sieve. Further specific gravity for each sand sample was determined using pycnometer method as detailed in the BS standard.

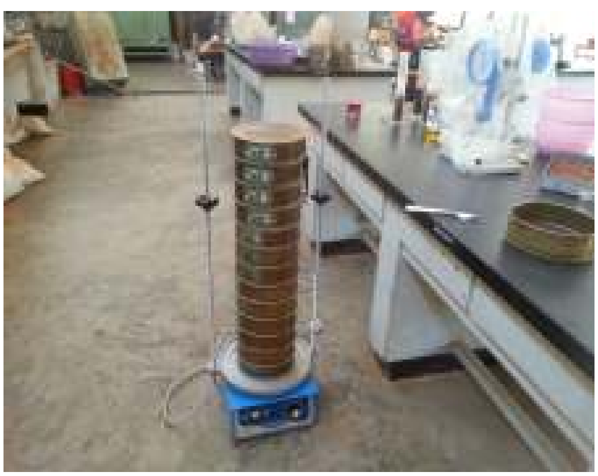


Plate 1: Vibration of sand samples in sieve analysis.

Plate 2: Testing for specific gravity using pycnometer

3.3.4 Determination of Impurities in Sand samples

Testing for silt and clay content was carried out as recommended in BS 812 and ASTM C117. Sun-dried sand samples were thoroughly washed in clean flowing water after which they were wet sieved to determine the amount of material finer than a 75-µm (No. 200) sieve in aggregate by washing. 50ml of 1% sodium chloride (NaCl) solution was added into the washing container as a catalyst in separation of silt and clay from sand. Each cylinder was covered with hand very tight and shaken rigorously for about 15 minutes after which the mixture was left standing for 3 hours. The silt settled and formed a layer which was used to determine the height of sand and results as percentage. The washed samples decanted off water, oven dried for 24 hours after which they were allowed to cool and were weighed. Clay particles and other aggregate particles that are dispersed by the wash water, as well as water-soluble materials, were removed from the aggregate during the test.

Sodium Hydroxide (NaOH) solution was used for the organic content determination test. The apparatus was a transparent cylinder. A 350ml transparent cylinder was filled with 3% solution of NaOH in distilled water up to 75ml mark. Sand was then added gradually until 125ml mark on the cylinder. The NaOH solution was then added up to 200ml mark. The cylinders were sealed, tightly held by hand and shaken vigorously and allowed to stand undisturbed for 24 hours. The reddish brown or dark red solution showed the presence of acid from organic materials. A clear yellow solution indicates that sand is suitable for construction work. A standard solution made using tannic acid added to solution of sodium hydroxide solution was used for colour comparison.

In order to remove the impurities such as clayey and silt materials in the sand samples, all the lumps were broken down with unaided fingers and the materials below 20 microns sieved out to determine the amount of impurities by weight. The loss in weight was determined as percentage of original weight to determine the amount of impurities. The results were compared with the allowable limit of 3 and 1 percent by weight for sand and coarse aggregates respectively according to British Standard BS 882. Further chemical tests were carried out at ICRAF laboratory using Laser Diffraction and Particle Size Analysis (LDPSA) and Total X-ray fluorescence (TXRF) methods.

For control sand sample, the visually cleanest river sand was washed to remove the amount of silt and clay impurities present. Clean control sand sample was dried and graded through sieve analysis and grading curve developed. Based on the preliminary testing of impurities in building sand samples, thirteen sand samples were chosen for compressive testing. Careful selection was carried out to ensure that samples with varying silt and clay, and organic impurities were representative.

Plate 3: Cleaning of control sample

Plate 4: Organic impurities testing

3.3.5 Chemical Elements Analysis Using TXRF and LDPSA Methods

The content of chemical elements present is sand samples were tested at ICRAF soil diagnostic laboratory and the results are shown in ***Appendix 2.*** Presence of key chemical elements was determined and compared with the available standards for sand used in concrete production. Silica and chloride levels were assessed. Due to cost implication and time limit testing for the oxides present could not be carried out.

3.3.6 Concrete Mix Design

Concrete design using mix ratio of 1:1.5:3 for cement: sand: coarse aggregate commonly used in structural building elements was carried and the quantity of sand, crushed stones (ballast), Portland Pozzolanic Cement and water designed. The expected compressive strength at 28 days was 25MPa. The effective water/cement ratio (by mass) for non-air-entrained concrete of 0.57 was used for aggregates maximum size 20 mm using Portland Pozzolanic Cement. A constant water cement ratio gave varying slump levels of difference sand samples. Crushed coarse aggregates were subjected to sieve analysis to achieve ratio of 1:2 for 10mm and 20mm respectively for use in all concrete castings. Weight of the impurities in the coarse aggregates was determined and expressed as percentage of sample weight.

In order to assess the effect of workability on compressive strength and bond strength, mix design for selected samples was carried out such that workability was maintained in two categories namely very low (0-25mm slump) to medium (50-100mm slump) during casting. Results on variation of concrete strength based on constant workability were compared with those obtained when workability was used. Samples were categorized based on their workability levels.

3.3.7 Compressive Strength Testing

Compressive strength testing of concrete cubes was carried out at described in ASTM C39-90. 150mm cubes moulds were filled with approximately 50mm layers of concrete and compacted to achieve not less than 25 stokes. Mechanical vibration may alternatively be used to achieve adequate vibration. De-moulding was done just before 24 hours of casting. Cube specimens were then stored in curing tank at 20+/-2^{0}C until the prescribed age of 7 days, 14 days and 28 days are achieved.

Plate 5: Batching, mixing and casting

Plate 6: Compaction of raw concrete

Plate 7: Slump testing **Plate 8: Specimens for strength testing**

Assessment of compressive strength of concrete was carried out using (a) standard compressive strength testing machine for concrete cubes (b) Schmidt rebound hammer. Where Rebound hammer is not available, then Windsor Probe Test can be used. Nine standard concrete cubes measuring 150x150x150mm were batched, mixed, cast and cured in water for each of the thirteen samples using water cement ratio of 0.57. Casting of four samples was repeated but this time using constant workability in two categories for comparison. The force required to crush concrete cube was read from the universal compressive testing machine in MPa.

For rebound hammer testing the procedure stipulated in ASTM C805 'Standard Test Method for Rebound Number of Hardened Concrete' was followed. For each concrete cube, at least ten readings were taken, with no two tests being closer to one another than one inch. Readings differing from the average of the ten readings by more than six units were discarded. Also, where two readings differed from the average by six units or more, the entire set of readings was discarded and ten new readings within the test area taken. Rebound number were read from the rebound hammer scale to enable computation of compressive strength for concrete samples in comparison with the compressive strength results obtained using the universal testing equipment.

3.3.8 Bond Strength Testing

For testing of the bond strength between steel reinforcement and concrete made from various sand samples, three standard concrete cubes measuring 150x150x150mm were cast from each sand sample and 12mm diameter twisted steel reinforcement bar placed at 75mm length of the bar from the top side of the concrete specimen. This gave a 75mm embedded length and 75mm concrete cover. Reinforcement support/holding mechanism was designed and fabricated to ensure that uniform reinforcement penetration distance was maintained for all samples. Pull out test was carried out at age of 28 days to determine the comparative force required to pull the reinforcement bar before failure as well as slip nature of reinforcement bar upon failure. Pull out force at failure was recorded and analyzed for comparison.

Concrete cubes made from clean sand as well as from sands sourced from various supply points in Nairobi and its environs, were tested using each of the above methods at the age of 7 days, 14 days and 28 days. For each sand sample and respective age, 3 samples were tested and mean value obtained. A total of 13 different sand samples comprising of 39 test specimens were tested. Thus in total 117 cubes and 39 pull out test specimen were cast. Pull out tests were done at age of 28 days only.

3.3.9 Data Analysis and Interpretation

Data on presence of silt and clay and organic contents in 27 sand samples were recorded and analyzed including ranking from the lowest to highest level of impurities. Results on particle shapes and texture was analyzed, categorized into classes having similar characteristics and presented in tables, graphs and charts. Data on specific gravity was analyzed and compared with parameters used in concrete mix design. Chemical analysis results were interpreted in regard to their effect on concrete performance.

Data was recorded and analyzed to compare the compressive strength and bond strengths obtained from various samples. Compressive strength results obtained for both constant and varying workability were categorized for comparison to assess the effect of silt and clay and organic impurities on samples having similar workability category, particle shapes and texture characteristic. Compressive strength obtained through the destructive test (universal testing machine) was analyzed and compared with the rebound number results. The allowable level of silt and clay content and organic impurities were determined beyond which concrete is likely to fail in strength.

Pull out force and bond strength results were analyzed and categorized based on their behavior and force applied. Type of pull out failures were observed and classified accordingly such as pull out, splitting or steel rapture failure and interpretations made in regard to concrete weakness observed. Data was presented and analyzed using tables, graphs and linear regression. The relationship between compressive and bond strength against varying levels of silt and clay content and organic impurities were generated as predictive regression equations. Two publishable scientific research papers were prepared, submitted and accepted for publication in international peer-reviewed journals.

CHAPTER 4: RESULTS AND DATA ANALYSIS

4.1 General Introduction

This chapter presents results from 27 sand samples subjected to preliminary tests such as sieve analysis, tests for silt and clay content, specific gravity test, organic impurities and particles shapes. It further presents data from concrete cube compressive tests using the universal compressive testing machine and rebound hammer as well as bond strength from pull out testing machine as detailed in the methodology section.

4.2 Preliminary Testing

Twenty seven sand samples sourced from eight sand supply points in Nairobi City County and its environs were subjected to preliminary testing before casting of concrete cubes for compressive and bond testing was done. These preliminary tests were;

a) Observations to determine particles shapes, texture and colour
b) Sieve analyses to determine degrees of finesses
c) Testing for silt and clay contents in sand samples
d) Testing for organic impurities in sand samples
e) Testing for specific gravity

4.2.1 Texture and Particle Shape Results

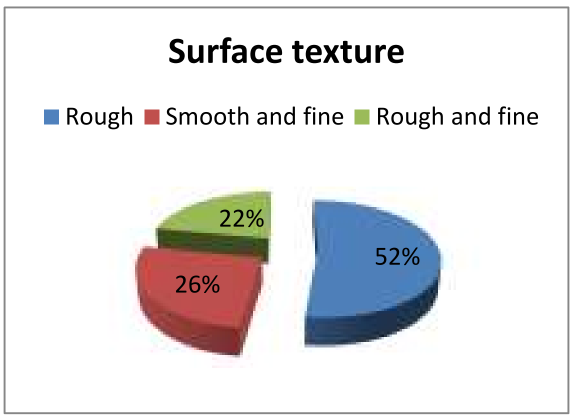
Twenty seven sand samples were subjected to texture and shape examination. 52% of the tested sand samples had rough texture compared to 26% that portrayed smooth and fine texture and 22% with rough and fine texture (see Tables 2, Table 3 and Figure 10 (a) below). 85% of the tested samples were observed to have irregular shaped particles while the rest had rounded shaped particles. During selection of samples for casting of concrete, care was taken to ensure that samples with each of these characteristic were included for comparison purposes. Particles with rough and angular surfaces bind more securely with cement paste and coarse aggregates compared to the smooth and round shaped particles. Reasonable effects on compressive strength are realized when the slump is widely varied. Angular particles are known to require more water to achieve similar workability compared with the smooth particles.

Table 2: Description of texture, shape and colour of sand particles

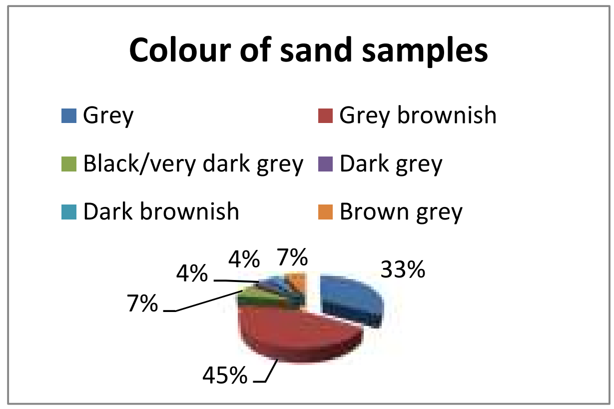
	Sample	Texture (rough or smooth and fine particles)	Shape (angular, rounded, irregular particle shapes)	Colour of sand samples
1	KT1	Rough	Irregular	Grey
2	KT2	Rough	Irregular	Grey
3	KT3	Rough	Irregular	Grey brownish
4	ML1	Smooth and fine	Irregular	Grey brownish
5	ML2	Rough	Irregular	Grey
6	ML3	Rough	Irregular	Grey brownish
7	ML4	Smooth and fine	Irregular	Grey brownish
8	KW1	Rough and fine	Irregular	Dark brownish
9	KW2	Rough and fine	Irregular	Grey
10	KW3	Rough	Irregular	Black/ very dark grey
11	DC1	Smooth and fine	Rounded	Grey
12	DC2	Smooth and fine	Rounded	Grey
13	DC3	Rough	Irregular	Grey brownish
14	DC4	Rough and fine	Irregular	Grey brownish
15	KB1	Rough and fine	Irregular	Grey brownish
16	KB2	Rough and fine	Irregular	Grey brownish
17	KB3	Smooth and fine	Rounded	Black/ very dark grey
18	NR1	Rough	Rounded	Brown grey
19	NR2	Smooth and fine	Irregular	Grey brownish
20	NR3	Rough and fine	Irregular	Grey brownish
21	NR4	Smooth and fine	Irregular	Brown grey
22	KBU1	Rough	Irregular	Black/ very dark grey
23	TK1	Rough	Irregular	Dark brown grey
24	TK2	Rough	Irregular	Grey brownish
25	TK3	Rough	Irregular	Grey
26	CL2	Rough	Irregular/ Angular	Grey
27	CL1	Rough	Irregular/ Angular	Grey

Table 3: Summary of shapes, texture, and colour of sand particles

Texture (number of samples and percentages)	Shape (number of samples and percentages)	Colour (number of samples and percentages)
Rough: 14; 52%	Irregular: 23; 85%	Grey: 9; 33%
Smooth and fine: 7; 26%	Rounded: 4; 15%	Grey brownish:12; 44%
Rough and fine: 6; 22%		Black/very dark grey: 2; 7%
		Dark grey: 1; 4%
		Dark brownish: 1; 4%
		Brown grey: 2; 7%



(a)



(b)

Figure 10: Texture e and colour of sand particles

Irregular and angular sand particles are common in river sands as a result of wave action and attrition forces in water. On the other hand, rounded particles are found in sand pits found on land where sand is mined.

Sand samples sourced from the eight supply points portrayed varied colours, ranging from black grey brownish to dark grey and brown grey as shown in Figure 11 below and in Tables 2 and 3 above. The dominant colours of sand samples were grey brownish (44%) and grey (33%).The two back samples were sourced from Mai Mahiu, a region characterized by volcanic eruption cooled magma.

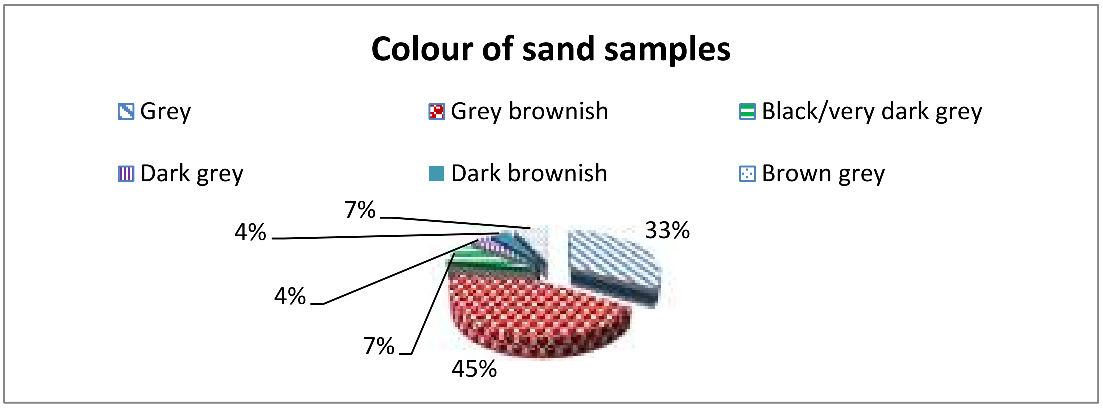


Figure 11: Colour of sand particles

4.2.2 Sieve Analysis Results

Detailed sieve analysis data is shown in Tables 4 and 5 and in Figures 12 below.

Table 4: Sieve analysis, degree of fineness and particles shape results for 27 sand samples

	Sieve size (mm)	10	5	2.36	1.2	0.6	0.3	0.15	0	Percentage of fines passing 600 microns	Grading Zone classification
	Sand Samples	Percentage passing the respective standard sieve size (%)									
1	ML1	99	98	97	93	60	27	2	0	60	III
2	ML4	100	96	92	73	36	9	1	0	36	II
3	KT3	100	96	93	81	51	10	1	0	51	II
4	KW1	100	100	99	97	86	59	5	0	86	IV
5	DC1	100	100	100	98	70	40	6	0	70	III
6	CL2	100	100	99	87	57	32	2	0	57	II
7	DC2	100	100	100	95	72	47	11	0	72	IV
8	TK1	100	97	94	81	54	32	3	0	54	II
9	KT1	100	99	96	82	53	31	3	0	53	II
10	KBU1	100	99	94	72	46	32	11	0	46	II
11	DC4	100	100	98	90	69	40	3	0	69	III
12	DC1	100	100	100	98	70	40	6	0	70	III
13	NR3	100	99	97	88	59	32	3	0	59	II
14	NR1	100	98	89	56	42	34	16	0	42	II
15	NR4	100	97	93	74	53	36	10	0	53	II
16	DC3	100	99	98	85	44	18	1	0	44	II
17	KW3	100	96	92	78	59	44	12	0	59	II
18	ML3	100	99	98	86	54	30	3	0	54	II
19	TK3	100	95	89	56	29	13	3	0	29	I
20	KW2	99	98	94	75	40	9	1	0	40	II
21	KB2	100	99	99	92	65	19	3	0	65	III
22	KB3	100	99	82	76	58	25	10	0	58	II
23	ML2	99	96	93	68	38	14	2	0	38	II
24	CL1	100	99	99	83	52	15	1	0	52	II
25	KT2	99	99	97	83	42	24	5	0	42	II
26	KB1	99	97	92	61	34	2	0	0	34	I
27	NR2	100	99	97	88	51	3	0	0	51	II

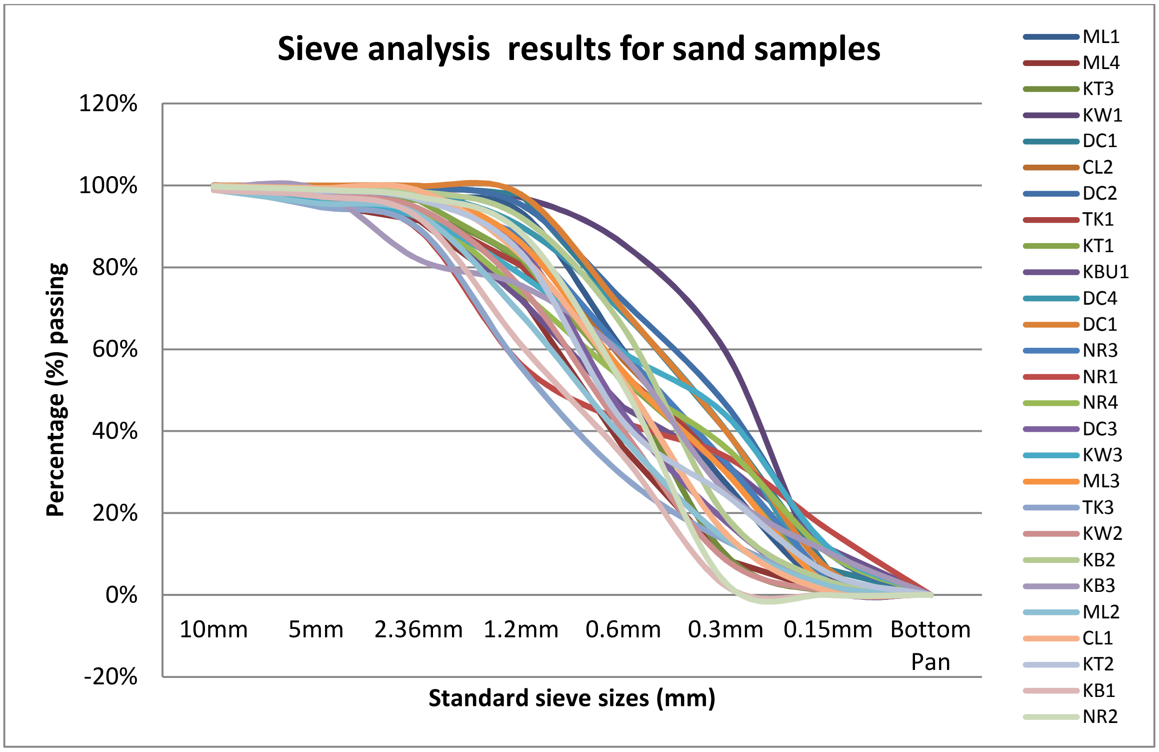


Figure 11: Grading curves for sand samples

Table 5: Summary of sieve analysis and geological grading zones classification

Grading Zones	Frequency (no)	Dominance (%)	Description
Zone I	2	7	Coarse sand
Zone II	18	67	Normal sand
Zone III	5	19	Fine sand
Zone III	2	7	Very fine sand

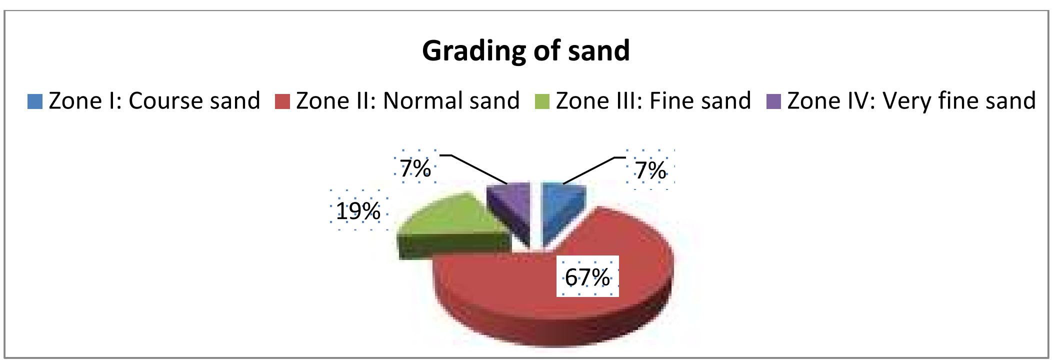


Figure 12: Zoning of sand samples based on fineness

Majority of sand samples (67%) were within Zone II of geological grading implying normal sand. A significant 7% of the tested samples comprised of very fine sand. Such fine grading requires proper mix design proportions to ensure that the quality of resulting concrete is not compromised. Sieve size 600 microns was used to determine degree of fineness in sands and soils. Results indicate that 26% or 7 out of 27 of the samples had over 60% of the samples passing sieve size 600 microns (see Table 4 and Figure 13). Comparatively, 66% or 18 out of 27 of the tested sand samples had over 50% of the samples passing the same sieve (see Table 4 and Figure 12).

4.2.3 Results on Silt and Clay Content, and Organic Impurities

4.2.2.1 Silt and Clay Content and Organic Impurities Results

Results on the varying levels of silt and clay contents and organic impurities in 27 samples sourced from Nairobi City County and its environs are shown in Table 6 below.

4.2.2.2. Silt and Clay Content in Sand

Based on the 27 sand samples tested, the maximum silt and clay content was 42% for NR1 sample compared with the minimum 3.3% for TK1 sand sample (see Table 6 and Figure 14).

Table 6: Results on silt and clay content and organic impurities in sand

S/No.	Name of sand supply point	Sample No.	Silt and clay content (%)	Organic impurities colour	Source of sand samples (as indicated by suppliers)
1	Kitengela	KT1	13.5	0.168	Machakos
3	Kitengela	KT3	6.7	0.327	Kajiado
4	Mlolongo	ML1	15.1	0.193	Kajiado
5	Mlolongo	ML2	7.0	0.029	Makueni
6	Mlolongo	ML3	7.2	0.080	Kitui
7	Mlolongo	ML4	4.8	0.106	Machakos
8	Kawangware	KW1	8.8	0.238	Kajiado
9	Kawangware	KW2	9.4	0.093	Machakos
10	Kawangware	KW3	13.1	0.244	Kajiado
11	Dagoretti Corner	DC1	18.9	0.415	Mai Mahiu
12	Dagoretti Corner	DC2	16.1	0.738	Matuu
13	Dagoretti Corner	DC3	4.9	0.208	Kitui
14	Dagoretti Corner	DC4	15.8	0.147	Kajiado
15	Kariobangi	KB1	17.6	0.215	Embu
16	Kariobangi	KB2	8.2	0.202	Machakos
17	Kariobangi	KB3	17.0	0.513	Kajiado
18	Njiru	NR1	42.8	0.594	Mai Mahiu
19	Njiru	NR2	16.2	0.522	Kangundo
20	Njiru	NR3	6.8	0.166	Kangundo
21	Njiru	NR4	19.6	0.418	Kajiado
22	Kiambu	KBU1	12.8	0.361	Kitui
23	Thika	TK1	3.3	0.614	Mai Mahiu
24	Thika	TK2	9.2	0.416	Kitui
25	Thika	TK3	3.4	0.619	Matuu
26	Clean control sample CL1	CL1	0.7	0.205	Machakos
27	Clean control sample CL2	CL2	0.3	0.023	Machakos

CL1 and CL2 were clean control river sand samples that were washed using clean water and sun dried. They had 0.7% and 0.3% silt and clay contents respectively after washing. CL2 was used in casting of concrete cubes because it had the lowest level of silt and clay impurities, and organic impurities hence selected to be the control sample.

BS 882 (1989) and IS (1970) recommends fine aggregates be used in concrete production should contain no more than a maximum of 4% silt and clay content as shown in Figure 14. Only 4 samples out of 27 samples met this limit, representing only 15%. An overwhelming 85% failed to meet the standard set in BS 882. Comparatively, the ASTM C117 (1995) allows 10% by weight of silt and clay content in sand used for concrete production also as shown in Figure 13. 15 samples met this limit, implying a failure rate of 44% of the tested sand samples by ASTM's standard.

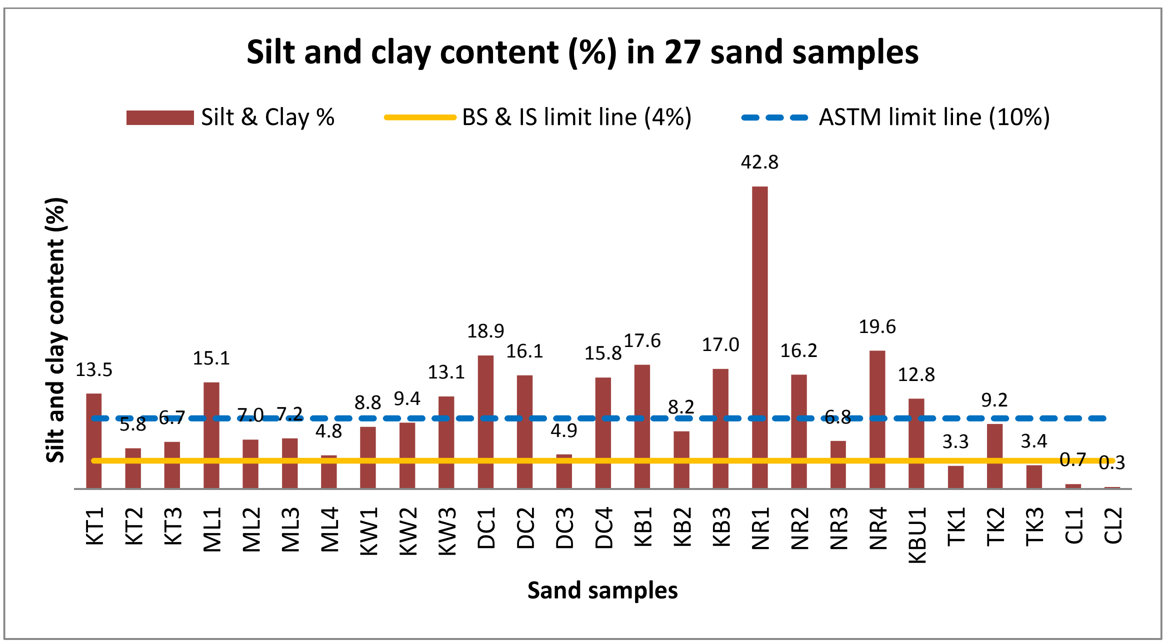


Figure 13: Silt and clay content in sand

From Figure 13 above, the maximum silt and clay content registered was a significant 42%. This implies that for one tonne of sand, 420kg is composed of silt and clay impurities. Therefore when such sand is bought for construction, value for money is not achieved since over half of the sand quantity comprises of silt and clay impurities.

4.2.2.3 Organic Impurities in Sand

With regard to testing for organic impurities in sand, standard requires that the color of sodium hydroxide solution in sand should be lighter than the solution of sodium hydroxide mixed with tannic acid, both solutions having been preserved for 24 hours after mixing as detailed in ASTM C40 (2004) and IS (1970). Table 7 show results from organic impurities tests.

Out of the 27 sand samples tested, only 6 samples indicated lighter color than the standard solution 24 hours after mixing. This indicates that 22% of the collected samples were within the organic content limit as set in ASTM C40 (2004), indicating a failure rate of 78%.

Table 7: Results on sand impurities in ranked order

(a) Results on organic impurities tests

S/No.	Sample ref. No.	Colour of standard solution after 24 hrs	Comparison with standard solution	Colour classification (ranked from smallest to largest)
	Standard solution	Light golden	Same	0.000
1	Cl 2	Clear	Lighter	0.023
2	ML2	Slightly lighter	Lighter	0.029
3	KT2	Slightly dark lighter	Lighter	0.048
4	ML3	Slightly dark darker	Darker	0.080
5	KW2	Slightly darker	Lighter	0.093
6	ML4	Slightly dark darker	Darker	0.106
7	DC4	Medium dark brown	Darker	0.147
8	NR3	Slightly darker	Darker	0.166
9	KT1	Slightly dark darker	Darker	0.168
10	ML1	Medium dark	Darker	0.193
11	KB2	Medium dark brown	Lighter	0.202
12	CL 1	Light yellow	Lighter	0.205
13	DC3	Slightly darker	Darker	0.208
14	KB1	Medium dark brown	Darker	0.215
15	KW1	Slightly darker	Darker	0.238
16	KW3	Medium dark	Darker	0.244
17	KT3	Slightly dark lighter	Darker	0.327
18	KBU1	Medium dark brown	Darker	0.361
19	DC1	Very dark brown	Darker	0.415
20	TK2	Medium dark brown	Darker	0.416
21	NR4	Dark	Darker	0.418
22	KB3	Light brown yellow	Darker	0.513
23	NR2	Medium dark brown	Darker	0.522
24	NR1	Medium dark brown	Darker	0.594
25	TK1	Very dark	Darker	0.614
26	DC2	Very dark brown	Darker	0.738
27	TK3	Medium dark brown	Darker	0.619

(b) Results on silt and clay content

S/No.	Sample	Silt and clay content (%) (ranked from smallest to largest)
1	CL2	0.3
2	CL1	0.7
3	TK1	3.3
4	TK3	3.4
5	ML4	4.8
6	DC3	4.9
7	KT2	5.8
8	KT3	6.7
9	NR3	6.8
10	ML2	7.0
11	ML3	7.2
12	KB2	8.2
13	KW1	8.8
14	TK2	9.2
15	KW2	9.4
16	KBU1	12.8
17	KW3	13.1
18	KT1	13.5
19	ML1	15.1
20	DC4	15.8
21	DC2	16.1
22	NR2	16.2
23	KB3	17.0
24	KB1	17.6
25	DC1	18.9
26	NR4	19.6
27	NR1	42.8

Further, color analysis was carried out using photometric equipment and results are shown in Figure 14 below. It was found that the maximum value of photometric resistance for clean sample was 0.205 ohms for CL1. CL2 recorded the lowest color resistance of 0.023 ohms indicating the lowest level of organic impurities. Consequently assuming 0.205 ohms for the washed sand sample to be the upper limit for the level of organic impurities, only 13 samples indicated value of less than 0.205. This implies over 50% of the sand samples exceeded the maximum organic content for the washed control sample.

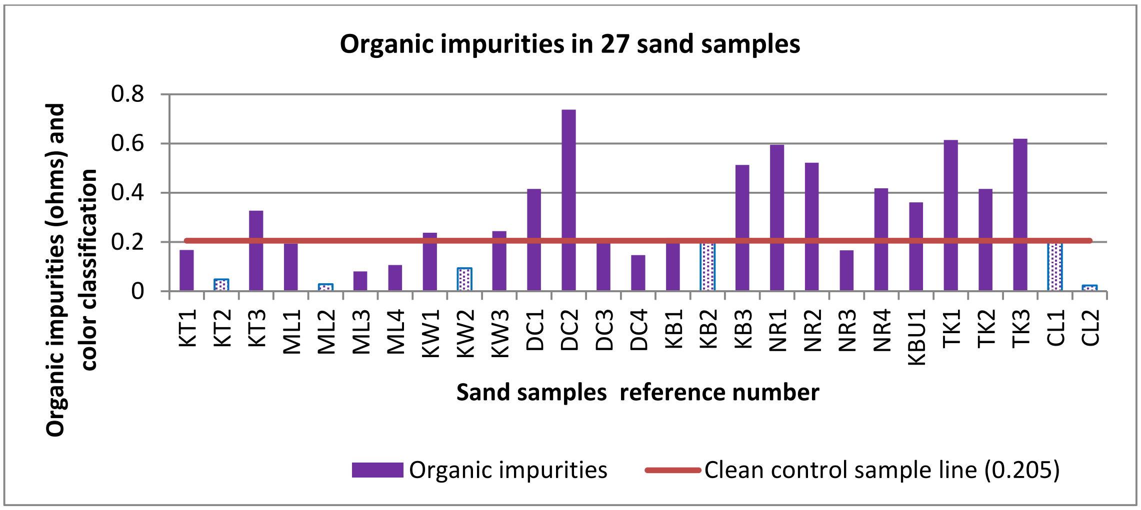


Figure 14: Organic impurities in 27 sand samples

4.2.4 Specific Gravity of Sand Samples

Sand samples were subjected to specific gravity tests as detailed in IS (1970) equivalent to ASTM D854 (2014) for aggregates less than 10mm diameter using the pycnometer glass vessel. Results showed that the average apparent specific gravity was 2.7 while the average water absorption of dry mass was 2.9 as shown in Table 8 below. This compares well with the expected specific gravity values of 2.6 for sand used in concrete production (,Arulraj and Rajam, 2013) implying that the sand used in this research represent the commonly used normal sand used in concrete making. This indicates that the sand samples used were within the normal range for building sand.

Bulk specific gravity is used for calculation of the volume occupied by the aggregate in various mixtures such as concrete. Apparent specific gravity pertains to the relative density of the sand making up the constituent particles not including the pore space within the particles that is accessible to water. Bulk density varied from 2.54 to 2.81 for TK2 and KT3 respectively. This explain why the slump observed and water absorption by pores was specific to a particular sand sample based on mode of sample formation e.g. river sand and pit sand.

Table 8: Results on specific gravity of sand samples

	Source of sand samples	Sample No.	Weight of dry sample (g)	Weight of saturated and surface dry sample (g) C	Weight of bottle + sample + water (g) A	Weight of bottle + water (g) B	Weight of oven dried sample (g) D	Specific gravity (oven dried) $\frac{D}{(C-(A-B))}$	Specific gravity (saturated and surface dry) $\frac{C}{(C-(A-B))}$	Apparent specific gravity $\frac{D}{(D-(A-B))}$	Water absorption of dry mass (%) $\frac{(C-D)}{D} \cdot 100$	Source of sand sample (as per supplier)
1	Kitengela	KT1	500	484	1696.5	1390.5	477.5	2.68	2.72	2.78	1.36	Machakos
2	Kitengela	KT2	500	475	1677.5	1390.5	469	2.49	2.53	2.58	1.28	Kajiado
3	Kitengela	KT3	500	477	1687.5	1395.5	469	2.54	2.58	2.65	1.71	Kajiado
4	Mlolongo	ML1	500	418.5	1665	1390.5	417.8	2.90	2.91	2.92	0.17	Makueni
5	Mlolongo	ML2	500	486	1717.5	1414.5	481.1	2.63	2.66	2.70	1.02	Kitui
6	Mlolongo	ML3	500	462.5	1678	1380.5	481.1	2.92	2.80	2.62	-3.87	Machakos
7	Mlolongo	ML4	500	471.5	1684.5	1390.5	457.5	2.58	2.66	2.80	3.06	Kajiado
8	Kawangware	KW1	500	452.5	1692	1392	469	3.08	2.97	2.78	-3.52	Machakos
9	Kawangware	KW2	500	449.5	1671.5	1392	443.5	2.61	2.64	2.70	1.35	Kajiado
10	Kawangware	KW3	500	452	1667	1392	429	2.42	2.55	2.79	5.36	Mai Mahiu
11	Dagoretti Corner	DC1	500	497	1664	1414.5	397.5	1.61	2.01	2.69	25.03	Matuu
12	Dagoretti Corner	DC2	500	432.6	1673	1392	429	2.83	2.85	2.90	0.84	Kitui
13	Dagoretti Corner	DC3	500	457.5	1690	1390.5	454.5	2.88	2.90	2.93	0.66	Kajiado
14	Dagoretti Corner	DC4	500	420.5	1664	1390.5	410	2.79	2.86	3.00	2.56	Embu
15	Kariobangi	KB1	500	416.5	1660	1390.5	407	2.77	2.83	2.96	2.33	Machakos
16	Kariobangi	KB2	500	459.5	1697.5	1414.5	452.5	2.56	2.60	2.67	1.55	Kajiado
17	Kariobangi	KB3	500	435.5	1637.5	1392	407	2.14	2.29	2.52	7.00	Mai Mahiu
18	Njiru	NR1	500	329	1601	1392	324.5	2.70	2.74	2.81	1.39	Kangundo
19	Njiru	NR2	500	475.5	1657	1392	415	1.97	2.26	2.77	14.58	Kangundo
20	Njiru	NR3	500	462.5	1701.5	1414.5	457.5	2.61	2.64	2.68	1.09	Kajiado
21	Njiru	NR4	500	402	1641.5	1392	397	2.60	2.64	2.69	1.26	Kitui
22	Kiambu	KBU1	500	462.5	1658.5	1392	435	2.22	2.36	2.58	6.32	Mai Mahiu
23	Thika	TK1	500	433	1655	1392	428	2.52	2.55	2.59	1.17	Kitui
24	Thika	TK2	500	457.5	1682.5	1390.5	450.5	2.72	2.76	2.84	1.55	Matuu
25	Thika	TK3	500	482.5	1703	1390.5	478.5	2.81	2.84	2.88	0.84	Machakos
26	Control Clean Sample	CL1	500	496	1700.5	1390.5	490.5	2.6	2.7	2.7	1.1	Kitui
27	Control clean sample	CL2	500	503.5	1699	1390.5	495	2.5	2.6	2.7	1.7	Kitui
	Overall Average							**2.6**	**2.6**	**2.7**	**2.9**	

4.2.5 Chemical Analysis Using TXRF and LDPSA Methods

Chemical analysis was carried out using TXRF and LDPSA methods in the ICRAF soil diagnostic laboratory and the results are shown in Appendix 2. It was observed that the significant elements in building sand included Na, Al, CL, K, Ti, Mn, Fe and Pb while minimum elements included Mg, P, S, Sc, Co and Ni.

Silica comprising of silicon dioxide (SiO_2) commonly known as quartz is the dominant element found in sand. Its chemical inertness, considerable hardness and mineral resistant to weathering make it suitable for construction work. Chloride is responsible for corrosion of steel in reinforced concrete exposed to moisture hence should be avoided in sand for concrete production. All the samples indicated presence of silicon in sand.

The limits stipulated in BS 882 (1992) on the chloride ion content by mass is 0.05, expressed as a percentage of the mass of the combined aggregate for concrete containing embedded metal with other cement (Dolage et al, 2013). KW3 and KB3 and KBU1 recorded very high chloride content.

4.2.6 Combination of Silt and Clay Content and Organic Impurities for Selection of Test Samples

Based on the results for levels of impurities obtained for the 27 sand samples, 13 samples with varying level of impurities were selected for casting of concrete cubes to enable compressive strength testing. To ensure even distribution of sand samples of various levels of impurities in the final set of samples selected for casting, samples were categorized under classes of pre-set ranges of levels of impurities starting with the lowest interval of 5%. Results of silt and clay content gave the classes 1-5%, 5-10%,-10-15%, 15-20% and 20-50% , while organic impurities were categorized into classes of 0.2-0.3 ohms, 0.3-0.4 ohms, 0.4-0.5 ohms, 0.5-0.6 ohms, 0.6-0.7 ohms, and 0.7-0.8 ohms. In the selection process for the final list of samples, a minimum of 30% of the samples falling in each class was chosen to ensure fair representation from each class for silt and clay content as well as organic impurities levels. Where 30% of any class was not achieved, the process entailed replacement of the sand sample until this representation was achieved as shown in Table 10 and Table 11. From the results obtained from 27 samples within the range of above classes and 13 samples selected were selected for casting of concrete cubes which was good representatives of the 27 samples collected as shown in Figure 16 below. The selected 13 samples were used for both compressive and bond strength testing.

Table 9: Selection based on silt and clay content is sand

S/No.	Sample No.	Percentage silt and clay content (%)	Source of sand sample (as per supplier)	Selected for cube tests	S/No.	Range (ohms)	No. in the range	% tested per class
1	TK1	3.3	Kitui	Yes	1	0-5	5	60
2	TK3	3.4	Machakos					
3	ML4	4.8	Kajiado	Yes	2	0-5		
4	DC3	4.9	Kajiado					
5	KT2	5.8	Kajiado				9	33
6	KT3	6.7	Kajiado					
7	NR3	6.8	Kajiado					
8	ML2	7.0	Kitui	Yes	3	5-10		
9	ML3	7.2	Machakos					
10	KB2	8.2	Kajiado	Yes	3	5-10		
11	KW1	8.8	Machakos	Yes	4	5-10		
12	TK2	9.2	Matuu					
13	KW2	9.4	Kajiado					
14	KBU1	12.8	Mai Mahiu	Yes	5	10-15	3	67
15	KW3	13.1	Mai Mahiu					
16	KT1	13.5	Machakos	Yes	6	10-15		
17	ML1	15.1	Makueni	Yes	7	15-20	8	50
18	DC4	15.8	Embu	Yes	8	15-20		
19	DC2	16.1	Kitui	Yes	9	15-20		
20	NR2	16.2	Kangundo					
21	KB3	17.0	Mai Mahiu	Yes	10	15-20		
22	KB1	17.6	Machakos					
23	DC1	18.9	Matuu	Yes	11	15-20		
24	NR4	19.6	Kitui					
25	NR1	42.8	Kangundo	yes	12	20-50	1	100
26	Clean sample CL2	0.003	Ukambani	Yes	13			
27	Clean sample CL1	0.7	Ukambani					

Table 10: Selection based on organic impurities in sand

S/No.	Sample No.	Colour of standard solution after 24 hrs	Comparison with standard solution	Colour classification (ohms)	Selected	Range	No. in the range	% tested
1	DW	Light golden	Same	0.000				
2	Cl 2	Clear	Lighter	0.023	Yes	0.0 - 0.1	5	40
3	ML2	Slightly lighter	Lighter	0.029	Yes			
4	KT2	Slightly lighter	Lighter	0.048				
5	ML3	Slightly darker	Darker	0.080				
6	KW2	Slightly darker	Lighter	0.093				
7	ML4	Slightly darker	Darker	0.106	Yes	0.1 - 0.2	5	60
8	DC4	Medium dark brown	Darker	0.147	Yes			
9	NR3	Slightly darker	Darker	0.166				
10	KT1	Slightly darker	Darker	0.168	Yes			
11	ML1	Medium dark	Darker	0.193				
12	KB2	Medium dark brown	Lighter	0.202	Yes	0.2-0.3	6	40
13	CL 1	Light yellow	Lighter	0.2050				
14	DC3	Slightly darker	Darker	0.208				
15	KB1	Medium dark brown	Darker	0.215				
16	KW1	Slightly darker	Darker	0.238				
17	KW3	Medium dark	Darker	0.244	Yes			
18	KT3	Slightly lighter	Darker	0.327		0.2-0.3	2	67
19	KBU1	Medium dark brown	Darker	0.361	Yes			
20	DC1	Very dark brown	Darker	0.415	Yes	0.4-0.5	3	67%
21	TK2	Medium dark brown		0.416				
22	NR4	Dark	Darker	0.418				
23	KB3	Light brown yellow	Darker	0.513	Yes	0.5-0.6	3	67
24	NR2	Medium dark brown	Darker	0.522				
25	NR1	Medium dark brown	Darker	0.594	Yes			
26	TK1	Very dark	Darker	0.614		0.6-0.7	1	100
27	DC2	Very dark brown	Darker	0.738	Yes	0.7-08	1	100

The characteristic of the sand samples selected for casting of concrete is as shown in Table 11 and Figure 15 below. Four samples had round shaped particles while four samples had smooth surface. The rest had irregular shaped particles and rough surface texture. Concrete was cast to assess the behavior of sand having these characteristics.

Table 11: Characteristics of 13 samples selected

	Sand sample ref	Source	Silt and clay content (%)	Organic impurities (ohms)	Particle shapes	Surface texture
1	ML4	Kajiado	4.8	0.106	Rounded	Smooth
2	DC1	Matuu	18.9	0.415	Rounded	Smooth
3	KB3	Mai Mahiu	17.0	0.513	Rounded	Smooth
4	DC2	Kitui	16.1	0.738	Irregular	Smooth
5	NR1	Kangundo	42.8	0.594	Rounded	Rough
6	KT1	Machakos	13.5	0.168	Irregular	Rough
7	TK1	Kitui	3.3	0.614	Irregular	Rough
8	KB2	Kajiado	8.2	0.202	Irregular	Rough
9	KW1	Machakos	8.8	0.238	Irregular	Rough
10	DC4	Embu	15.8	0.147	Irregular	Rough
11	KBU1	Mai Mahiu	12.8	0.361	Irregular	Rough
12	ML2	Kitui	7.0	0.029	Irregular	Rough
13	CL2	Kitui	0.3	0.023	Irregular	Rough

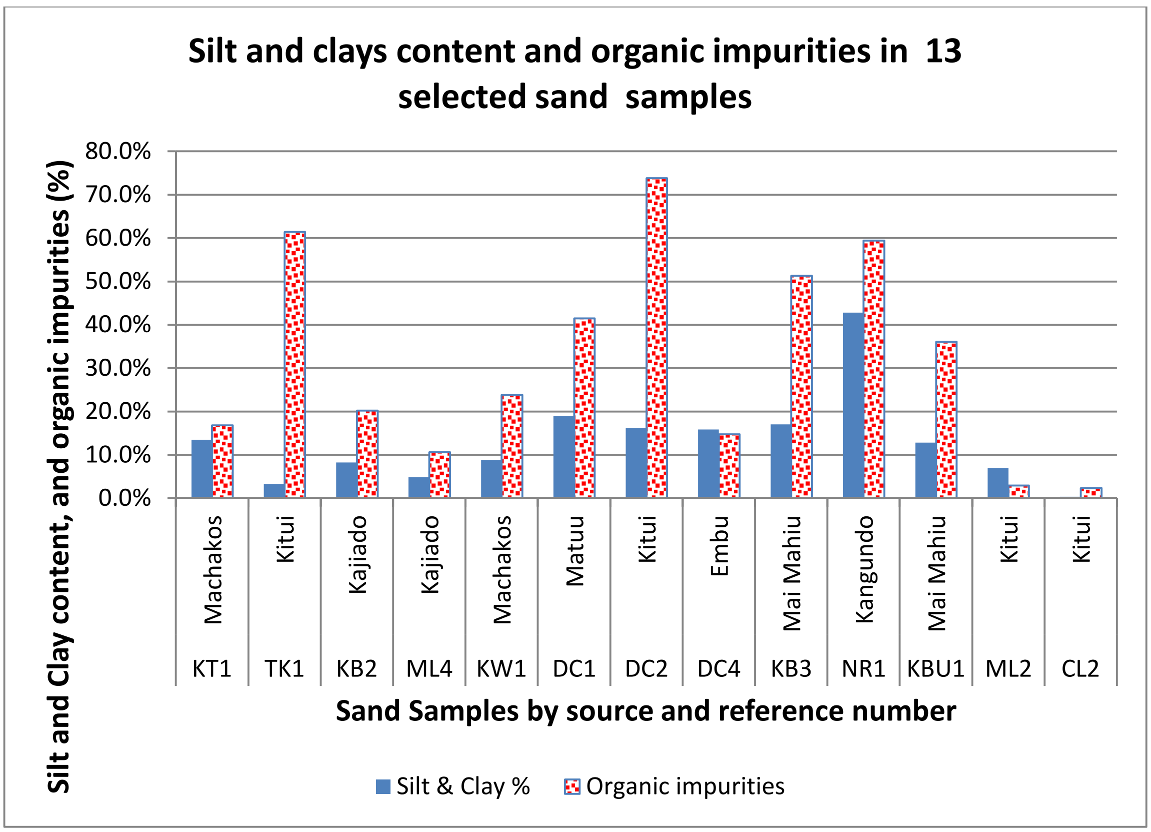


Figure 15: Organic impurities, and silt and clay content in 13 selected sand samples

4.3 Compressive Strength Test Results

4.3.1 A Case of Constant Slump

In order the assess the effect of workability on the compressive strength of concrete made from selected sand samples having varying level of silt and clay and inorganic impurities, 4 sand samples were cast while maintaining workability constant. A set of concrete cubes was cast while maintaining workability to be within Very Low (0-25mm) category as shown by KBU1 (a), DC 2(a), CL2 (a) and DC4 (a) . A second set was made from the same sand samples was cast using a constant workability of Medium (50-100mm) category as shown by KBU1 (b), DC 2(b), CL2 (b) and DC4 (b). The results are presented in Table 12 and Figure 14 below.

Table 12: Compressive strength for selected samples with constant workability

Sample	Silt and clay content (%)	Organic Impurities (ohms)	Day 7 strength (N/mm^2)	Day 14 strength (N/mm^2)	Day 28 strength (N/mm^2)	% deviation from expected	Slump (using cone)	Workability classification	Source
KBU1(a)	12.8	0.361	22.45	32.13	37.45	49.8	9mm	Very low	Mai Mahiu
KBU1(b)	12.8	0.361	12.93	16.55	20.73	-17.1	86mm	Medium	Mai Mahiu
DC2 (a)	16.1	0.738	19.98	25.05	26.98	7.9	11mm	Very low	Kitui
DC2 (b)	16.1	0.738	16.19	19.35	24.05	-3.8	69mm	Medium	Kitui
CL2 (c)	0.3	0.023	24.23	26.95	31.86	27.4	13.5mm	Very low	Kitui
CL2 (c)	0.3	0.023	16.05	19.20	24.68	-1.3	58mm	Medium	Kitui
DC4 (d)	15.8	0.147	19.02	25.52	28.93	15.7	10mm	Very low	Embu
DC4 (d)	15.8	0.147	12.40	16.20	19.62	-21.5	65mm	Medium	Embu

It is clear from the results above that workability plays a significant role in determination of compressive strength of concrete. By varying slump from very low (0-25mm) to medium (50-100mm), it was observed that compressive strength reduced by a margin of between $17N/mm^2$ for KBU1 to $2N/mm^2$ for DC2. This is a reduction in the expected strength ($25N/mm^2$) by a significant margin of -17.1%.

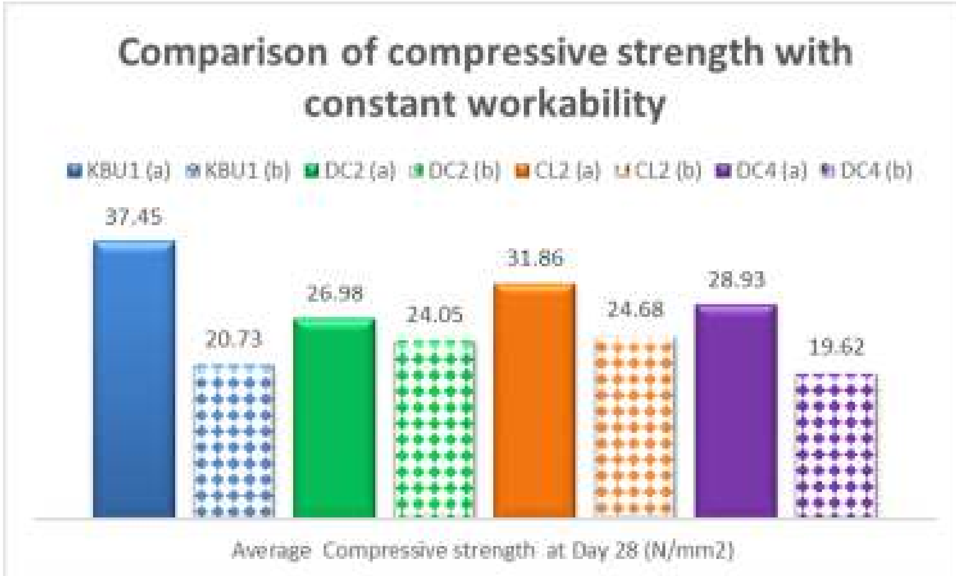


Figure 16: Compressive strength testing with constant workability

At very low slump, KBU1 depicted the highest compressive strength of 37.45 N/mm^2 compared with DC2 that registered the lowest compressive strength of 20.73 $N/mm^{2.}$ On the other hand, at medium slump CL2 registered the highest compressive strength (24.68N/mm^2) while DC4 registered the lowest strength (19.62N/mm^2). Comparatively DC2 had the minimum strength effects (2.9N/mm^2) with changes in the slump level while KBU1 had the largest effect (16.7N/mm^2) on compressive strength with changes in slump level. This implies that DC2 is a better sand sample since significant savings on water can be made during casting without significant changes in compressive strength. Its deviation in compressive strength is a minimum 7.9% (that is (3.85N/mm^2) from the expected strength of 25N/mm^2. It is observed that workability plays key role on the compressive strength of concrete.

KBU1 had rough and irregular shaped particles while DC2 had smooth and sand rounded particles. DC4 had rough and fine particles that were irregular in shape while CL2 had irregular shaped rough particles. This implies that effect of workability on the compressive strength of concrete is more pronounced in rough and irregular shaped sand particles in comparison with rounded and smooth sand particles.

4.3.2 A Case of Constant Water Cement Ratio

The 13 samples selected above were used for cube compressive strength testing according to ASTM C39 (1990) and BS 1881 (1983) using a universal testing machine. A constant water cement ratio of 0.57 was used for all concrete the samples cast. For each sand sample, a total of 9 cubes were cast and cured under water at room temperature. Three concrete cubes made from each sand sample were tested at the age of 7 days, 14 days and 28 days after casting using a universal testing machine. The average was obtained from 3 cubes tested and results are as shown in Table 13 and Figure 17 below. The expected compressive strength at day 7 (E7DS), day 14 (E14DS) and day 28(E28DS) are also shown. Based on their slump level while using a constant water cement ratio of 0.57, the samples were further categorized into 4 groups as shown ikn the table below.

Table 13: Compressive strength of concrete cubes

	Sample Ref No.	7-day Strength (N/mm^2)	14 day strength (N/mm^2)	28 day strength (N/mm^2)	Deviation of 28 day strength from expected	Deviation (%)	Slump (mm)
	Group 1 based on very low slump level						
1	NR1	15.667	22.042	24.937	-0.06	-0.3	3
2	KW1	20.549	21.110	24.955	-0.05	-0.2	4
3	KB3	19.977	26.102	30.393	5.39	21.6	5
	Group 2 based on low slump level						
4	KBU1	22.450	32.130	37.455	12.46	49.8	9
5	DC2	19.982	25.051	26.979	1.98	7.9	11
6	DC4	19.021	25.523	28.929	3.93	15.7	10
7	CL2	24.231	26.953	31.858	6.86	27.4	13.5
	Group 3 based on medium slump level						
8	TK1	18.173	20.329	25.679	0.68	2.7	34
9	DC1	19.008	22.218	27.188	2.19	8.8	52
10	ML4	16.057	18.998	21.552	-3.45	-13.8	56
	Group 4 based on high slump level						
11	KB2	16.696	20.641	24.403	-0.60	-2.4	79
12	KT1	17.458	21.137	24.537	-0.46	-1.9	93
13	ML2	18.551	22.416	27.177	2.18	8.7	115
	Analysis						
Expected strength (E7DS, E14DS and E28DS) for Class 25 concrete (Mix 1:1.5:3)		16.75	20	25			
Samples below expected strength 25KNmm2		NR1, ML4 and KB2	ML4	NR1, KW1, KT1,ML4, KB2			
Thus 5 samples failed at 28 days strength (38%).							

It is important to note that a uniform mix design used for most low rise structural buildings was adopted, that is 1:1.5:3: 0.57: for cement: fine aggregates: coarse aggregates: water. For KBU1 sample, the slump was zero (too stiff, extremely low) hence water: cement ratio adjusted to 0.58 hence slump of 9mm was obtained. KBU1 was made from volcanic pit sands and it was observed that it requires more water during mixing to achieve medium to low workability levels. It was noted that this sample requires more water to achieve normal workability and had irregular shaped and rough texture.

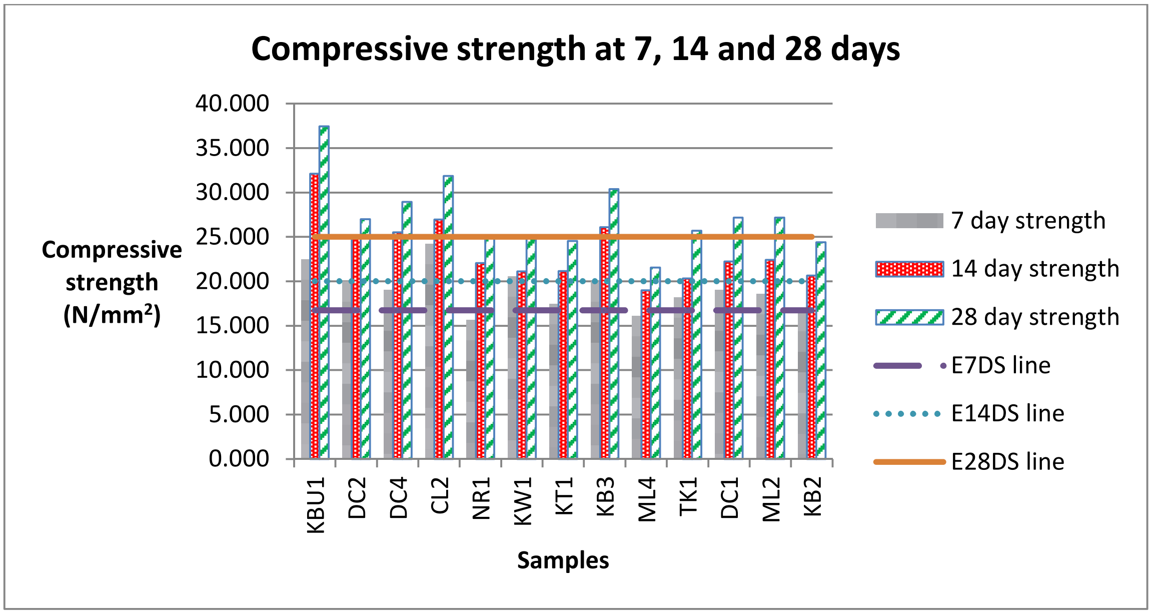


Figure 17: Results from concrete cube compressive strength testing

From the above results, three samples (that is NR1, ML4 and KB2) failed to meet the minimum strength expected at day 7, one sample (ML4) failed at day 14 and 5 samples (NR1, KW1, KT1, ML4, KB2) failed to meet the compressive strength expected at day 28. This represents 38% failure rate at 28 days. The maximum reduction in strength from the expected 25N/mm^2 at 28 days is 13.8% for ML4. Since all the samples were subjected to similar casting and curing conditions, this failure is largely attributed to the presence of silt and clay content and organic impurities in sand and to some extent to particles shapes, sizes and texture. It was observed that all the samples that failed at day 7 and day 14 also failed at day 28. However not all samples that failed at day 28 had indicated failure at day 7 and day 14. These include KW1 and KT1 that had passed the strength requirement at day 7 and 14 but failed at day 28. This affirms the importance of concrete strength testing up to 28 days maturity.

Generally, samples with low slump level recorded low compressive strength. Although ML2 had very high workability as indicated by 115mm high slump, it recorded high compressive strength. This implies that ML2 is comparatively a good sample since the expected compressive strength was surpassed at the age of 7, 14 and 28 days even with high workability. Although ML4, KB2 and KT1 failed to meet the expected strength at 28 days, it is expected that at workability level (say group 2), the samples may met the expected strength.

Table 14: Characteristics of samples that failed under compressive

	Sample	Strength at 28 days (MPa)	Silt and clay content (%)	Organic impurities (photometric ohms)	Workability (mm)	Source of sand (as per suppliers)	Particle texture and shape
1	NR1	24.937	42.8	0.594	3	Kangundo	Rough, Smooth
2	KW1	24.955	8.8	0.238	4	Machakos	Rough & fine, Irregular
3	ML4	21.552	4.8	0.106	56	Kajiado	Smooth & fine, Irregular
4	KB2	24.403	8.2	0.202	79	Kajiado	Rough & fine, Irregular
5	KT1	24.537	13.5	0.168	93	Machakos	Rough, Irregular

Table 14 above shows the characteristics of samples that failed to meet the expected strength. The slump level varied from 3mm to 93mm when using a constant water cement ratio of 0.57. Since NR1 and KW1 failed when using stiff workability, it implies that at higher slump, samples NR1 and KW1 would yield very low strength. Therefore NR1 and KW1 are not good for concrete production since they failed even at stiff workability (low slump). It is further deduced that the lowest level of impurities is 4.8% while the lowest level for organic impurities was 0.106 ohms photometric color classification. It can be taken that any sample having of 4.8% silt and clay content and 0.106 ohms for organic impurities or more is likely to fail. Two (ML4 and NR1) out of the five samples that failed on compressive strength testing had smooth particles implying that particles sizes play some role in concrete compressive strength. It is noted that 3 (KB2, KT1 and KW1) of the failed samples that portrayed rough and irregular particles had higher silt and clay content of more than 8%.

Smooth and round sand surfaces provide a weak interlocking bond between cement and coarse aggregates thus contributing to reduced compressive strength of concrete. Since 3 out of 5 samples that failed to meet the expected compressive strength at day 28 had rough texture and irregular shape particles, it implies that besides silt and clay and organic impurities in sand, particle sizes and shapes form a significant factor in determination of compressive strength of concrete.

4.3.3 Cube's Compressive Strength Using Rebound Hammer

The rebound hammer test was carried out as described in ASTM C805 (2013), EN12504-2 (2012) and in BS 1881: part 202 (1983). At least 15 rebound hammer readings were taken per concrete cube and care was taken to ensure that that the distance from one reading to another was not less than 1 inch apart on the cube. Where the rebound number exceeded the average of at least 10 reads by 6 units or more, then such reading was discarded and the test repeated. Where two readings differed from the average by six units or more, then the entire set of readings was discarded and new readings taken within the test area. The standard recommends generation of a correlation curve for conversion of the rebound number into the compressive strength of concrete. The relation between rebound number and compressive strength of concrete obtained using the universal testing machine (destructive method) is illustrated in Figure below.

$$y = 2.9552x1 - 24.734 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{(4)}$$

Where y= compressive strength of concrete at 28 days

x = rebound hammer number

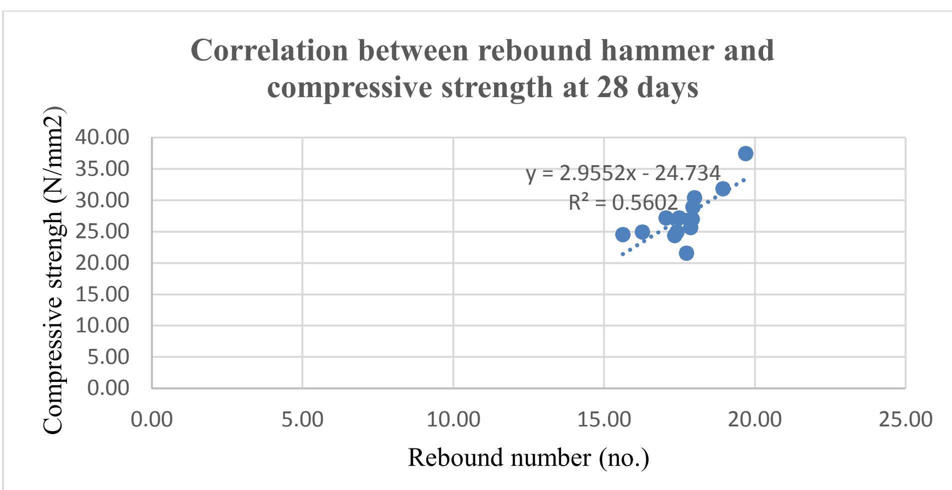


Figure 18: Relationship between rebound numbers against compressive strength

The above equation was applied to compute the compressive strength values for concrete cubes tested at day 7, day 14 and day 28 as shown in the table below.

Table 15: Comparison of cube compressive strength using DT and NDT method

		7 days results			14 days results			28 days results		
	Sample	R	NDT cube strength (N/mm^2)	DT strength (N/mm^2)	R	NDT cube strength (N/mm^2)	DT cube strength (N/mm^2)	R	NDT cube strength (N/mm^2)	DT cube strength (N/mm^2)
1	KBU1	18.73	30.63	22.45	19.15	31.86	32.13	19.69	33.46	37.45
2	DC2	16.77	24.83	19.98	16.90	25.22	25.05	17.92	28.22	26.98
3	DC4	15.73	21.76	19.02	17.70	27.57	25.52	17.95	28.31	28.93
4	CL2	18.06	28.63	24.23	18.42	29.69	26.95	18.94	31.24	31.86
5	NR1	14.55	18.26	15.67	15.44	20.89	22.04	16.27	23.33	24.94
6	KW1	15.21	20.22	20.55	16.90	25.20	21.11	17.41	26.72	24.96
7	KT1	14.13	17.02	17.46	15.12	19.96	21.14	15.62	21.42	24.54
8	KB3	15.42	20.85	19.98	16.02	22.61	26.10	18.00	28.45	30.39
9	ML4	13.76	15.92	16.06	16.68	24.56	19.00	17.73	27.67	21.55
10	TK1	14.56	18.29	18.17	16.27	23.35	20.33	17.87	28.09	25.68
11	DC1	13.91	16.38	19.01	16.06	22.73	22.22	17.49	26.96	27.19
12	ML2	14.08	16.87	18.55	16.80	24.91	22.42	17.05	25.65	27.18
13	KB2	14.64	18.52	16.70	16.14	22.95	20.64	17.34	26.52	24.40

NOTE
R are the averaged rebound hammer readings (number)
NDT cube strengths calculated from regression equation $y = 2.9552x - 24.734$
DT cube strength from cube crushing tests using universal testing machine

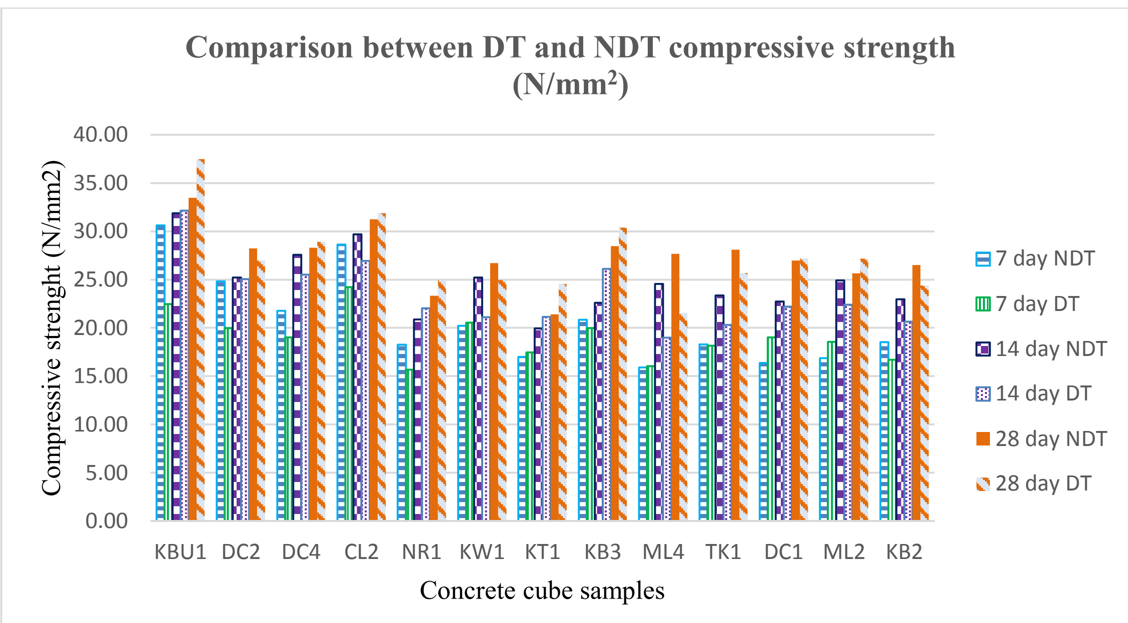


Figure 19: Cube compressive strength for DT and NDT at 7, 14 and 28 days

From the results above it is observed that rebound hammer is a useful and convenience tool for inspection of compressive strength for structural building.

Table 16: Differences between cube compressive strength obtained through rebound hammer tests and universal testing machine

$Differences\ in\ strength\ values = DT\ values - NDT\ values$				Differences in strength (%)	Workability	Particle size & Shapes
Sample	**7 days (N/mm^2)**	**14 days (N/mm^2)**	**28 days (N/mm^2)**			
NR1	-2.59	1.15	1.60	-14.2%	3mm	Rough & Rounded
KW1	0.33	-4.09	-1.76	-16.2%	4mm	Rough and fine & Irregular
KB3	-0.87	**3.50**	1.94	15.5%	5mm	Smooth and fine & rounded
KBU1	**-8.18**	0.27	**3.99**	-26.7%	9mm	Rough & Irregular
DC4	-2.74	-2.05	0.62	-12.6%	10mm	Rough and fine & Irregular
DC2	-4.85	-0.17	-1.24	-19.5%	11mm	Smooth and fine & Irregular
CL2	-4.39	-2.74	0.62	-15.3%	13.5mm	Rough & Irregular
KT1	0.44	1.17	3.12	14.6%	93mm	Rough & irregular
TK1	-0.12	-3.03	-2.41	-13.0%	34mm	Rough & irregular
DC1	2.63	-0.51	0.23	16.1%	52mm	Smooth and fine & rounded
ML4	0.13	-5.57	**-6.12**	-22.1%	56mm	Smooth and fine & rounded
KB2	-1.83	-2.31	-2.11	-9.3%	79mm	Rough and fine & Irregular
ML2	1.68	-2.49	1.53	-10.0%	115mm	Rough & irregular

NOTE

Differences in strength (%) is obtained as largest differences among 7, 14 and 14 days computed as percentage of NDT strength shown in table 14

It was observed that the results on the compressive strength obtained through the destructive method (universal testing machine) and non-destructive method (rebound hammer) compared well with the deviation ranging +3.99 and -8.18 for KBU1 at day 7 and day 28 respectively. This was followed by a margin of +3.50 for KB3 at 14 days and - 6.16 for ML4 at 28 days. This translate into a maximum difference of -26.7% for KBU1 and +16.1% for DC1. This implies that rebound hammer is a more conservative method where the overestimation of strength (-26%) is lower than the underestimation of strength (16.1%). KB3 and ML4 were characterized by the smooth particle surfaces while KBU1 was characterized by rough particles surface. DC2 had smooth surface texture and irregular shaped particles. The results show that the difference in strength was not directly depended on workability. Since there were no major strength deviations between DT and NDT results, the two methods are comparable. Frequent use of rebound hammer in buildings inspection is thus very suitable in Kenya and other African countries where its use has been limited.

It is concluded that rebound hammer presents a convenient methods for assessing surface hardness and hence compressive strength of concrete for quality assurance of buildings.

4.3.4 Analysis of the Correlation between Compressive Strength and Sand Impurities

In order to assess the relationship between compressive strength obtained from concrete made using sand with different levels of silt and clay content and organic impurities the compressive strength results were categories into 3 categories as shown in table below. A constant water cement ratio of 0.57 was used. The samples were categorized based on similar or closely related characteristic of surface texture, particle shapes, slump level and degree of fineness obtained from percentage passing 600 microns sieve size.

Table 17: Categorization of compressive strength data for regression analysis

	Sample	Average strength (N/mm2) Day 28 y)	Silt and clay content (%) (x1)	Organic Impurities (x2)	Texture	Particles Shape	Grading	slump
	a) Samples with Rough surface texture, moderate grading & high workability							
1	KB2	24.403	0.082	0.202	Rough	Irregular	65%	79mm
2	KT1	24.537	0.135	0.168	Rough	Irregular	53%	93mm
3	KBU1	20.730	0.128	0.361	Rough	Irregular	46%	86mm
4	CL2	24.680	0.003	0.023	Rough	Irregular	57%	58mm
5	DC4	19.620	0.158	0.147	Rough	Irregular	69%	65mm
	b) Samples with Rough surface texture, moderate grading & low workability							
6	KW1	24.955	0.088	0.238	Rough	Irregular	86%	4mm
7	DC4	28.929	0.158	0.147	Rough	Irregular	69%	10mm
8	CL2	31.858	0.003	0.023	Rough	Irregular	57%	13.5mm
9	KBU1	37.455	0.128	0.361	Rough	Irregular	46%	9mm
	c) Samples with Smooth surface texture, varied grading & varied workability							
10	DC2	26.979	0.161	0.738	Smooth	Rounded	72%	11mm
11	KB3	30.393	0.17	0.513	Smooth	Rounded	58%	5mm
12	DC1	27.188	0.189	0.415	Smooth	Rounded	70%	52mm
13	NR1	24.937	0.428	0.594	Rough	Rounded	42%	3mm

Note
Grading is measured in terms of percentage passing 600microns standard sieve

The samples used for regression analysis were carefully selected to ensure that their properties are almost similar or as close as possible and that only silt and clay and organic impurities significantly varied. By use of 5 sand samples which had similar texture, particles shapes and closely linked grading curves as indicated is group (a) in the table above regression analysis was used to derive the relationship between compressive strength of concrete cubes with varying silt and clay content as shown in Figure 8 below.

A regression equation for predicting compressive strength of concrete made from sand containing varying level of silt and clay contents was found to be:

$$y = ax1 + bx2 + c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

or

$$Fcu\ 28 = -\ 23.20\ SCI - 2.416\ ORG + 25.57\ with\ R2\ =\ 0.444 \ \ldots\ldots\ldots\ldots \quad (6)$$

where F_{cu28} = cube compressive strength at day 28

SCI = silt and clay content in sand

ORG = Organic impurities content in sand

The output from regression and correlation analysis showing the relationship between silt and clay content and organic impurities against compressive strength of concrete are shown in Table 18 and Table 19 below.

Table 18: Regression analysis sand impurities and compressive strength

Multiple R	0.666429
R^2	0.444128
Adjusted R^2	-0.11174
Standard Error	2.556553

	Coefficients	**Standard Error**	**t- Statistic**	**P-value**
Intercept	25.577	2.530	10.111	0.010
SCI (Variable 1)	-23.203	25.720	-0.902	0.462
ORG (Variable 2)	-2.417	12.997	-0.186	0.870

From the R^2 value, it is deduced that the contribution of the silt and clay content and organic impurities to the overall compressive strength of concrete is a significant 44%. This implies that although there are other factors contributing to the compressive strength of concrete, presence of silt and clay content and organic impurities plays a major role. The other factors may include mode of sand formation and workability, workmanship, quality of coarse aggregates and quality of water among others. Therefore concrete designers must provide adequate factor of safety to guard against structural failure as a result these impurities in building sand. Frequent testing of sand for construction purposes is therefore highly recommended to ensure measures are put in place e.g. washing of sand in a bid to prevent collapse of buildings as a result of excessive levels of silt and clay content and organic impurities.

From the table below, it is deduced that the contribution of silt and clay content (SCI) toward compressive strength is a significant 65%. Similarly the contribution of organic impurities (ORG) toward compressive strength of concrete is 46%.

Table 19: Correlation analysis between silt and clay content and organic impurities and compressive strength

	y (Fcu_{28})	*x_1 (SCI)*	*x_2 (ORG)*
y	1		
x_1 (SCI)	-0.65918	1	
x_2 (ORG)	-0.46683	0.587901	1

Silt and content and organic impurities contribute 65.9% and 46.7% respectively. It is deduced that the contribution of silt and clay content towards compressive strength of concrete is more significant compared with the organic impurities. This implies that the higher the level of impurities the high the reduction in compressive strength.

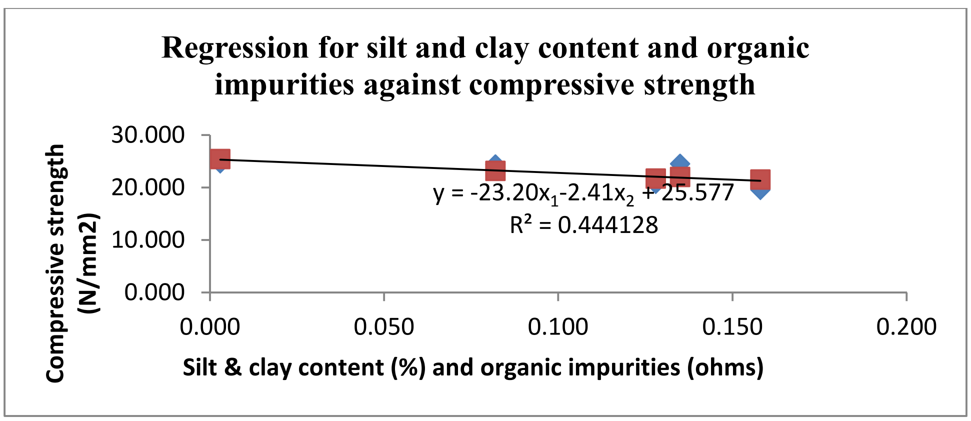


Figure 20: Regression analysis for compressive strength relationship

From the graph in Figure 20 above, it is clear that increase in silt and clay content and organic impurities significantly reduces the compressive strength of concrete. The 44% contribution represents a contribution of $11N/mm^2$ for concrete with target strength of $25N/mm^2$.

It thus deduced that other factors such as specific gravity, curing and workability among others play a significant contribution to the overall compressive strength characteristic of concrete and must be considered in concrete mix design. Besides presence of silt and clay content and organic impurities having some contribution to buildings failure, other factors such as workmanship, adherence to structure designs, works supervision and quality of other concrete ingredients plays important role in buildings failure.

4.4 Bond Strength of Concrete Made Using Sand with Varying Level of Impurities

4.4.1 Pull Out Force for Samples with Constant Water Cement Ratio

The pull out test specimens were prepared using the 13 sand samples selected for casting of concrete as detailed in section 4.2.6. For each sand sample selected, three 150x150x150 concrete cubes with a 12mm diameter reinforcement bar inserted at the middle were carefully cast while ensuring that the point of contact between reinforcement and concrete was not disturbed after casting and throughout the curing process. The average pull out forces arising from three concrete specimens made from each sand sample at the age of 28 days was recorded as given in Table 20 below. The results indicate that the maximum force exerted by the hydraulic jack to pull the reinforcement bar from concrete cube at bond failure.

From the table, it is deduced that 8 samples registered less pull out force than the control sample. These are NR1, KW1, KB3, TK1, ML4, KB2, KT1 and ML2. This is a significant 61% of the sand samples failing to meet the bond strength of the clean control sand sample as illustrated in Figure 22 below. The average pull out force (18.55kN) was less than the control sample pull out force of 19.25kN.

It was observed that all the 3 sand samples that depicted very stiff workability when a constant water cement ratio of 0.57 was used, they all registered lower pull out force than the control sample. This is attributed to the reduced ability to achieve even compaction throughout the test specimen due to very low workability. Low compaction effect affect the contact face between reinforcement bar and the concrete resulting in air being trapped hence low concrete-reinforcement bonding.

Table 20: Pull out force and mode of bond failure for concrete samples

Sample	Silt and clay content (%)	Organic impurities	Pull out force (Average for 3 specimens) (kN)*	Mode of failure for 3 specimens per sample (bar slip, concrete splitting and steel rapture)	Description of visible cracks on the 3 concrete cubes upon bond failure	Deviation from pull force from clean sample (%)	Workability (mm)	Particle shape; Particle texture	Source of sand (as given sand suppliers)
	Group 1 based on slump level								
NR1	42.80	0.594	14.75	1 cube slips 2 cubes split	I crack vertical then diagonal	-23.4	3	Rough ; rounded	Kangundo

KW1	8.80	0.238	16.25	Splitting	1 diagonal and 1 vertical	-15.6	4	Rough and fine; Irregular	Machakos
KB3	17.00	0.513	12.75	Splitting	No crack, concrete spall around bar	-33.8	5	Smooth and fine; rounded	Mai Mahiu
	Group 2 based on slump level								
KBU1	12.80	0.361	24	Spitting	2 vertical	24.7	9	Rough ; irregular	Mai Mahiu
DC2	16.10	0.738	21.5	Splitting	1 diagonal and 1 vertical	11.7	11	Smooth and fine; rounded	Kitui
DC4	15.80	0.147	17.5	Splitting	1 vertical	-9.1	10	Rough and fine ; Irregular	Embu
CL1	0.30	0.023	**19.25**	Splitting	No crack, concrete spall around bar	0.0	13.5	Rough ; irregular	Kitui
	Group 3 based on slump level								
TK1	3.30	0.614	15.25	Splitting	1 diagonal & 1 vertical	-20.8	34	Rough; irregular	Kitui
DC1	18.90	0.415	22	Splitting	No crack, concrete spall around bar	14.3	52	Smooth and fine; rounded	matuu
ML4	4.80	0.106	16.5	Splitting	1 diagonal and 1 vertical	-14.3	56	Smooth and fine; rounded	Kajiado
	Group 4 based on slump level								
KB2	8.20	0.202	18.00	2 cube slips 1 cubes split	2 vertical cracks	-6.5	79	Rough and fine; Irregular	Kajiado
KT1	13.50	0.168	15.25	1 cube slips, 2 cubes split	2 diagonal and 1 vertical cracks	-20.8	93	Rough; irregular	Machakos
ML2	7.00	0.029	14.25	Splitting	1 diagonal	-26.0	115	Rough; irregular	Kitui
Average	**13**	**0. 319**	**17.48**		**NR1, KT1 and KB2 failed by slip mode of bond failure**				
					More than 8 samples (61.5%) recorded pull out force less than clean sample				

It was also observed that although all the 3 sand samples (KB2, KT1 and ML2) that recorded very high workability also recorded less pull out force than the clean control sample. This is attributed to the reduced compressive strength of concrete with increased workability thus reducing the ability of the surrounding concrete to resist the frictional force and the pulling force

It was noted that the pull out force was not directly related to workability, implying that there are other significant factors affecting the bond strength between reinforcement bar and concrete. These factors include particle shapes, sizes, texture, mode of formation and specific gravity that were unique per sand sample. The largest deviation of pull out force between the clean sand and samples with varying impurities is a significant 33.8% as shown by KB3.

Four (4) out of thirty nine (39) pull out concrete specimens registered bar slip failure while the remaining 35 specimens representing 90% of the specimens failed by concrete splitting.

The four specimens are NR1, KT1 and KB2 (two test specimens). It was observed that all the four samples that depicted slip failure also recorded lower pull out force than the clean control sample CL2. The failure mode by concrete splitting indicates that the resisting frictional force between concrete and reinforcement is higher than the pulling force thus resisting the pulling action and indicating stronger bond strength. This mode of failure was the most dominant one as indicated by 35 samples representing 90% of the tested samples. No sample failed by steel rapture mode of failure implying that the bond strength between concrete and reinforcement bar was much lower than the resisting stress in the reinforcement bar. Bar slip mode of failure implies a weak bond between concrete and reinforcement bar as a result of reduced resistance force to resist the pulling force. Presence of silt and clay and organic impurities in sand result in reduced the bond strength by allowing slip of reinforcement due to reduced friction and mechanical interlocking between concrete and reinforcement.

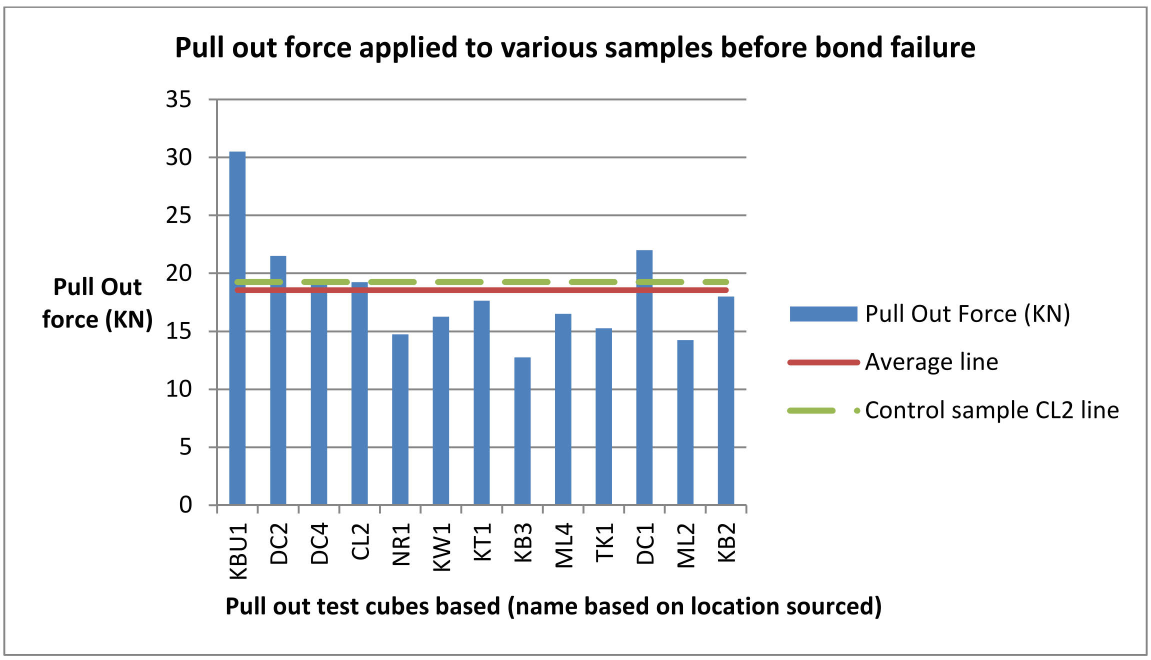


Figure 21: Pull out force at bond failure between concrete and steel reinforcement bar

Concrete splitting failure is characterized by splitting of concrete specimen surrounding the reinforcement bar in a brittle manner. Bar slip or pull out failure is an indication that the surrounding concrete fails due to the pulling force acting against the bar. Slipping failure is an indication that bond resistance is inadequate thus slipping out of concrete. In reinforced concrete members, sudden loss of bond between reinforcement bars and concrete in anchorage zones causes brittle failure and is common in buildings that collapse during construction. Steel rapture failure indicates high resistance force against the pulling force hence stronger bond between concrete and the embedded reinforcement bar. Impurities in building sands contribute to weak bond strength by allowing slip of reinforcement due to reduced friction and mechanical interlocking between concrete and reinforcement.

4.4.2 A Case of Constant Workability

With the aim of assessing the effect of pull out force on the samples at various categories of workability, four sand samples were cast in two sets where the workability of the first set was maintained as very low while the workability of set 2 was maintained at medium category as shown in the table below.

Table 21: Pull out force for a case of constant workability

Sample	Silt and clay content (%)	Organic Impurities	Pull out force (kN)	Workability (mm)	Workability classification	Source
KBU1 (a)	12.8	0.361	30.50	9	Very low	Mai Mahiu
KBU1(b)	12.8	0.361	28.00	86	Medium	Mai Mahiu
DC2 (a)	16.1	0.738	21.50	11	Very low	Kitui
DC2 (b)	16.1	0.738	20.63	69	Medium	Kitui
CL2 (a)	0.3	0.023	19.50	13.5	Very low	Kitui
CL2 (b)	0.3	0.023	18.25	58	Medium	Kitui
DC4 (a)	15.8	0.147	19.50	10	Very low	Embu
DC4 (b)	15.8	0.147	18.00	65	Medium	Embu

From the table above, it is deduced that low workability results in significant reduction in the pull out force hence the reduced bond strength as depicted by KBU1, DC2, CL2 and DC4. Comparatively the range difference was 2.5 kN for KBU1 to 0.88 kN for DC2. This behavior is attributed to the reduced both strength of concrete as a result of increase slump level whereby the resisting force is significantly reduced by increased water content, thus making concrete weaker thus the specimen fails.

4.4.3 Regression Analysis of the Pull Out Force and Sand Impurities

Four samples with closely related characteristic were used in regression analysis and are shown in Table 22 below.

Table 22: Characteristics of closely related samples for regression analysis

	Sample	Pull out force (kN)	Silt and clay content (%)	Organic Impuriti es	Texture	Particles Shape	Degree of fineness	slump

		y	x_1	x_2				
1	KB2	18.000	8.2	0.202	Rough	Irregular	65%	79mm
2	KT1	15.250	13.5	0.168	Rough	Irregular	53%	93mm
4	CL2	19.250	0.3	0.023	Rough	Irregular	57%	58mm
5	DC4	17.500	15.8	0.147	Rough	Irregular	69%	65mm

Regression analysis was carried showing the relationship between the pull out force and the varying silt and clay contents in sand (see Table 23) as represented by the following regression equation:

$$\boldsymbol{y = -15.59x_1 - 3.14x_2 + 19.4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{(4)}$$

with $\boldsymbol{R^2}$ **=0.568**

where $y =$ pull out force (kN)

x_1 = silt and clay content in sand (%)

x_2 = organic impurities (photometric ohms)

Table 23: Regression analysis for pull out force for constant water cement ratio case

Multiple R	0.753676
R^2	0.568027
Adjusted R^2	-0.29592
Standard Error	1.902044

	Coefficients	Standard Error	t- Statistic	P-value
Intercept	19.39691	2.135528	9.082957	0.069808
SCI (Variable 1)	-15.5882	22.81633	-0.6832	0.618433
ORG (Variable 2)	-3.13947	20.11794	-0.15605	0.901448

This implies that the contribution of both silt and clay content and organic impurities to the pull out force is a significant 56.8% as shown by the R square.

Table 24: Correlation between pull out force and sand impurities

	y	x_1	x_2
y	1		
x_1	-0.74666	1	
x_2	-0.60531	0.714589	1

From the correction equation above it is depicted that the contribution of silt and clay content to the pull out force is 75% compared with that of organic impurities of 61%.

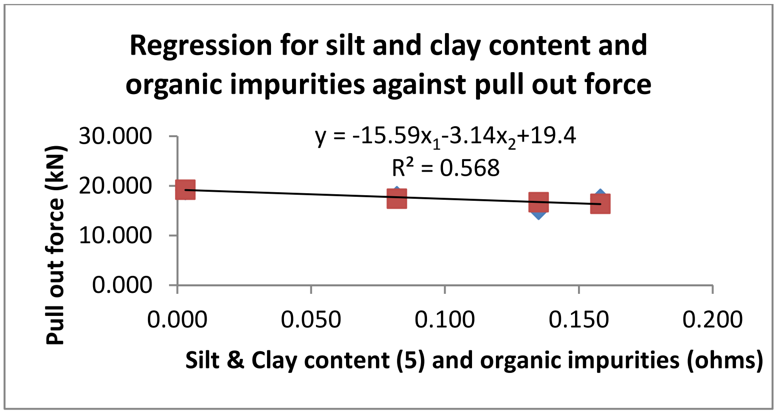


Figure 22: Regression analysis for bond strength relationship

It is observed that increase in silt and clay content and organic impurities in sand lead to decrease in the pull out force applied for reinforcement bar embedded in concrete before bond failure. This implies that the higher the silt and clay and organic impurities, the lower the bond strength between concrete and reinforcement bar in reinforced concrete structures. Presence of these impurities reduced the resistance of the concrete-reinforcement bar bond against the frictional forces in action.

The overall combined effect of the silt and clay and organic impurities to the pull out force bore bond failure is 56.8% as represented by the R square. It is clear from the relationships above that increase in organic impurities and silt and clay content reduces the bond strength between steel reinforcement bar and surrounding concrete.

Although presence of silt and clay and organic impurities in sand reduced pull out force and hence resultant bond strength, they are not the only determining factors. The contribution of these impurities to the overall pull out force is 56.8% which is significant and should be address during concrete production. The equation shows that there are other factors affecting bond strength of concrete. These include mode of particles formation, workability and specific gravity among others. Further other factors such as workmanship, adherence to structure designs and quality of other concrete ingredients play important role in buildings failure.

CHAPTER 5: DISCUSSION OF RESULTS

From the study, it is observed that building sand being supplied in Nairobi City County and its environs contained silt and clay contents, and organic impurities that exceeded the allowable limits. The level of silt and clay content obtained range from 3.3% to 42% while organic impurities ranged from 0.029 to 0.738 photometric ohms for the unwashed sand samples. An overwhelming 85% of the tested samples failed to meet silt and clay content limits of 4% as set out in BS 882 while 44% exceeded the limit of 10% set out in ASTM standard. With regard to organic content, 77% of the sand samples studied exceeded the recommended organic content for concrete production as specified in ASTM standard. A total of 38% of the concrete cubes made from sand with varying sand impurities failed to meet the design strength of 25Mpa at the age of 28 days.

It was observed that all the samples that indicated strength failure at day 7 and day 14 also failed at day 28. This shows that a sample that fails to meet the required compressive strength prior to 28 days will also fail at day 28. It is further deduced that the lowest level of silt and clay impurities is 4.8% while the lowest level for organic impurities was 0.106 ohms photometric color classification for samples that did not fail for meet the required cube strength. It can be taken that any sample having 4.8% of silt and clay content and 0.106 ohms for organic impurities is more is likely to fail. The washed control sample met the required compressive strength. It is concluded that presence of impurities in sand contribute to reduction in concrete strengths which may lead to collapse of buildings.

Regression equation $Fcu_{28} = -23.20\,SCI - 2.416\,ORG + 25.57$ with $R^2 = 0.444$ was generated to predict the compressive strength (Fcu_{28}) of concrete with varying levels of silt and clay contents (SCI), and organic impurities (ORG). It is noted that 44.4% of compressive strength of concrete is contributed by silt and clay content and organic impurities in sand used for concrete production. Since presence of these impurities significantly affects compressive strength of concrete, they cannot be ignored hence the need to ensure that only sand free from these impurities is used during concrete production.

On bond strength testing, 3 samples representing 10% of the tested samples failed by slip mode of failure depicting the weak bond between concrete and reinforcement bar with pull out force of 14.75 kN, 17.36kN and 18kN. All the three samples had higher levels of impurities and showed lower pull out forces compared to the washed control sand sample CL2. The failure mode by concrete splitting indicates that resisting frictional force between concrete and reinforcement is stronger thus resisting the pulling force hence stronger bond strength. This mode of failure was the most dominant one as indicated by 35 samples representing 90% of the tested samples. Steel rapture mode of failure shows that the bond strength between concrete and reinforcement bar is much lower than the resisting stress in the reinforcement bar. The reinforcement thus fails by tension. No sample failed by rapture mode of failure. It is thus concluded that presence of impurities in sand lead to weak bond between concrete and reinforcement bars which could contribute to decreased concrete structural strength integrity and may lead to failure of concrete structures.

Predictive regression equation $\boldsymbol{y = -15.59x_1 - 3.14x_2 + 19.4}$ with $R^2 = 0.568$ was generated to show the relationship between bond strength of concrete y with varying levels of silt and clay contents x_1, and organic impurities x_2 respectively combined. The equations show that contribution of silt and clay content and organic impurities to the overall bond strength is a majority 56.8% as indicated by R^2. It is further deduced that other factors such as particle sizes, shapes, texture, workability, mode of sand formation and specific gravity also play an important role in regard to the bond strength between concrete and reinforcement bar.

By comparing the compressive strength results obtained using NDT (using rebound hammer) and DT (using universal testing machine) methods, it was observed that the results compared very well with the deviation ranging from +3.99 to -8.18 N/mm^2 for KBU1 at day 7 and day 28 respectively. Therefore NDTs present a convenient approach in buildings inspections. Construction professionals need to upscale the use of rebound hammer in monitoring strength of buildings aimed at carrying out assessments to advise on repairs or reconstructions needs hence promoting sustainable construction management by preventing or reducing use of virgin natural resources for construction.

This research study advocates the sustainable use and promotion of the use of good quality materials especially sand in concrete production thus ensuring longer lifespan of buildings and high returns on investment. High quality materials will result in high quality buildings thus reducing frequent failures and/or demolitions hence optimizing on the exploitation of natural resources such as sand.

From this research, it is apparent that the silt and clay, and organic impurities in building sands affect both the compressive and bond strength of concrete. Besides, silt and clay content and organic impurities in sand other factors such as particle sizes, shape, mode of formation and specific gravity also play a significant role indetermination of strength properties of concrete. Consequently workability, adherence to designs, adequate curing and supervision of construction by professionals play a big role in prevention of buildings failure.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter presents the conclusions and recommendations drawn from this research. Areas for further research are also recommended.

6.2 Conclusions

The findings from this research should be very useful to construction professionals, contractors, developers, academic fraternity, government institutions and indeed to all stakeholders in the construction industry. It is concluded that;

i. Building sand being supplied in Nairobi City County and its environs exceeds the allowable limits of silt and clay content and organic impurities. The highest and lowest silt and clay content in unwashed sand samples used in this study was found to be 42% and 3.3% respectively. This represents loss of investment and reduction of value for money for every purchase and will also lead to frequent collapse and increased maintenance cost of buildings. In addition 85% of the tested samples failed to meet silt and clay content limits of 4% as set out in BS 882 while 44% exceeded the limit of 10% set out in ASTM standard. On the other hand, 77% of the sand samples exceeded the recommended organic content for concrete production as specified in ASTM standard.

ii. The allowable limits of silt and clay content in sand is 4.8% while and 0.106 photometric ohms is the limit for organic impurities is sand used for concrete production. Beyond this limits, concrete is likely to fail leading to collapse of buildings.

iii. Presence of silt and clay content and organic impurities contribute to reduction in compressive by up to 17%. The trend from the results show that the higher the amount of impurities the lower will be the compressive strength.

iv. Compressive strength results obtained using the destructive testing methods (universal concrete cube testing machine) of concrete has a close correlation with rebound hammer results. The maximum deviation between the two methods was ranging from +3.99 to -8.18 N/mm^2 for 25MPa concrete. Therefore rebound hammer is accurate as a non-destructive method and presents a more a convenient method for monitoring structures.

v. Presence of silt and clay content and organic impurities contribute to reduction in bond strength of concrete by up to 33.8% compared with the clean sand sample. The level of silt and clay content and organic impurities in sand for construction must be taken into consideration in designs to ensure that they do not go beyond the acceptable limit.
vi. Other factors such as particle shapes, texture and workability have contribution to the overall compressive strength of concrete. They should therefore be taken into consideration in construction as this will compromise compressive strength and affect the structural integrity of buildings.

The main limitations regarding this research study included inadequate laboratory facilities especially equipment necessitating outsourcing of equipment from other organizations which resulted in delays and increased costs.

Due to resource constraints and time limit the research focused on collection of sand samples from the main supply points in Nairobi City County and its environs in order to assess the quality of sand at the point of purchase. It is appreciated that some suppliers do adulterate sand by mixing sand with soils for unjustified economic gains. This was evident during samples collection where it was observed that some suppliers received sand from different sources and mixed it up to dilute the negative color, texture and silt and clay content levels. With regard to construction management practices, construction professionals are expected to enhance inspection of the quality of building materials to ensure that material quality, costs, time and customer expectations for concrete structures are not compromised and to avoid the failure of concrete structures. It is noted that investors lose up to 40% of their investment through purchase of sand with impurities. Kenya and other developing countries need to formulate policies to govern allowable limits of silt and clay and organic impurities in sand and ensure that materials are inspected and approved by a construction professional before use.

6.3 Recommendations

This research recommends the following;

1. Policies need to be developed regarding;
    a. The monitoring and surveillance of sand quality at construction sites, at dumping sites prior to delivery to construction sites and indeed at the delivery entry points of trucks ferrying sand in Nairobi City County and its environs. This should be geared towards prevention of adulteration of building sand at the supply points and along the supply chain.
    b. Holding of all players in the construction industry accountable throughout the design stages, construction stages and supervision processes towards prevention of building failures due to poor design, poor workmanship and in the use of poor quality construction materials in Nairobi City County, Kenya as a whole and indeed globally everywhere.
2. Presence of silt and clay content and organic impurities should be tested in every construction site. Compressive strength and bond strength reduction as a result of presence of silt and clay content and organic impurities in sand should be taken into consideration by every structural project designer during concrete design mix. Structural designs should ensure that the target strength of the resultant concrete is not compromised.
3. Construction professionals should use rebound hammer and other non-destructive methods during regular monitoring of buildings in order to assess their structural integrity and in determination of buildings that require repair and rehabilitation thus promoting sustainable development. Rebound hammer is a convenient, easy to use and ensures that the test element is not destroyed during the testing process unlike destructive methods where the test element is destroyed.

6.4 Recommended for Areas for Further Research

1. This study recommends further study to establish the quality of sand collected directly from the sources (rivers, quarry pit, etc) in comparison to the quality of sand sourced at the supply points (market places). This is to establish the extent of adulteration within the supply chain as well as the quality of sand at source.

2. Further experimental research on the relationship between particle shapes, sizes texture and specific gravity with compressive and bond strength of concrete is recommended.
3. It was observed that 3, 1 and 5 samples respectively failed on compressive strength at 7, 14 and 28 days. Although it is expected that at 28 days concrete has developed almost all its compressive strength, this study recommends monitoring of strength at 56 days and beyond to establish any trend beyond 28 day. Such a trend will indicate if the number of samples that failure to meet the expected strength increases with age.

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APPENDICES

Appendix 1: Reported cases of collapsed buildings in Kenya (2003-2013)

	Location	**Building Description**	**Date**	**No. reported deaths**	**No. of injured**	**Suspected causes from print media**
1	Ronald Ngara Street, Nairobi CBD (Nyamakima)	Five storey commercial building	24th June 2006	20	35	Inadequate curing
2	Kiambu town	Three storey commercial building	19th October 2009	11	14	Structural failure
3	Kiambu town	Rental residential building	January 2010	3	4	Heavy down pour
4	Mulolongo, Nairobi	Six storey building	9th June 2012	4	15	Substandard material, lack of proper supervision, inappropriate foundation design for water logged area
5	Langata, southern bypass, Nairobi	Langata Southern Bypass building	20th June 2011	None	6	Use of poor quality sand for beams and columns
6	Mosocho in Kisii County	One-storey building	7th May 2012	None	3	Heavy rains, cheap and poor quality materials
7	Ngara, Nairobi City	One storey building under construction	30th July 2011	None	5	Poor workmanship, Owner ignored construction standards
8	Makupa, Mombasa County	Four storey building storey building	April 09, 2009	3	7	Cracks and weak building
9	Luanda, Vihiga, Western Kenya	Three storey building	September 2011	3	5	Heavy rains. Lack of involvement of Structural engineer and poor concrete mix
10	Westlands, Nairobi	Seven storey building	May 2012	Unknown	2	Increase of number of floors from approved 3 to 5. Structurally unsound.
11	Kasarani, Nairobi	Residential buildings	5th February 2012	None	6	Large spans between the beams and columns, weakening the structure
12	Embakasi, Pipeline estate	Six storey building	June 2011	2	6	Poor workmanship and use of substandard materials
13	Matigari Building along Thika Road near Mathare North	Not reported	9th Sept 2011	Not reported	Not reported	Not known
14	Kisumu	Six storey building	16th Jan 2013	7	35	Poor workmanship, lack of columns on the side adjacent to existing building

Source: Print and electronic media in Kenya as detailed in references.

Appendix 2: Chemical Analysis of the Contents of Sand Samples

	Chemical element	1	2	3	4	5	6	7	8	9	10	11	12	13
	Sample	Na	Mg	Al	P	S	Cl	K	Ca	Sc	Ti	V	Cr	Mn
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1	KT1	24117.23	4559.00	32325.89	43.60	38.31	20.53	24329.09	12708.67	3.89	1625.29	11.40	14.84	197.74
2	KT2	16068.99	4559.00	25357.91	43.60	38.31	75.43	20701.97	16370.29	3.89	1468.44	5.23	4.90	604.83
3	KT3	17684.86	4559.00	23539.89	43.60	38.31	77.24	19718.96	6863.32	3.89	1351.82	5.56	4.66	577.85
4	ML1	21499.61	4559.00	28624.87	43.60	38.31	20.53	40495.42	2317.12	3.89	541.92	5.69	5.00	247.78
5	ML2	23672.27	4559.00	27479.42	43.60	38.31	20.53	20440.30	10851.96	3.89	2097.36	12.02	7.68	164.28
6	ML3	17049.90	4559.00	26421.98	43.60	38.31	35.02	21769.11	7905.12	3.89	754.17	9.69	3.77	127.52
7	ML4	25937.39	4559.00	16767.54	43.60	38.31	63.69	11093.58	11177.48	5.43	543.71	9.89	3.63	302.67
8	KW1	22136.41	4559.00	33345.14	43.60	38.31	42.81	21778.66	10158.71	3.89	2068.49	13.44	5.94	308.57
9	KW2	18704.62	4559.00	26377.91	43.60	38.31	52.50	19957.29	11204.45	8.69	743.37	17.51	5.54	385.14
10	KW3	24480.57	4559.00	37901.76	43.60	38.31	1090.19	42265.19	7357.23	3.89	2231.46	1.02	23.71	1231.63
11	DC1	24766.34	4559.00	12448.34	43.60	38.31	47.34	8545.13	1536.49	3.89	885.74	5.38	2.17	56.60
12	DC2	24239.91	4559.00	16275.43	43.60	38.31	28.99	13235.36	2046.55	3.89	1028.91	8.56	2.66	74.61
13	DC3	32027.40	4559.00	29712.56	43.60	38.31	32.46	19501.24	8506.99	6.58	667.48	11.63	5.00	113.12
14	DC4	21732.83	4559.00	29746.52	43.60	38.31	49.32	26497.87	8809.70	3.89	1069.66	20.16	8.46	268.45
15	KB1	23551.18	4559.00	28668.30	43.60	38.31	30.28	19656.16	8628.65	7.97	1104.45	15.52	2.86	206.99
16	KB2	23518.09	4559.00	23900.63	43.60	38.31	68.82	15917.09	16442.32	3.89	1275.99	21.79	3.05	258.38
17	KB3	33867.94	4559.00	47246.99	43.60	38.31	1490.24	47032.00	8632.33	3.89	2474.11	1.02	18.31	1370.05
18	NR1	23925.71	4559.00	23582.46	43.60	38.31	67.78	24398.09	3460.91	3.89	1101.27	11.99	2.01	1504.86
19	NR2	17404.08	4559.00	19479.90	43.60	38.31	20.53	14514.57	1999.66	3.89	1000.17	12.87	23.87	1127.61
20	NR3	16335.16	4559.00	26667.99	43.60	38.31	20.53	22558.61	3774.96	3.89	1168.15	11.41	20.72	1103.73
21	NB4	23448.08	4559.00	22424.25	43.60	38.31	20.53	31678.27	2251.45	3.89	559.53	11.42	2.85	313.69
22	KBU 1	25203.49	4559.00	41223.45	43.60	38.31	1648.31	44796.68	8069.88	3.89	2325.34	1.02	19.03	1364.69
23	TK1	19462.37	4559.00	25499.55	43.60	38.31	65.47	20470.06	6758.26	3.89	4814.00	24.82	10.31	497.95
24	TK2	20950.30	4559.00	18586.38	43.60	38.31	154.99	29506.24	671.06	3.89	330.67	9.39	1.82	240.59
25	TK3	25094.91	4559.00	23234.07	43.60	38.31	97.98	21705.91	5433.51	3.89	1960.19	27.47	14.03	171.28
26	CL1	28173.27	4559.00	28233.28	43.60	38.31	20.53	24048.26	8687.93	3.89	625.71	12.60	5.49	145.78

Appendix 2 (continued): Chemical Analysis of the Contents of Sand Samples

	Chemical element	14	15	16	17	18	19	20	21	22	23	24	25
	Sample	Fe	Co	Ni	Cu	Zn	Ga	As	Br	Rb	Sr	Y	Zr
	Sample	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1	KT1	8691.70	0.61	4.91	3.67	8.72	7.70	0.30	0.17	25.40	307.22	6.03	21.98
2	KT2	7771.89	0.61	1.44	2.41	19.18	6.62	0.30	0.17	29.79	182.06	10.83	21.98
3	KT3	9482.62	0.61	1.16	2.21	14.92	5.88	0.30	0.17	29.46	121.61	15.00	21.98
4	ML1	5527.80	0.61	0.72	2.39	9.57	8.21	0.30	0.17	67.04	95.90	5.23	21.98
5	ML2	8331.24	0.61	1.26	2.69	7.88	6.70	0.30	0.17	20.23	262.11	5.30	21.98
6	ML3	5039.14	0.61	1.62	3.39	5.03	5.96	0.30	0.17	29.49	177.53	6.32	21.98
7	ML4	4735.27	0.61	2.75	2.44	7.32	3.24	0.30	0.17	13.83	133.26	5.88	21.98
8	KW1	15668.52	0.61	2.20	3.58	18.64	8.01	0.30	0.17	29.73	201.55	12.92	21.98
9	KW2	6410.27	0.61	4.86	4.24	7.31	4.90	0.30	0.17	28.27	215.88	3.98	21.98
10	KW3	37653.85	0.61	0.30	2.04	134.11	21.99	0.30	0.21	101.29	10.18	41.00	47.30
11	DC1	2138.10	0.61	0.71	1.52	3.41	2.94	0.30	0.17	8.30	110.47	2.68	21.98
12	DC2	2900.87	0.61	0.66	2.44	5.77	4.52	0.30	0.17	12.02	181.68	4.62	21.98
13	DC3	5445.12	0.61	2.26	2.81	21.00	7.02	0.30	0.17	23.67	134.89	3.60	21.98
14	DC4	9852.99	0.61	3.34	5.58	10.93	6.07	0.30	0.17	38.78	149.81	6.06	21.98
15	KB1	6291.31	0.61	2.45	3.53	7.72	7.04	0.30	0.17	20.59	197.05	5.27	21.98
16	KB2	7033.01	0.61	6.24	3.15	8.50	5.36	0.30	0.17	17.65	223.76	5.21	21.98
17	KB3	42768.33	0.61	0.30	3.04	158.43	24.57	0.30	0.60	128.00	16.51	51.46	69.73
18	NR1	14386.80	0.61	2.37	2.84	33.75	6.71	0.30	0.17	59.36	95.62	10.65	21.98
19	NR2	17136.29	0.61	7.26	10.67	38.17	4.51	258.61	0.42	40.43	50.22	6.67	21.98
20	NR3	16029.41	0.61	3.85	7.60	34.54	6.15	87.46	0.77	39.88	119.54	8.96	21.98
21	NB4	5583.33	0.61	1.16	1.78	9.22	6.27	0.30	0.17	50.37	78.20	4.74	21.98
22	KBU 1	41938.05	0.61	0.30	2.75	158.45	23.82	0.30	0.69	122.30	9.99	50.31	66.88
23	TK1	19183.49	0.61	5.46	6.12	216.37	5.78	0.30	0.17	31.90	238.84	8.70	21.98
24	TK2	2447.36	0.61	0.30	1.18	3.44	3.66	0.30	0.17	48.92	34.63	1.47	21.98
25	TK3	17424.05	0.61	2.95	9.58	11.79	4.74	0.30	0.17	22.36	416.57	2.32	21.98
26	CL1	5280.18	0.61	1.31	2.03	4.59	6.39	0.30	0.17	23.07	276.65	2.36	21.98

Appendix 2 (continued): Chemical Analysis of the Contents of Sand Samples

		26	27	28	29	30	31	32	33	34	35	36	37
	Chemical element	Ba	La	Ce	Pr	Nd	Sm	Hf	Ta	W	Pb	Bi	Th
	Sample	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1	KT1	4728.43	407.65	16.12	0.73	6.58	8.45	0.95	0.12	0.18	11.33	0.11	0.26
2	KT2	2821.84	416.36	34.67	0.57	3.47	8.95	0.19	0.33	0.18	11.59	0.11	0.26
3	KT3	2683.78	439.80	33.61	0.57	5.08	13.73	0.43	0.32	0.18	10.02	0.11	0.26
4	ML1	3049.13	216.54	18.20	0.86	5.00	6.99	1.08	0.28	0.18	18.07	0.14	0.33
5	ML2	3846.45	510.25	24.42	0.57	5.57	8.73	0.93	0.16	0.18	8.44	0.11	0.35
6	ML3	2562.56	213.23	14.63	0.90	2.61	4.92	0.19	0.18	0.18	8.31	0.11	0.31
7	ML4	2855.11	236.88	21.98	1.04	6.69	3.87	0.19	0.12	0.18	2.96	0.19	0.26
8	KW1	3491.81	694.41	39.79	0.57	6.68	7.13	0.43	0.86	0.18	16.26	0.11	0.26
9	KW2	3319.49	272.62	22.96	1.24	4.87	6.72	0.19	0.12	0.18	11.18	0.11	0.26
10	KW3	462.82	1664.53	132.72	0.88	36.23	4.99	4.50	3.85	1.31	9.43	0.11	8.46
11	DC1	1623.13	164.09	7.17	0.57	1.39	1.06	2.30	0.12	0.18	10.86	0.11	0.26
12	DC2	2501.49	244.02	13.13	0.57	2.73	2.35	2.40	0.18	0.18	3.63	0.11	0.26
13	DC3	2615.61	235.26	15.98	0.75	5.81	5.08	0.19	0.31	0.18	6.88	0.11	0.26
14	DC4	3273.35	386.38	27.95	0.71	4.12	11.05	0.19	0.71	0.18	10.21	0.11	0.26
15	KB1	2996.27	353.70	33.51	1.01	4.61	7.20	0.60	0.41	0.18	6.39	0.15	0.26
16	KB2	2694.56	434.11	34.36	0.73	3.94	6.53	0.27	0.49	0.18	6.19	0.11	0.26
17	KB3	526.53	1995.29	146.83	1.05	46.07	6.63	5.47	4.27	1.10	29.03	0.11	10.06
18	NR1	2867.06	756.29	109.42	1.15	8.70	8.27	0.49	1.50	0.18	22.56	0.11	0.90
19	NR2	1551.61	721.44	96.77	0.57	7.03	8.29	0.25	1.36	0.18	427.61	0.20	0.39
20	NR3	2557.11	739.96	97.24	0.81	14.14	0.78	0.37	1.35	0.18	387.18	0.11	0.26
21	NB4	2437.70	248.80	49.54	1.05	3.11	6.72	0.89	0.42	0.18	31.98	0.19	0.26
22	KBU 1	250.47	2008.32	158.27	1.20	61.82	5.02	5.00	3.99	0.44	16.25	0.11	8.68
23	TK1	2972.45	1454.78	85.45	1.71	5.19	13.53	0.19	2.04	0.18	17.29	0.11	0.79
24	TK2	2646.51	148.72	18.04	0.82	2.90	2.53	0.19	0.22	0.18	8.24	0.24	0.26
25	TK3	5709.47	767.78	32.72	1.24	6.40	0.78	0.19	0.87	0.18	11.32	0.11	0.26
26	CL1	5030.75	216.63	13.67	1.46	6.40	5.41	1.17	0.12	0.18	13.54	0.11	0.26

Tests carried out at ICRAF Diagnostic laboratory, Nairobi

<u>NOTE:</u> Significant chemical elements in the sand samples included Na, Al, CL, K, Ti, Mn, Fe, Pb while minimum elements included Mg, P, S, Sc, Co, Ni,