

## *Full Length Research*

# **Full Replacement of Fine Aggregate in Concrete with Crushed Ceramic Waste.**

**Amos Kiptoo Koech**

Author's E-mail: [amoskoech868@gmail.com](mailto:amoskoech868@gmail.com)

**Accepted 9<sup>th</sup> September 2017.**

The study investigated properties of concrete made using crushed ceramic waste as fine aggregate. The study strived to determine whether crushed ceramics can be used in structural concrete and achieve strengths that can be equalled to that of river sand concrete. Rapid population growth has increased rate of depletion of natural resources and increased dump sites. Waste materials generated during construction and demolition of structures can cause serious problems due to costs associated with disposal and environmental pollution. The rate of environmental degradation can be reduced by diversifying materials and sources of aggregates for convectional aggregates extracted from quarrying. Materials such as ceramic waste are a usable substitute for conventional aggregate. The study was conducted through experimental research approach whereby laboratory experiments were conducted before coming up with a feasible conclusion and recommendation. Class 25 control specimen using river sand as fine aggregate was prepared and compared to specimen that used crushed ceramic waste as fine aggregate. Properties of aggregates, fresh and hardened concrete were obtained through observation and data analysis of the results through tables and graphs. The study established that compressive, tensile and flexural strengths slightly reduced in crushed ceramic concrete. Concrete produced with crushed ceramic waste as fine aggregate for class 25 did not meet the required strength at 28 days. Slump test for ceramic fine aggregate reduced in class 25 concrete. Crushed ceramic fine aggregate had higher water absorption of 16.92% compared to 5% for river sand. Ceramics' high water absorption resulted to a lower workability. Ceramic fine aggregate had a lower specific gravity of 2.53 compared to 2.62 for river sand. Specific gravity affects density thus concrete produced and the density of ceramic concrete was expected to reduce. The study concluded that crushed ceramic waste cannot replace river sand as a fine aggregate as the engineering properties of the concrete are inferior to that of the designed concrete. Class 25 concrete with ceramic waste as fine aggregate which is structural concrete cannot be used as it did not meet the required strength at 28 days.

**Keywords:** Fine Aggregate, Concrete, Crushed Ceramic Waste.

## **INTRODUCTION**

### **BACKGROUND**

Concrete is a composite material composed of; aggregates, binder and water all mixed together in specific proportions to form a homogenous material. Concrete is flexible and therefore provide designers and constructors with capacity to create aesthetic and serviceable buildings and structures. Aggregates are extracted from quarries and transported to construction sites. Quarrying has environmental impacts as it uses up energy and leads to emission of carbon dioxide.

Aggregates used in concrete are of two categories:

- Fine aggregate (sand) comprise of natural sand or crushed rock with particle sizes less than 4mm.
- Coarse aggregates ( gravel or ballast) with particle sizes greater than 5 mm

Aggregates used in concrete are inert materials that are durable due to their high resistance to physical, chemical and biological dilapidation forces. Ceramic wastes

possess similar traits and can thus be investigated to be incorporated in concrete. Conventional fine aggregate is obtained from:

- Natural sand in river valleys after it has been detached by the water from parent rock (natural disintegration) and has been deposited in the middle stage of a river.
- Crushing rocks or gravel.
- Processing of manufactured aggregate. (3.8, 3.9 BS EN 12620:2002 I)

Excavation for these raw materials causes environmental pollution by degradation of the earth surface and encouraging soil erosion. Gaping holes are left after excavation of virgin aggregates. This rugged environment is a visual intrusion to environmental conscious persons.

Construction and Demolition (C&D) wastes contribute the highest percentage of wastes worldwide (75%). Furthermore, ceramic materials contribute the highest percentage of wastes within the C&D wastes (54%) (Limbachiya, 2004). The current option for disposal of ceramic wastes is landfill. This is due to unavailability of standards, avoidance of risk, lack of knowledge and experience in using ceramic wastes in construction. This is where my project comes in:

The aim of my project is to investigate the feasibility of using ceramic waste as a substitute of fine aggregate. I obtained the ceramic waste from Ruaka, Kiambu in a construction site. On obtaining the ceramic waste, it was crushed in a standard manner to the prescribed grade and put under a sieve. The particles passing the 9.5mm sieve, almost entirely passing the 5mm sieve and predominantly retained on the 75  $\mu$ m sieve were collected to be used as the fine aggregate. Mix design was then be done to come up with a sample for testing. The sample was then be tested for its workability and its specific gravity to ascertain that it can in fact be used as fine aggregate. After this step, the sample was used to make concrete in different quantities and the compressive, flexural and tensile strength of concrete made with ceramic waste as a fine aggregate replacement was tested.

### Justification of the Study

The need to sustain human development by using natural resources should also correspond to protection of natural environment in order to sustain sustainable use in the present and future generation. The use of alternative materials from discarded waste or recycled material is geared to fulfil this need. Construction industry can handle most of the ceramic waste produced from anthropogenic activities as well reduce rate utilization of quarried natural resources. Use of ceramic waste in concrete is not only economical but also it solves disposal issues.

The current study aims to determine properties of concrete produced by use of crushed ceramic waste as fine aggregate so as to increase its use in constructions. Engineers design the required characteristics of concrete to be used in construction based on the stress the structure will be exposed. Ceramic waste aggregate require standards that defines its use thus experimental studies are required to determine characteristics of concrete that can be produced from these aggregate. Ceramic waste in Kenya has been on a steady increase and is currently accumulating.

### Problem Statement

Rapid industrial development has increased rate of depletion of natural resources and increased dump sites. Waste materials generated during construction and demolition of structures can cause serious problems due to costs associated with disposal and environmental pollution. The rate of environmental degradation can be reduced by diversifying materials and sources of aggregates for conventional aggregates extracted from quarrying. Materials such as ceramic waste are a usable substitute for conventional aggregate. However, there is lack of adequate information regarding to the use of ceramic waste as fine aggregate. There is need to analyse and document the engineering of properties of concrete formed by using waste materials as fine aggregate; this report evaluates its properties.

### Objectives of the Study

#### General Objective

To determine properties of concrete made using crushed ceramic waste as fine aggregate.

#### Specific Objectives

- To design concrete mixes for class 25 concrete.
- To determine compressive strengths of ceramic concrete and compare with that of control mixes.
- To determine tensile strengths of ceramic concrete and compare with that of control mixes.
- To determine flexural strengths of ceramic concrete and compare with that of control mixes.
- To determine slump of ceramic concrete and compare with that of control mixes.
- To determine aggregate grading curves
- To determine aggregates' water absorption and specific density

### Research Hypothesis

Properties of concrete made using crushed

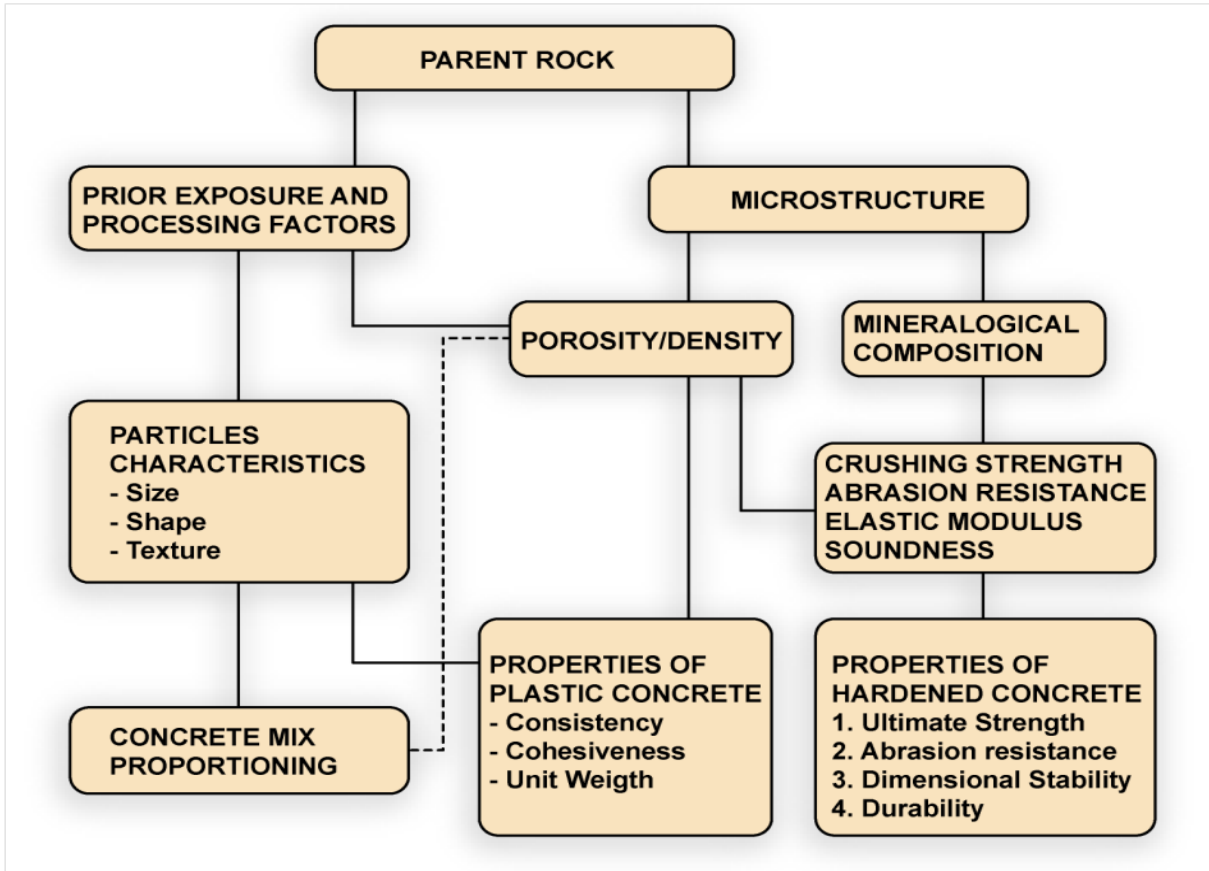


Figure 1: Aggregate properties (P.K. Mehta and P.J.M. Monteiro, 2005)

ceramic waste as fine aggregate have the required engineering properties to be used as structural material.

**Scope of the Study**

The study focused on the comparison of engineering properties of concrete made by using sand as fine aggregate with crushed ceramic waste as fine aggregate. The study involved tests on coarse and fine aggregates and concrete mixes to determine their properties. Sand was the reference fine aggregate in the study. Concrete mix used conventional ballast as coarse aggregate. Crushed waste ceramic and sand was used as fine aggregate.

**LITERATURE REVIEW**

Aggregates used in concrete have to conform to the required standards (EN 12620:2002 (E)). Properties

of aggregate that affect properties of concrete are shown in Figure 1

Construction industry has the capacity to be the end user of virtually all the ceramic materials thus solving the environmental problem moderately on its own. Adoption of waste products in concrete not only solves disposal issues but it is also economical. Crushed ceramic waste aggregate has the capacity to be used to produce light weight concrete without upsetting the strength (as cited in BJ Odero et al., 2014).

The high demand for raw materials by the construction industry, results in environmental damage and chronic shortage of construction materials. In the last decade, there have been various researches conducted on the exploitation of waste products in concrete so as to reduce the exploitation of natural resources. A research by T. Sekar et al established through testing that compressive strength of concrete cubes made with glass insulator and ceramic insulator were determined to be 26.34% and 16% respectively less than the conventional concrete(T. Sekar et al., 2011).

Research by P. Tugut and E. Yahlizade submitted that replacing 20% by weight of fine aggregate with fine aggregate using fine glass had a substantial effect on tension, flexural and compression properties of concrete paving block as compared with the reference control sample (P. Turgut and E. Yahlizade, 2009). Veera Reddy's research concluded that excess replacement of more than 20% of coarse aggregate by ceramic waste leads to decline of strength below the conventional mix (Veera Reddy, 2010). Lopez et al. research established replacement of aggregates with ceramic waste would increase compressive strength marginally (De Brito et al., 2005)

### Types of Aggregates

Aggregates can be classified into:

- i. Natural aggregates.
- ii. Artificial aggregates.
- iii. Normal aggregates.
- iv. Light aggregates.
- v. Heavy aggregates.

### Natural Aggregates

They are obtained from natural sources e.g. river deposits, gravels, sand and rocks. The geological processes by which a deposit was formed are responsible for its shape, size, grading, rounding and degree of uniformity of the aggregates. Various rock types when crushed are suitable for use as aggregates.

These include;

**Limestone:** Are sedimentary rocks chiefly composed of calcium carbonate. The harder and denser types particularly the carboniferous types are suitable for concrete. Less hard types are unsatisfactory.

**Igneous rocks:** The most common are the granites, basalts and gabbros. Granitic aggregates are commonly because they are hard, tough and dense and are excellent in bonding with cement. Although it's excellent in concrete production, its overexploitation has adversely affected the environment thus the need for research on alternatives.

**Metamorphic rocks:** They have variable characteristics. Marbles and quartzites are usually massive, dense and adequately tough thus provide good aggregates. However schists and slates are often thinly laminated and are therefore unsuitable. Other rocks such as shale and sandstones among others are rarely available. Shales are poor aggregates because they are weak, soft and absorptive. In sandstones, imperfect cementation of constituent grains makes some sandstone friable and very porous thus unsatisfactory

aggregates. Since natural aggregates are formed by geological processes or by crushing rock, their many properties depend on the properties of the parent rock e.g. chemical and mineral composition, petrology, specific gravity, hardness, strength, pore structure, colour etc. these properties have a considerable influence on the quality of fresh and hardened concrete.

### Artificial Aggregates

These are manufactured mainly from industrial by-products, waste materials or sometimes natural materials. They are mainly lightweight aggregates. Examples are;

**Pulverized Fuel or Fly Ash (PFA):** This is the residue of the combustion of pulverized coal used as a fuel in thermal power stations. PFA is used in the manufacture of lightweight aggregates in Germany and Great Britain to reduce dead loads of high rise structures (L.J. Murdock 1991). PFA powder is pelletized with water in a rotating pan and the pellets burnt in horizontal grate at a temperature of 1200-1300°C. They are then cooled and screened in different particle size fractions.

**Foamed slag:** This is a by-product in the manufacture of pig iron in blast furnace. The slag is transformed into molten state at 1400-1500°C. Steam and compressed air is injected in the process. This produces numerous bubbles which causes the slag to expand so that on cooling it becomes an artificial rock like material with cellular structure – internally porous and honey combed (The concrete society 1980). The artificial rock is then crushed and screened to give different particle sizes.

**Sintered Glass aggregates:** They are manufactured mainly north of France. The raw material used comes from waste glass bottles. The bottles are crushed, dried and ground in a rotary mill at a fineness of 3600cm<sup>3</sup>/g Blaine. Before grinding, 2.5% of calcium carbonate (CaCO<sub>3</sub>) is added as an expansive agent. The powder is well homogenized and pelletized with water in a rotary pan. According to the speed and inclination of the pan, it is possible to obtain several diameters. The pellets are then dried in hot air and pre-heated up to 680°C and passed quickly through a rotary kiln at 800°C. They are then cooled and screened (The concrete society Ci80, 1980).

**Furnace Clinker:** It comes from the combustion of coal in domestic or firing systems. The clinker is sometimes used as lightweight aggregate after being crushed and screened. Aggregates are dark in colour with a sintered or slaggy appearance. This type of aggregate is relatively little used due to its stability which must be verified by chemical and physical testing. It must not contain harmful substances like burnt lime and magnesia, sulphides, and sulphates which are deleterious in concrete.

Other artificial aggregates

- Wood aggregates (industrial production in Eastern France and Switzerland).
- Expanded minerals aggregates – clay, shale and slate (great developments in Europe).
- Rice balls (Researches being made).
- Expanded polystyrene (Expensive polystyrene limits production).
- Vermiculite (industrial production, though minimal, in Netherlands, Italy, France and Belgium).
- Cork aggregates (Major developments in Spain and France)

### Normal Weight Aggregates

Many natural aggregates, from granites, gravels, basalts, limestone among others fall under this category. All these aggregates have specific gravities within a limited range of 2.55-2.75 and therefore they produce concretes with similar densities, normally in the range of 22.5-24.5 KN/m<sup>3</sup> depending on the mix proportions.

### Construction and Demolition Waste

Construction and demolition waste has had a lot of research as a construction material in concrete. Y. Kasai initiated the research into the use of materials in demolished structures in 1973. Kasai spear headed the research after the establishment of a committee on Disposal and reuse of Construction Waste by Builders Contractors Society in Japan (Kasai, 1994).

Globally, roughly eight to eleven billion tonnes of aggregate (gravel, sand and crushed rock) is used for production of concrete annually (Tarun, and Moriconi, 2005). However, there is a shortage of unused aggregate which could be substituted with construction waste such as ceramics. Japan produces 77 million tonnes and United States of America produces 325 million tonnes Europe generates 1.3 billion tonnes of waste annually according to a report by Cement Sustainability Initiative (CSI) (2009, p. 3) of which approximately 40% is construction and demolition waste.

R. Kamala et al. conducted a research on partial replacement of conventional of conventional coarse aggregate with demolition waste to determine the optimum replacement percentage. The tests involved casting of cubes, cylinders and beams cured after 7, 28 and 56 days. The results showed that partial replacement of up to 40% was effective without affecting the design strength (R. Kamala, 2012).

In Kenya, unplanned settlements and illegally grabbed land by developers has led to frequent demolitions to pave way for public utilities. In 2006 to pave way for Mombasa road expansion, 60 structures were demolished Mlolongo by the government (East

African Standard, 01 December 2006). In developing countries like Kenya, change in land use has led to renovations in structures to accommodate the expected land use. Renovations involving removal of ceramic tiles and bathroom wares cause breakage thus producing ceramic waste as ceramic is a brittle material.

### Light Weight Aggregates

They are used to produce low density concretes which are advantageous in reducing the self-weight (dead loads) of a structure. They have better thermal insulation than normal weight aggregates. The reduced specific gravity is obtained from air voids within the aggregate particles.

Most artificial aggregates fall under this category e.g. sintered PFA, LECA, Foamed slag etc. An example of natural lightweight aggregate is Pumice. It is a naturally occurring volcanic rock of low density. It has been used since Roman times but it is only available in few locations e.g. in Kenya, it is found in Longonot, Rift valley province.

Because they all achieve lower specific gravity and increased porosity, they result in lowering in concrete strength. Lightweight aggregates are not as rigid as normal weight aggregates thus produce concretes with higher elastic modulus, creep and shrinkage. The strength properties of lightweight aggregates depend on type, source and whether lightweight fines or natural sand are used.

A density of 1850Kg/m<sup>3</sup> may be considered as the upper limit of a true lightweight aggregate although this value may sometimes be exceeded. (K.M Brook, 1991)

### Heavy Weight Aggregates

They are mainly used in concretes which require high density e.g. in radiation shielding in nuclear power plants etc. Concrete densities of 3500Kg/m<sup>3</sup>– 4500Kg/m<sup>3</sup> are obtained. Example of these aggregates is Barytes (a barium sulphate ore). Steel shots can produce concrete of about 7000Kg/m<sup>3</sup> density (J.M Illston 1994).

### Waste Ceramic Recycling

Previous research by different teams has shown that material of ceramic origin has been used as road fill (koyuncu H. et al., 2004). Civil engineering projects in Europe use recycled aggregate; bricks, recycled concrete and ceramics as fill material. Concrete technology has advanced and due to continued research. Europe has begun using recycled aggregate for the production of new concrete (Weil, Jeske & Schebek, 2006). Crushed ceramic waste aggregate has the property to produce lightweight concrete without interfering with strength (as cited in BJ Odero et al.,



2014). Ceramic waste has been tested as a partial replacement of traditional coarse aggregate, effects are promising but they underachieve in water absorption hence ceramic waste use as a fine aggregate is a better choice (F Pacheco-Torgal et al., 2010).

### Merits of Recycling Crushed Ceramic Waste (CCW)

Ceramic waste as a construction material brings about various benefits corresponding to its physical and chemical properties. Merits of using ceramic waste in concrete include:

- Lower self-weight of concrete produced due to ceramic's low density than conventional crushed stone aggregate (D. Tavakoli; A. Heidari and M. Karimian, 2013).
- Environmental benefit from the use of ceramic tile waste in concrete. This use leads to removal of those ceramic waste materials from disposal sites (Nadeem et al., 2012).
- Environmental benefit as a result of reduction in the utilization of natural resources such as raw construction material (T. Sekar et al., 2011). Sand mining in rivers lowers the water table.

### Properties of Crushed Ceramic Waste (CCW)

#### Classification of ceramics

Ceramic waste can be classified into 2 categories according to the source of raw materials. The first category is produced by all fired wastes generated by structural ceramic plants that only use red pastes to produce their products such as blocks, brick, and roof tiles. The second category is produced by all fired wastes generated in stoneware ceramic such as floor tiles, wall and sanitary ware. These category use white and red pastes, however, the use of white paste is more common and is produced in higher volume. In each classification the fired ceramic waste was classified in accordance to the production process. This classification is shown in the diagram (Figure 2).

#### Ceramic waste chemical properties

The chemical composition of ceramic raw material is not significantly different from that of ceramic products. Table 1 shows the chemical composition of fired ceramic products. Only the mineralogical composition of ceramic raw material changes when the materials are heated. The most significant oxides present in ceramic paste are alumina and silica and they depend on the clay used. The red paste in ceramics contains a high percentage of iron oxide and is responsible for the red colour.

### Physical properties of ceramic waste

Based on experimental research water absorption of ceramic waste was 0.18% and that for natural aggregate was 0.10%. Ceramic waste has higher water absorption because of pore structure, surface area and clay content. Ceramic aggregate has a crystalline structure (Sudarsana Rao hunchate, 2013). Specific gravity of fine aggregate from ceramic waste depends on the chemical composition of the ceramics. Siddesha H used homogenous ceramic tiles with physical properties shown in table (Siddesha, 2011).

### Properties of Crushed Ceramic Waste Concrete

Punit Malik et al. from Department of Civil Engineering, Dronacharya College of Engineering, in India designed class 25 concrete (25MPa) using natural fine aggregate and crushed ceramic tiles coarse aggregate. Punit Malik et al concluded that;

- The mass of aggregate reduced by 50% which consequently reduced the weight of concrete.
- Ceramic waste coarse aggregate is within the range of aggregate properties used in concrete according to Indian Standards and can be used as a coarse aggregate.

(Punit Malik et al., 2014)

Ay and Unal investigated the prospect of replacing cement with powdered waste ceramic tile in concrete. It was found that powdered waste ceramic tile had pozzolanic properties and it was possible to replace cement with 35% by weight of powdered waste ceramic tile (Ay and Unal, 2000).

Khaloo studied the use of crushed tile as a coarse aggregate in concrete. The crushed tile (coarse aggregate) had a much higher water absorption value and lower gravity compared to natural crushed stones. The test concrete was made with coarse aggregate; 100% crushed tile had a lesser density, higher compressive (+2%), flexural (+29%) and tensile (+70%) strengths (Khaloo, 1995).

Akhtaruzzaman and Hasnat studied the use of manually crushed clay bricks as 100% coarse aggregate. Mechanical and physical properties were determined from four grades of concrete. The crushed brick aggregate particles had a bulk specific gravity, unit weight and water absorption value of 1.93%, 953kg/m<sup>3</sup> and 11.2% respectively. The concrete cast had a compressive strength from 13.5 MPa to MPa and a unit weight between 2000kg/m<sup>3</sup> and 2080 kg/m<sup>3</sup>. Comparing the properties of concrete with natural aggregates; modulus of elasticity was 30% lower, the unit weight was 17% less and the tensile strength was approximately 11% higher (Akhtaruzzaman and Hasnat 1988).

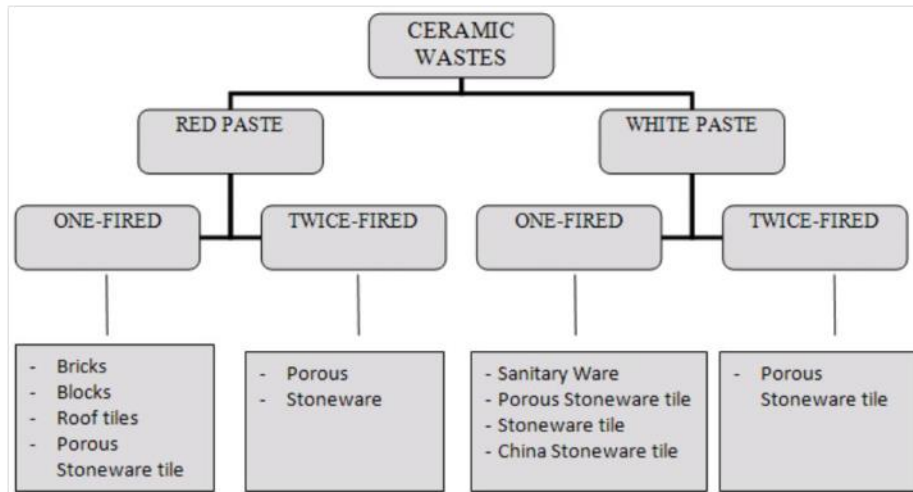


Figure 2: Classification of ceramic wastes by type and production process (B. J. Odero et al. 2014)

Table 1: Chemical composition of ceramic pastes (F.Pacheco and S. Jalali, 2010)

Type	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>
Red paste twice fired ceramic	51.7	18.2	6.1	6.1	2.4	0.2	4.6	0.8
White paste once-fired ceramic	58.0	18.0	1.0	8.3	0.6	0.2	1.2	0.8
White paste for twice - fired ceramic	59.8	18.6	1.7	5.5	3.5	1.6	2.5	0.4
Red paste for stoneware tile	29.1	20.3	7.7	1.2	1.1	0.4	4.2	0.9
White paste for stoneware tile	65.0	21.3	1.3	0.2	0.3	2.5	3.7	0.2
White paste for sanitary ware	65.8	22.2	0.6	0.1	0.1	1.0	3.5	0.3

Table 2: Properties of ceramic waste (Siddesha H, 2011)

Crushed ceramic waste has a limit percentage of substitution when used as a coarse aggregate. Cachim used partial replacement (15, 20 and 30%) of natural coarse aggregates with crushed and used waste from various kinds of ceramic products, it was noted that 15% substitution did not cause a change in the concrete strength, whilst with 15-20% substitution the strength of concrete varied according to the source of aggregate. 20-30% substitution caused a reduction in the concrete strength regardless of the source of ceramic (Cachim,

2009). Reduction in strength may have resulted after an increase in the flaky aggregate (Tavakoli, 2013).

Padmini et al. used a fractional factorial experimental design method to study the comparative influence of various parameters on the strength of concrete using low strength (6 MPa - 13 MPa) bricks as aggregates. It was determined that the strength of the brick was influenced by aggregate conditions (i.e. dry or pre-wet before mixing), cement content and the strength of brick that was crushed to form aggregates (Padmini et al., 2001).

**Table 3:** Properties of ceramic waste (Siddesha H, 2011)

Property	Crushed aggregate	Ceramic aggregate
Specific gravity	2.68	2.50
Water absorption%	0.10	0.18
Impact value %	18.60	22.0
Crushing value %	15.30	20.0
Abrasion value %	14.25	19.0
Bulk density		
Loose condition kg/m <sup>3</sup>	1219	1069
Dense condition kg/m <sup>3</sup>	1425	1188

**Table 4:** Represents properties of hardened concrete (Ivana et al., 2008)

	Compressive strength MPa	Flexural strength MPa
Control mixture MC1	46.88	10.1
Mixture MC2	35.73	6.63
Mixture MC3	31.56	6.01

To determine impacts on strength and long term durability of concrete by using different types of brick aggregates, Kibriya and Speare used three types of aggregates. Concrete produced from brick aggregates had a comparable tensile, compressive and flexural strength to those of conventional concrete but modulus of elasticity was significantly reduced (Kibriya and Speare 1996).

Mansur et al. investigated the suitability of crushed bricks as coarse aggregate in concrete, comparing its properties with those of normal concrete, produced from granite aggregates. Four grades from 30 to 60 MPa were used (Mansur et al., 1999). For the same mix proportions, the use of crushed brick aggregates resulted in higher tensile and compressive strengths, lower drying shrinkage and practically an identical specific creep. The use of crushed brick led to a significant loss in workability of fresh concrete and a substantial reduction in the modulus of elasticity.

Ivana et al. determined the density of crushed tiles aggregate micro concrete was found to be 12.7% lower, and density of crushed brick aggregate micro-concrete was found to be 16.4% lower than the control micro concrete density (Ivana et al., 2008). Experimental results for compressive and flexural strength of crushed tile; river and recycled crushed brick aggregate micro-concrete are shown in Table 3. After 28 days, the compressive strength of micro-concrete with crushed tiles was about 32.7% lower and with recycled crushed brick aggregate the strength was about 23.8% lower than that for river aggregate micro-concrete. Ivana et al. concluded that micro-concrete produced with crushed

bricks and tile aggregates does not perform in comparison to concrete produced with regular river aggregates in terms of strength. Conversely, the concrete still has adequate strength that would make it suitable for specific applications that require reduction of self-weight due to the benefit of lower density it possess (Ivana et al., 2008).

After 28 days, the flexural strength of micro-concrete with crushed tiles was about 40.5% lower and with recycled crushed brick aggregate was about 34.4% lower than the strength of river aggregate micro-concrete. From these results it could be established that there was a significant reduction in flexural strength when crushed tiles or bricks aggregates were used instead of the conventional river aggregate (Ivana et al., 2008).

Concrete having tiles can consequently be used similarly as conventional concrete (Tavakoli, 2013). Table 3 reveals the results of substitution of coarse aggregate. The report further shows that, compressive strength of concrete increased by 5.1% using a substitution of 10%. Compressive strength of cement using a replacement of 40% remained almost similar to that with 100% normal aggregate. Reduction in strength may have resulted after an increase in the flaky aggregate (Tavakoli, 2013).

Variation in the unit weight was represented in figure 3. Unit weight of concrete reduced as percentage of substitution with tiles increased. The sample that had a 40% replacement had a decrease in unit weight by 2.3%.



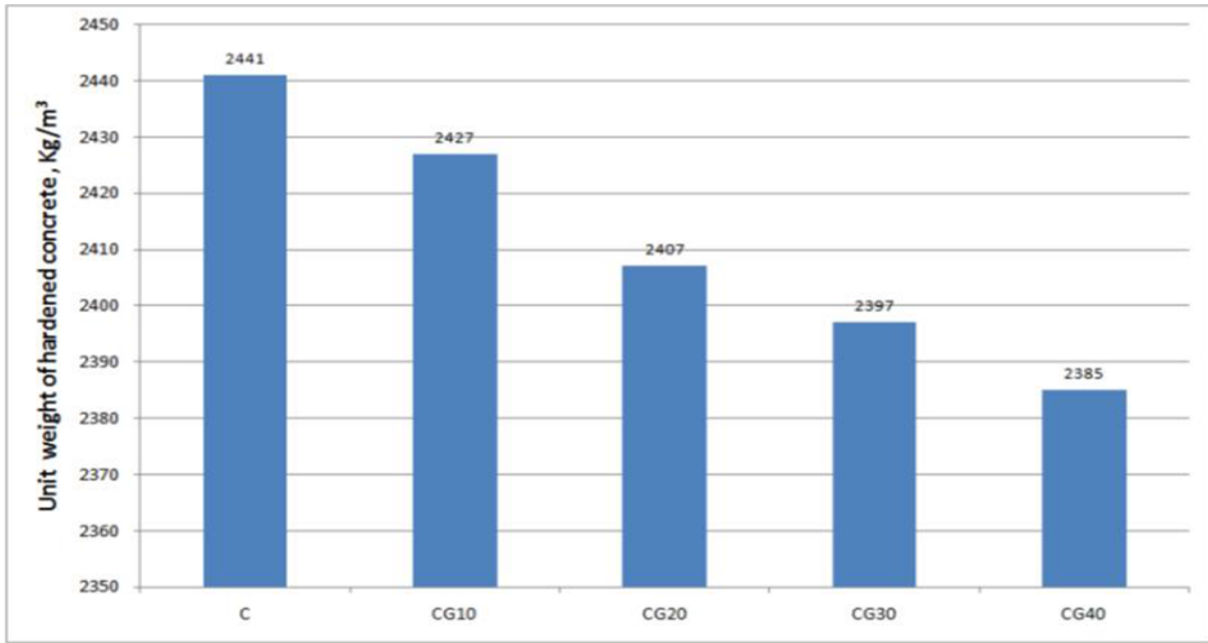


Figure 3: Variation in the unit weight of concrete with increased substitution of ceramics

Table 5: Mechanical and physical properties of concrete mixes (Tavakoli, 2013)

Sample	Slump (mm)	Specific Weight(kg/m <sup>3</sup> )	Water absorption (%)	Average strength (MPa)	
				7 days	28 days
C	60	2441	5.05	26.9	33.1
CG10	50	2427	4.9	28.2	34.8
CG20	50	2407	5.2	27	34.3
CG30	45	2397	5.45	27.2	34.1
CG40	40	2385	5.7	25.7	33

Table 6: Minimum Mass of Samples for Testing (BS 812: 102:1989)

Maximum particle size present in substantial proportion	Minimum mass of sample dispatched for testing kg
28 or larger	50
Between 5 and 28	25
5 or smaller	13

### Sampling

Tests done on properties of aggregate are performed on samples collected from the parent material to represent its properties. To achieve a representative sample, careful collection of material and sampling method is required. During collection of the sample scooping is preferred to shovelling in order to prevent some particle sizes from rolling off when the shovel is lifted. Sampling involves collection of a main sample that

is made up several portions of the different parts of the material. The minimum size of the sample depends on the maximum particle size present in substantial proportion. The table 5 is an extract from BS 812: 102:1989 (replaced by BS EN 932-1:1997)

The main sample is further reduced in size by either quartering or riffing; each method divides the sample into two parts. Riffing gives less variable results than quartering hence in this project, riffing was used.

## Mix Design Principles

### Strength Margin

Due to variability of concrete strengths, the mix must be designed to have higher mean strengths than the characteristic strength. The difference between the two is the Margin. The margin is based on the variability of concrete strengths from previous production data expressed as a standard deviation.

### Workability

Two alternative methods were used to determine workability; Slump test which is more appropriate for higher workability mixes and the compacting factor test which is particularly appropriate for mixes which are applicable to mixes compacted by vibration.

### Free-water

The total water in a concrete mix consists of water absorbed by the aggregate to bring it to saturated surface-dry condition and the free-water available for hydration of cement and for the workability of the fresh concrete. The workability of fresh concrete depends on a large extent on its free-water content. In practice, aggregates are often wet and they contain both absorbed water and free surface water so that the water added to the mixer is less than the free-water content. The strength of concrete is better related to the free-water /cement ratio since on this basis the strength of concrete does not depend on the absorption characteristics of the aggregates.

### Types of aggregates

Two characteristics of aggregates particles that affect the properties of concrete are particle shape and surface texture. Particle shape affects workability of the concrete and the surface texture affects the bond between the cement matrix and the aggregates particles and thus the strength of concrete. Two types of aggregates are considered for design on this basis; Crushed and Uncrushed.

### Aggregate grading

The design of mixes was based on specific grading curves of aggregates. The curves of fine aggregates must comply with grading zones of BS 882.

### Mix parameters

The approach to be adopted for specifying mix parameters was reference to the weights of materials in

a unit volume of fully compacted concrete. This approach required the knowledge of expected density of fresh concrete which depends primarily on the relative density of the aggregate and the water content of the mix. This method resulted in the mix being specified in terms of the weights in kilograms of different materials required to produce 1m<sup>3</sup> of finished concrete.

### Trial Mixes

Trial mixes are carried out in order to evaluate whether or not the selected aggregates or cement chosen for use performed as anticipated. Modifications may be made to the initial mix proportions, if required based on the results obtained in the trial mixes compared to the design mixes. Based on these, actions to be considered are;

- To use trial mix proportions in the production of mixes.
- To modify the trial mix proportions slightly in the production of mixes.
- To prepare further trial mixes incorporating major changes to the mix proportions.

Trial mixes were prepared in accordance to the requirements of BS 1881-108: 1983 and BS 1881 part 125 which allow the use of aggregates in any of the four moisture conditions;

- i. Oven-dry conditions.
- ii. Air-dried conditions.
- iii. Saturated surface-dry conditions.
- iv. Saturated by soaking in water for at least 24 hours.

The aggregates that was used was brought to saturated surface-dry condition by addition of water of the required amount for absorption by the aggregate as specified in BS 1881-125:1983.

### Gap In Research on Crushed Ceramic Waste

Research on use of ceramic waste as aggregate has primarily dealt on partial replacement of conventional aggregates with ceramic waste in concrete. Research has not shown variation in properties of different classes of concrete when using ceramic waste fully as fine aggregate. This research investigates these concrete properties.

## RESEARCH DESIGN

Experimental research design was employed. The main research method was laboratory research. Samples of concrete mixes containing ceramic waste as fine aggregates was made and subjected to the appropriate tests to determine their properties. Certain properties of ceramic waste aggregates were also determined by laboratory tests as explained below.

The main highlights of the methodology were as below.

1. Collection and crushing of waste ceramic waste to obtain fine aggregate.
2. Sampling
3. Grading of aggregates according to BS 882.
4. Determination of the specific gravity of the aggregates (natural fine, natural coarse and ceramic waste fine aggregate).
5. Determination of the water absorption for the aggregates.
6. Determination of mix designs for the control mixes; 100% natural fine aggregate (sand). Class 25.
7. Conduct fully replacement of control fine aggregate (sand) with crushed ceramic waste fine aggregate.
8. Determine the slump of the various mixes.
9. Establishing the properties of the cured concrete specimen at 7 days, 14 days and 28 days of curing. The properties determined was:
  - Compressive strength
  - Flexural strength
  - Modulus of Elasticity

### Sampling

Crushed ceramic waste aggregate obtained from manual crushing followed by machine grinding was sampled using riffing method. In riffing method, the sample is split into two halves using a riffle box. This is a box with a number of parallel vertical divisions, alternate ones discharging to the left and to the right. The sample is discharged into the riffle box over its full width and the two halves are collected into the boxes at the bottom of the chutes on each side. One half is discarded and riffing of the other half is repeated until the sample is reduced to the desired size.

### Data Collection

The primary source of data was from experiments done at the laboratories. Secondary data was also used. Two types of tests were carried out:

- I. Tests to determine Aggregate properties.
- II. Tests on concrete specimen.

### Tests to Determine Aggregate Properties

#### Sieve Analysis

This is an operation of dividing a sample of aggregate into fractions, each consisting of particles of the same size. Sieve analysis is used to determine particle size distribution.

### Objective

- i. To determine the particle size distribution of specified aggregates.
- ii. To draw grading curves for the aggregates specified.

### Apparatus required

- Balance accurate to 0.5g of mass of test sample.
- Sample splitter
- Test sieves as per BS 882.
- Oven capable of maintaining constant temperature to within 5%.
- Mechanism of shaking sieves. Chart for recoding results.

### Procedure

- The test samples was dried to a constant mass by oven drying at about 105<sup>0</sup>C
- An approximate sample was taken from the original by riffing.
- The required sample was weighed out.
- The sieve of the largest mesh size was placed in the tray and the weighed sample put on to the sieve making sure the sieves are dry and clean before using them.
- The sieve was shaken horizontally with a jerking motion in all directions for at least 2 minutes and until no more than a trace of a sample was passing, ensuring that all material passing fall into the tray.
- Any material retained on the sieve was weighed.
- The results were tabulated. The cumulative weigh passing each sieve was calculated as a percentage of the total sample to the nearest whole number.
- A grading curve for the sample was plotted in the grading chart.

### Calculations

- 1) Record the various masses on a test data sheet.
- 2) Calculate the mass retained on each sieve as a percentage of the original dry mass.
- 3) Calculate the cumulative percentage of the original dry mass passing each sieve down to the smallest aperture sieve (see table 6 and 7).

### Water Absorption

The absorption of the aggregate can influence such properties of concrete as the workability. Water absorption of aggregate can interfere with effective water-cement ratio if not checked. High level of absorption in aggregates reduces the workability of concrete (Hye-Yang Kim, 2011).

**Table 7:** Fine aggregate sieve analysis results table.

Test Sieve (mm)	Mass Retained (g)	Mass Passing (g)	Percentage Retained by Mass (g)	Percentage Passing by Mass (g)
9.52				
4.75				
2.38				
1.2				
0.60				
0.30				
0.15				
Pan				
Total				

**Table 8:** Coarse aggregate sieve analysis results table

Test Sieve (mm)	Mass Retained (g)	Mass Passing (g)	Percentage Retained by Mass (g)	Percentage Passing by Mass (g)
38.1				
25				
20				
10				
5				
2.38				
Pan				
Total				

### Specific Gravity

Specific gravity affects the volume of substitution of aggregates in concrete in order to produce equivalent mixture (A. E. B. CABRAL, 2008). Specific gravity is thus important in estimating the volume of components (cement, aggregate and water).

#### Apparatus required

- Digital weighing balance.
- Container of steel or enamelled iron with rubber plate.
- Wire basket of opening 3mm or less, diameter 20 cm and height 20 cm.
- Large absorbent material

#### Procedure (For fine aggregates)

##### Preparing the Sample

- A representative sample was obtained by riffing.
- The sample was washed thoroughly with water to remove the dust on the surface of the grain and soaked in water at 25°C for 24 hours.
- The specimen was removed from water, shaken off, and rolled in large absorbent cloth until all the visible films of water was removed.
- The large particles were wiped individually.

- The sample was divided into three parts (Sample S1, Sample S2 and Sample S3) to use each for one test.

#### Testing

- The sample was weighed to the nearest 0.5 g ( $W_s$ ) to achieve a saturated surface dry condition.
- It was then placed in the wire basket, immersed in water at room temperature, and tapped to remove entrapped air on the surface and between the grains. It was then weighed while immersed ( $W_w$ ).
- The sample was removed from the water, dried in drying oven to constant weight at the temperature of 105°C and cooled at room temperature and then weighed to the nearest 0.5g ( $W_d$ ).

#### Analysis of Results

Weight of the materials was recorded in the table 8.

The various parameters were determined as follows. The Results was tabulated.

- ❖ Specific gravity on saturated- surface dry basic

$$= \frac{W_s}{W_s - W_w}$$

- ❖ Absolute dry specific gravity

$$= \frac{W_d}{W_s - W_w}$$

- ❖ Water absorption (% of dry weight)

**Table 9:** Specific gravity and water absorption result table.

Material Sample	Surface dry condition ( $W_s$ )	Submerged Weight ( $W_w$ )	Dry Weight ( $W_d$ )	Specific Gravity Saturated-Surface dry	Absolute Dry Specific Gravity (g)	Water absorption (%)
S1						
S2						
S3						
AVERAGE						

$$= \frac{W_s - W_d}{W_d}$$

**Mix Design**

A control mix with 100% fine aggregate was done using the mix design procedure as stipulated in DOE mix design process. The results of the mix design are as on appendices D and E. stages of mix design are:

1. Selection of Target Water/Cement (W/C) ratio.
2. Selection of free – water content.
3. Determination of cement content.
4. Determination of total aggregate content.
5. Selection of fine and coarse aggregate content.
6. Mix proportioning.

**Special Treatment of Crushed Ceramic Waste (CCW) Aggregate Before Casting**

- ❖ Fines in CCW was reduced by sieving through 4.75mm and discarding a fraction of the fines to reduce amount of fines to less than 5% (mass fraction) as per the requirements of Table 2 BS8500-2-2002.
- ❖ Crushed ceramic waste fine aggregate was sprinkled with water to achieve Saturated Surface Dry condition before casting.

**Batching**

Weight batching was used lather than volume batching to cater for bulking of sand. Bulking of sand causes a certain weight of sand to occupy a larger volume. Volume batching cause concrete to appear stony and is prone to segregation and honey combing. Steps taken to achieve saturated surface-dry condition;

1. The batch weights of fine and coarse dry aggregates required for the trial mix was calculated by multiplying the batch weights derived from mix design by  $\frac{100}{100 \times A}$ , where A is the percentage by weight of the water needed to bring the aggregate to the saturated surface - dry condition.
2. The dry aggregates was brought to a saturated surface-dry condition before mixing process by addition

of the required amount of water for absorption by the aggregate according to BS 1881-125:1983.

3. Increasing the weight of mixing water to allow for the absorption of some mixing water by the dry aggregate during mixing process.

Batching of concrete materials by weight may be expressed as follows;

$$Wt_{(C)} + Wt_{(CA)} + Wt_{(FA)} + Wt_{(AIR)} = Wt_{(CC)}$$

Where;

$Wt_{(C)}$  = Weight of cement.

$Wt_{(CA)}$  = Weight of coarse aggregate.

$Wt_{(FA)}$  = Weight of fine aggregate.

$Wt_{(AIR)}$  = Weight of entrained air.

$Wt_{(CC)}$  = Weight of compacted concrete.

**Trial Mixes and Curing**

Trial mixes was checked during the mixing process to determine adjustment of water content. Adjustments in water content were based on the workability of the mix. The curing method that was used is the immersion method. The specimens shall be weighed and then immersed in water. Curing shall be done at room temperature. This is done according to the *BS 1881 Part 111*.

**Tests on Concrete Specimen**

**Slump Test**

The slump test is the most well-known and widely used test method to characterize the workability of fresh concrete. This is an expensive test, which measures consistency, is used on job sites to determine rapidly whether a concrete batch should be accepted or rejected.

**Apparatus**

- Mould in the shape of a frustum of a cone with a base diameter of 8 inches, a top diameter of 4 inches, and a height of 12 inches.



**Table 10:** Compressive Strength Results table

Material	Cube Label	Compressive Strength (N/mm <sup>2</sup> )		
		Day 7	Day 14	Day 28
Class 25	A1			
	B1			
	C1			
	Average			

- Tamping rod

#### **Procedure**

- The mould was filled with concrete in three layers of equal volume.
- Each layer was compacted with 25 strokes of a tamping rod.
- The slump cone mould was lifted vertically upward and the change in height of the concrete was measured.

#### **Compressive Strength Test**

The compressive strength is the most common performance measure used by the engineer in design of concrete structures. Compressive strength was measured by crushing 150 mm cubes on the universal testing machine. Compressive test is done as per (BS EN 12390: 2001).

#### **Apparatus**

- Compression Testing Machine

#### **Procedure**

- The specimen was placed in the machine with the two cast faces in contact with the platens of the testing machine.
- The load was applied at a rate of 14N/mm<sup>2</sup> until failure occurred.
- The compressive strength was recorded to the nearest 0.1N/mm

#### **Tensile Strength Test BS 1881:117 – 1983**

The method adopted was the indirect tensile splitting test of cylindrical concrete specimens.

#### **Apparatus**

- Cylinder moulds 100mm diameter
- Tensile testing machine
- Poker vibrator

#### **Casting**

#### **Procedure**

- Concrete mixes was prepared and the fresh concrete cast in 100mm diameter moulds.
- Compaction was done in three layers using a poker vibrator to achieve the required compaction.
- The upper surfaces of the cylinders were then smoothed using a plasterer's float and the outside of the moulds wiped clean.
- The specimens was then stored in an undisturbed environment for 24 hours then cured in a curing tank for the required number of days.

#### **Tensile splitting test**

#### **Procedure**

- The test specimens after curing for the required age was then removed and wiped.
- The specimens were then placed in the centring jig with loading pieces carefully positioned along the top and bottom of the plane of the loading system.
- The load was then applied and gradually increased at a normal rate of 0.02-0.04N/ mm<sup>2</sup> and maintained until failure of the specimens.
- The maximum loads applied to each specimen were then recorded.

The tensile splitting strength was computed as shown below;

$$\sigma_{ct} = \frac{2F}{\pi \times l \times d}$$

Where; F = Maximum load at failure (N)

$l$  = Length of specimen.

$d$  = Cross – sectional area of the specimen.

Tensile strength of normal concrete usually varies from 1/8<sup>th</sup> of compressive strength at early stages to about 1/20<sup>th</sup> later. Tensile strength is of crucial importance in resisting cracking due to changes in moisture content. Tensile tests are sometimes used for concrete roads and airfields (table 10).

**Table: 11:** Tensile strength results table

Material	Beam Cylinder Label	Maximum Load (N) Day 28	Flexural strength (N/mm <sup>2</sup> )
Class 25 (N/mm <sup>2</sup> )	Ac1		
	Bc2		
	Cb3		
	Average		

**RESULTS AND DISCUSSION**

The data was collected and analysed and the processed data is presented in this chapter.

**Mix Design**

Control mix 25 with 100% river sand were done using the mix design procedure as stipulated in DOE mix design process. Percentage passing 0.6mm sieve in river sand was 47.12%. For the trial mix 0.070862 m<sup>3</sup> was required for the class. A factor of 1.3 was used to cater for losses during casting. Water/Cement ratio in table 11 was

**Table: 12:** Mix design per cubic meters of concrete

1. C25 0.57

Concrete Class (N/mm <sup>2</sup> )	Coarse Aggregate (kg/m <sup>3</sup> )	Sand (kg/m <sup>3</sup> )	Cement (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )	W/C Ratio
25	985	840	360	210	0.57

**Table: 13:** Compressive strength development

	Compressive Strength N/mm <sup>2</sup>	
	Control	Ceramic
0	0	0
7	16.595	13.463
14	19.218	16.231
28	24.534	21.517

**Properties of Fresh Concrete**

**Compressive Strength Test**

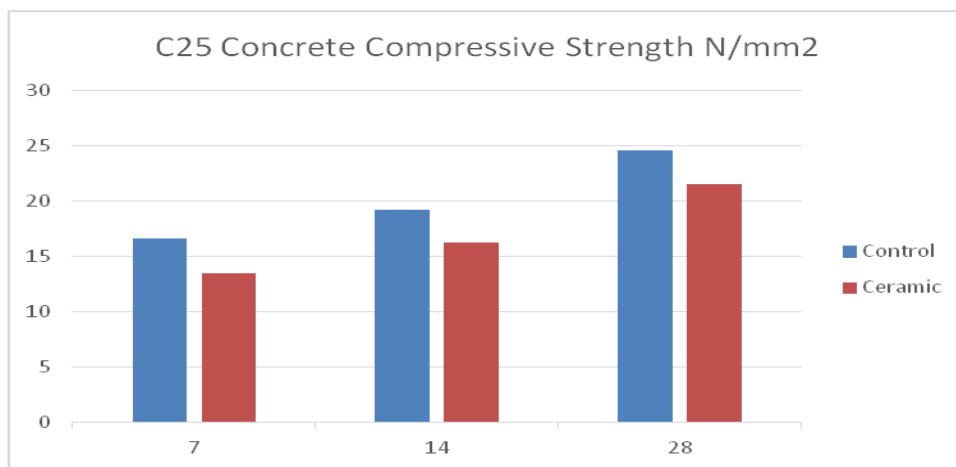
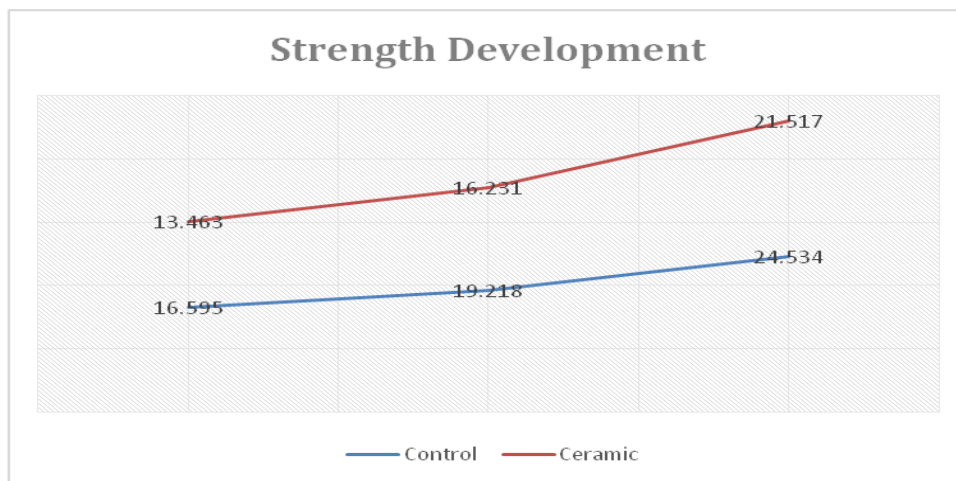
Concrete class 25 from the cast cubes was tested for compressive strength at 7, 14 and 28 days in accordance to BS 1881: part 116. Compressive strength of concrete cast increased with age. The table 12, 13 and figure 4 and shows the results.

**Discussion.**

Compressive strength of ceramic waste concrete reduced in classes 25 that was tested. Control class 25 conformed to the required standard that requires the test results of compressive test not to deviate by more than or equal to 3N/mm<sup>2</sup> of the required compressive strength for class 20 and above. Class 25 concrete using crushed ceramics as fine aggregate deviated with 3.483 N/mm<sup>2</sup> thus it did not meet the requirement in BS 5328: 1990:

**Table 14:** Compressive Strength deviation from expected strength

	Compressive Strength N/mm <sup>2</sup>	
	C25	
	Control	Ceramic
28 days Strength	24.534	21.517
Expected Strength	25	25
Strength deviation	0.466	3.483

**Figure 4:** Compressive strength**Figure 5 :** Compressive strength development

part 4 Table 1.

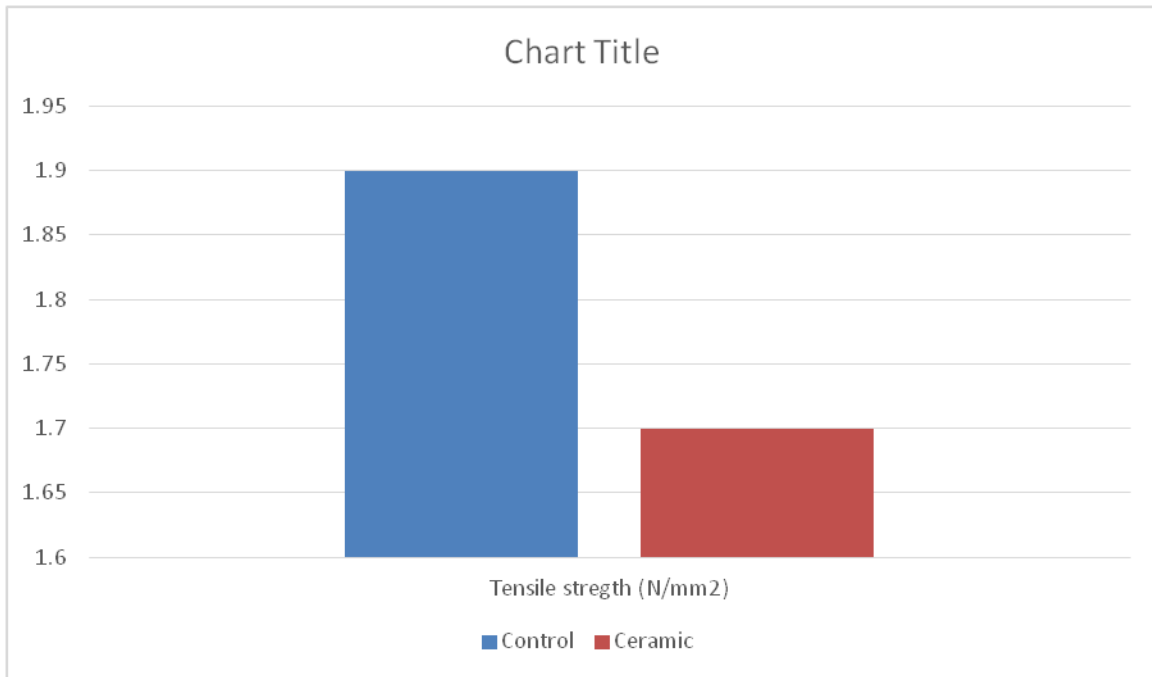
#### Tensile Strength Test BS 1881:117 – 1983

Concrete cylinders were cured for 28 days and tested using indirect tensile splitting test method.

Concrete using river sand achieved a higher strength compared to crushed ceramic tensile strength. Concrete is poor in tensile strength but regardless it is important to prevent cracking (table 14 and figure 6).

**Table 15:** Tensile Strength (N/mm<sup>2</sup>)

	Tensile strength (N/mm <sup>2</sup> )	
	C25	
	Control	Ceramic
28 day Tensile Strength	1.9	1.7



**Figure 6:** Tensile strength.

**Table 16:** Fresh concrete slump results

	Slump.	
	C25	
	Control	Ceramic
Slump (mm)	44	15

**Discussion.**

The tensile strength of concrete with ceramics as fine aggregate slightly decreased in C25 concrete. Concrete is not designed to withstand tensile loads but is required to resist cracking.

**Slump Test**

The graph below shows that river sand had a higher workability compared to crushed ceramic fine aggregate which had a stiffer mix. Variation of workability of the mix was affected by water absorption of different aggregates used (table 15 and figure 7).

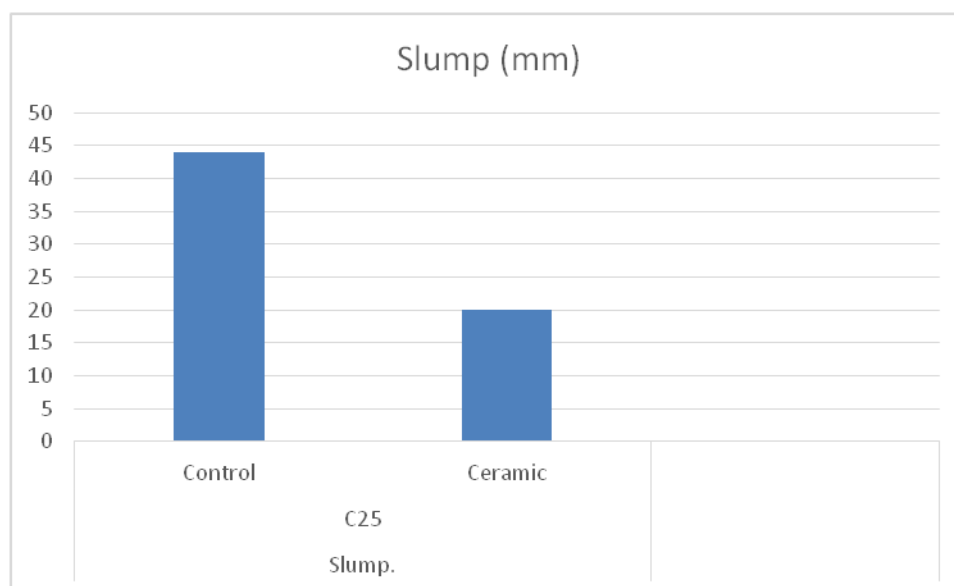


Figure 7: Slump test

Table 17: Sand sieve analysis

Sieve No.	Sieve Size(mm)	Weight of sieve (g)	Weight of Retained sand and sieve	Weight of Retained sand	Cumulative Retained	Cumulative Passing	% Passing	% Upper Limit	% Lower Limit
10	10	501.5	504.5	3	3	992.5	99.70	100	100
5	5	483.5	507	23.5	26.5	969	97.34	100	91
2.36	2.36	254.5	271	16.5	43	952.5	95.68	100	65
1.2	1.2	582	729.5	147.5	190.5	805	80.86	96	44
0.6	0.6	408.5	744	335.5	526	469.5	47.16	80	24
0.3	0.3	392.5	623	230.5	756.5	239	24.01	48	4
0.15	0.15	362.5	552	189.5	946	49.5	4.97	10	1
Pan	0.01	301.5	351	49.5	995.5	0	0.00	0	0
Sum	995.5								

### Discussion.

Slump test for ceramic fine aggregate reduced in C25 concrete. The slump was affected by water absorption of the aggregates.

### Physical Properties of Aggregates

#### Sieve Analysis BS 882-1992

Sieve analysis of river sand used in control concrete conformed to zone 2 grading according to Bs

882-1992. Graph showing upper and lower limits of fine aggregate are shown in figure 4. Crushed ceramic fine aggregate contained less fines passing 0.6mm sieve. Graph of upper and lower limits of fine aggregate and crushed ceramic fine aggregate shown in figure 5 was within the limits hence no need for adjustment.

Sieve analysis of crushed coarse aggregate used was within the recommended limits as shown in figure 6.

### Discussion.

Sieve analysis of ceramic fine aggregate and river sand was conducted and it conformed to the required



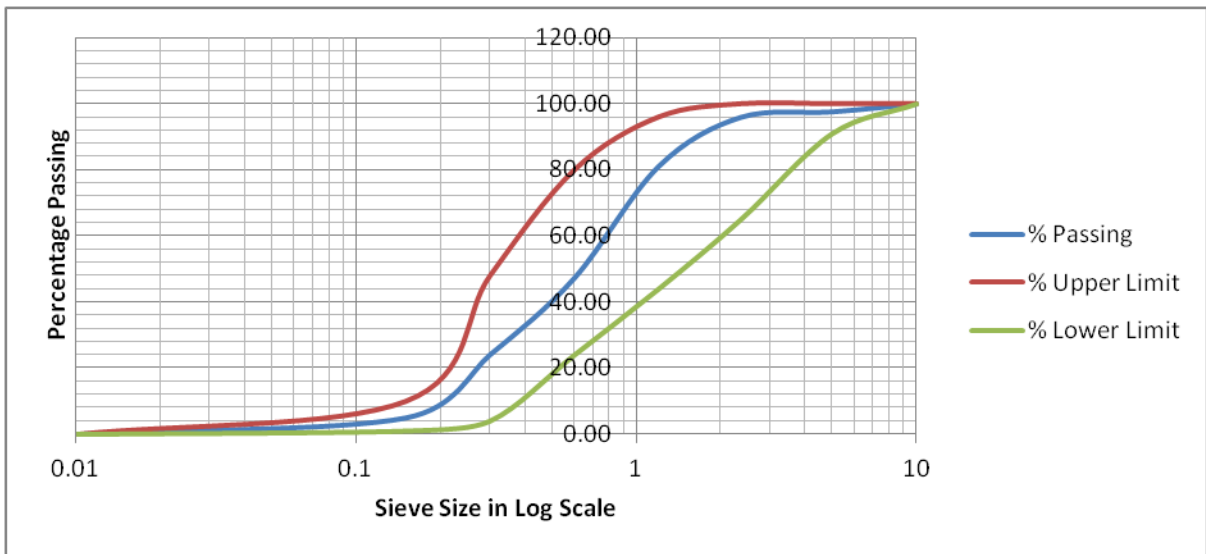


Figure 8: Sieve analysis of sand in log scale

Table 18: Crushed ceramic sieve analysis

Sieve No.	Sieve Size(mm)	Weight of sieve (g)	Weight of Retained sand and sieve	Weight of Retained sand	Cumulative Retained	Cumulative Passing	Ceramic % Passing	% Upper Limit	% Lower Limit
10	10	501.5	501.5	0	0	987	100.00	100	100
5	5	483.5	492.5	9	9	978	99.09	100	91
2.36	2.36	254.5	379	124.5	133.5	853.5	86.47	100	65
1.2	1.2	582	855.5	273.5	407	580	58.76	96	44
0.6	0.6	408.5	639	230.5	637.5	349.5	35.41	80	24
0.3	0.3	392.5	642.5	250	887.5	99.5	10.08	48	4
0.15	0.15	362.5	417	54.5	942	45	4.56	10	1
Pan	0.01	301.5	346.5	45	987	0	0.00	0	0
Sum	987								

standard according to Bs 882-1992. Particle distribution of crushed aggregate depends on the crushing machinery and blending. Crushed ceramic aggregate using the improvised diesel powered crusher that is shown in Figure15 attained the required particle distribution.

**Water Absorption**

Crushed ceramic fine aggregate percentage water absorption was three times that of river sand. Water absorption affects workability of mix. Addition water was required to be sprinkled on crushed ceramic fine aggregate to achieve saturated surface dry condition (table 18,19 and figure11).

**Discussion.**

Crushed ceramic fine aggregate had higher water absorption of 16.92% compared to 5% for river sand. Ceramics’ high water absorption resulted to a lower workability. To improve workability of concrete made using crushed ceramic as fine aggregate, the aggregate should be at saturated surface dry condition.

**Specific Gravity**

Crushed ceramic fine aggregate had a lower specific gravity as compared to river sand used. Specific gravity influences the density of concrete produced. Crushed ceramic fine aggregate concrete was expected

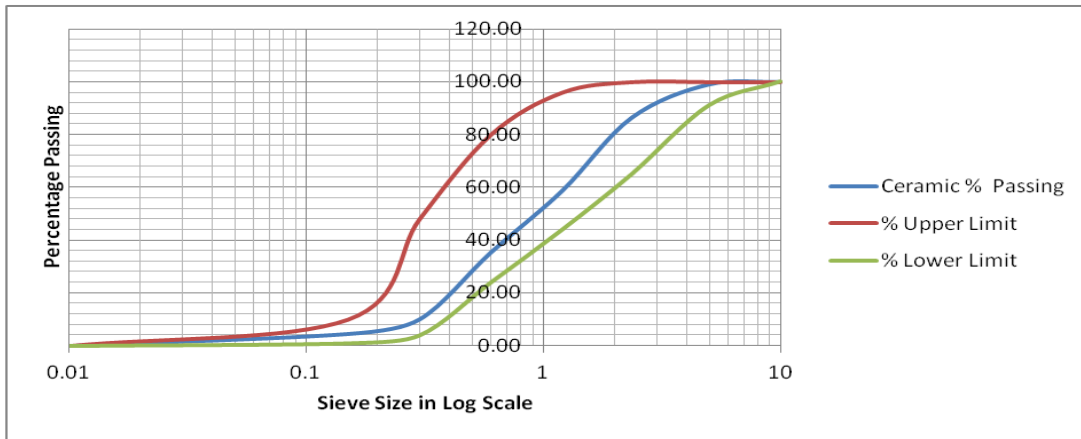


Figure 9: Crushed ceramic sieve analysis in log scale

Table 19: Coarse aggregate sieve analysis

Coarse Aggregate			
Sieve size(mm)	Upper Limit	Lower Limit	Ballast Used
1	0	0	0
5	16	4	10
10	60	30	52
15	85	60	80
20	98	91	94
25	100	96	100
30	100	99	100
37.5	100	100	100

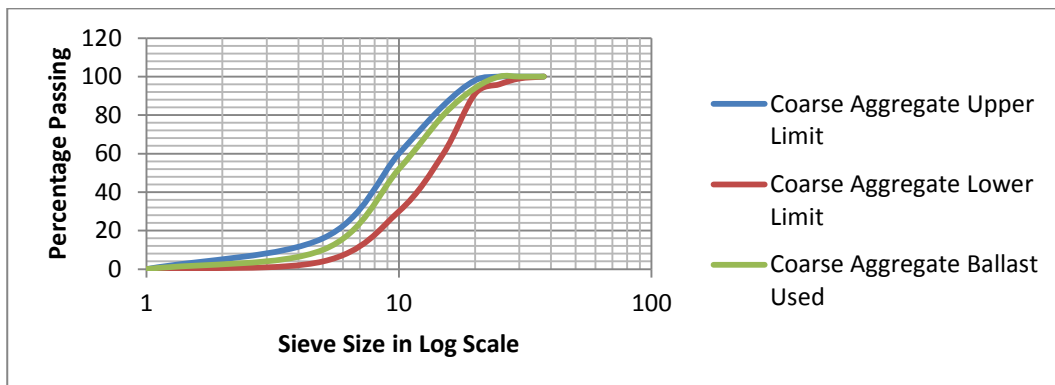


Figure 10: Coarse aggregate sieve analysis in log scale

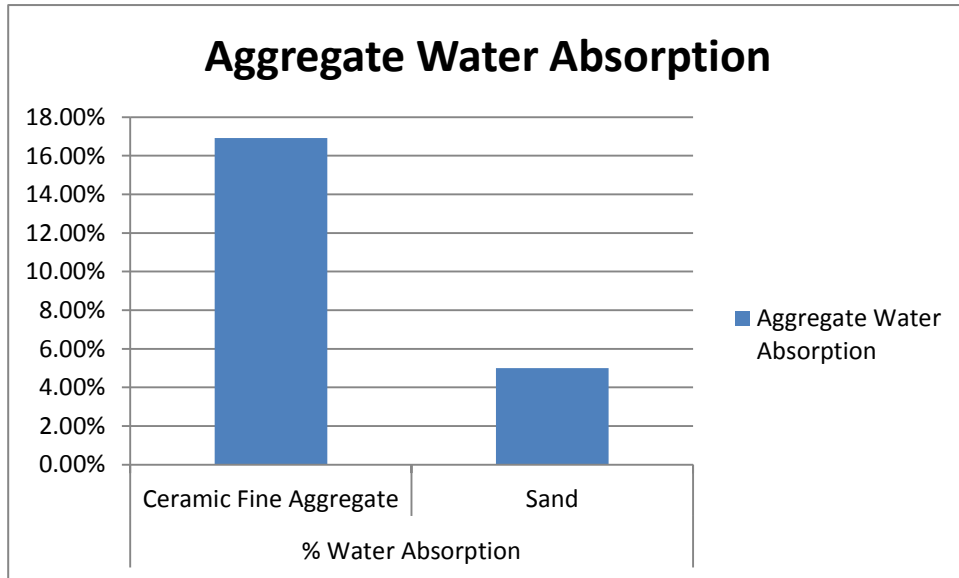
to have a lower density (table 20 and figure 12).

Ceramic fine aggregate had a lower specific gravity of 2.53 compared to 2.62 for river sand. Specific

gravity affects density thus concrete produced and the density of ceramic concrete was expected to reduce.

**Table 20:** Fine Aggregate Water Absorption

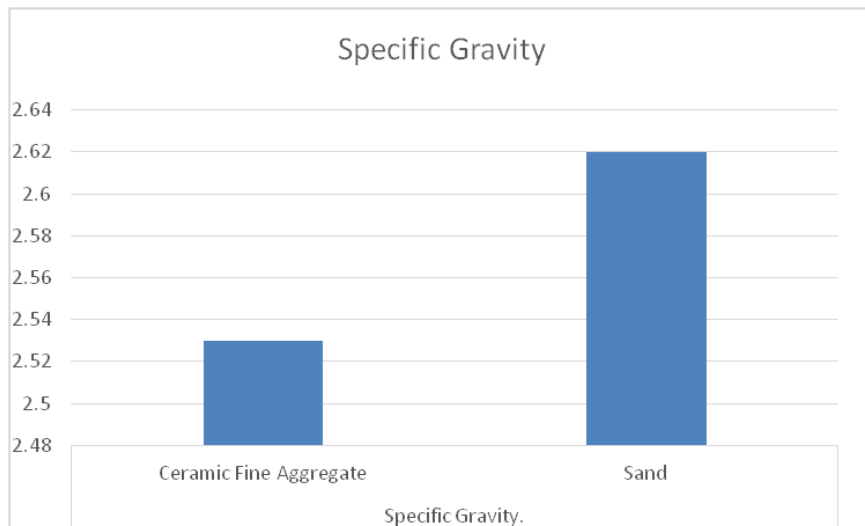
% Water Absorption	
Ceramic Fine Aggregate	Sand
16.92%	5.00%



**Figure 11:** Fine Aggregate Water Absorption

**Table 21:** Aggregates' specific gravity

Specific Gravity.	
Ceramic Fine Aggregate	Sand
2.53	2.62



**Figure 12:** Aggregate specific gravity

### Conclusion.

Concrete produced by full replacement of river sand in concrete do not acquire compressive, tensile strengths greater than or equal to that of river sand hence crushed ceramic fine aggregate should not be used as a replacement of river sand for Class 25 tested.

### CONCLUSIONS AND RECOMMENDATIONS

The objectives of the project were met and physical properties of concrete made using ceramic waste as fine aggregate were determined. From the study,

- i. The compressive strength of concrete with ceramics as fine aggregate slightly decreased in Class 25 concrete. Class 25 concrete with ceramic waste as fine aggregate did not meet the required strength at 28 days.
- ii. The tensile strength of concrete with ceramics as fine aggregate slightly decreased in Class 25 concrete. Concrete is not designed to withstand tensile loads but is required to resist cracking.
- iii. Slump test for ceramic fine aggregate reduced in the batch 25. The slump was affected by water absorption of the aggregates.
- iv. Sieve analysis of ceramic fine aggregate and river sand was conducted and it conformed to the required standard according to Bs 882-1992. Particle distribution of crushed aggregate depends on the crushing machinery and blending. Crushed ceramic aggregate using the improvised diesel powered crusher attained the required particle distribution.
- v. Crushed ceramic fine aggregate had higher water absorption of 16.92% compared to 5% for river sand. Ceramics' high water absorption resulted to a lower workability.
- vi. Ceramic fine aggregate had a lower specific gravity of 2.53 compared to 2.62 for river sand. Specific gravity affects density thus concrete produced and the density of ceramic concrete was expected to reduce.
- vii. Concrete produced by full replacement of river sand in concrete did not acquire compressive, and tensile strengths greater than or equal to that of river sand hence crushed ceramic fine aggregate should not be used as a replacement of river sand for class 25 tested.

### RECOMMENDATIONS

- i. Class 25 concrete with ceramic waste as fine aggregate which is structural concrete cannot be used as it did not meet the required strength at 28 days.

- ii. To improve workability of concrete made using crushed ceramic as fine aggregate, the aggregate should be at saturated surface dry condition.

### ACKNOWLEDGEMENT

I would like to sincerely give my deepest appreciation to the following personalities for their technical advice, knowledge and information in this proposal. Their fulfilling contribution from the commencement of the research has led to the success of this proposal. Also Dr. Siphila Wanjiku Mumenya, Chairperson of Civil and Construction Engineering Department and Mrs. Roslyn giving me the opportunity to use the Highways lab. Mr. Muchina for allowing me to use his Concrete lab.

I particularly give appreciation to my supervisor, Dr. Siphila Wanjiku Mumenya for the essential technical advice and provision of solutions towards the challenges throughout the project proposal.

I cannot forget my fellow students for their advice.

### REFERENCES

- B. J. Odero, R. N. Mutuku and C. K. Kabubo (2014). A review on mechanical characteristics of normal concrete partially replaced with recycled ceramics aggregates, *JKUAT journals*. 379-387
- F Pacheco-Torgal, S Jalali, (2010). Reusing ceramic wastes in concrete. *Construction and Building Materials*, 24, 832-838
- Progress Report. (2009). *Cement Sustainability Initiative (CSI)*. p. 3
- Veera Reddy, M, (2010). Investigations on stone dust and ceramic scrap as aggregate replacement in concrete. *International journal of civil and structural engineering* Volume 1, No. 3, ISSN 0976 – 4399.
- Turgut, P. and Yahlizade, E. S. (2009). Research into Concrete Blocks with Waste Glass. *International Journal of Civil and Environmental Engineering*, 1: pp 4.
- Padmini, A. K., Ramamurthy, K., and Mathews, M. S. (2001). Behavior of concrete with lowstrength bricks as lightweight coarse aggregate. *Magazine of Concrete Research*, 53 (6), pp 367-375
- The concrete society Ci80 (1980). *Lightweight aggregates*. London UK
- Punit Malik, Jatin Malhotra, Arjun Verma, Piyush Bhardwaj, Akhil Dhoundyal and Nitin Yadva (2014). *International Journal of Civil Engineering Research*. ISSN 2278-3652 Volume 5, Number 2, pp. 151-154

- De Brito, J., Pereira, A. S. and Correia, J. R. (2005). Mechanical behaviour of nonstructural concrete made with recycled ceramic aggregates. *Cement & Concrete Composites*, 27, 429-433
- Naik, Tarun R., and Moriconi, G. (2005), Environmental-Friendly Durable
- Ay, N. and Unal, M. (2000). The use of waste ceramic tile in cement production. *Cement and Concrete Research*, 30, pp 497-499.
- Weil, M., Jeske, U. & Schebek, L. (2006). Closed-loop recycling of construction and demolition waste in Germany in view of stricter environmental threshold values.
- Akhtaruzzaman, A. A. and Hasnat, A. (1988). Properties of concrete using crushed bricks as aggregate. *Concrete International*, 5(2), pp 58–63
- Koyuncu, H.; Guney, Y.; Yilmaz, G.; Koyuncu, S.; Bakis, R. Utilization of ceramic wastes in the construction sector. *Key Engineering Materials*, vol. 264 – 268 (2004), pp. 2509 – 2512
- Nadeem, M. and Pofale, A. D. (2012) Replacement of Natural Fine Aggregate with Granular Slag - A Waste Industrial By-Product in Cement Mortar Applications as an Alternative Construction Materials, *International Journal of Engineering Research and Applications*, 1258 -1264.
- Cachim, P.B. (2009) Mechanical properties of brick aggregate concrete. *Construction and Building Materials*, vol. 23, Issue 3, (March 2009), 1292 – 1297, 0950-0618.
- Khaloo, A. R. (1995). Crushed tile coarse aggregate concrete. *Cement and Concrete Aggregate*, No. 2, 17 pp 119-25.
- P.K. Mehta and P.J.M. Monteiro(2005), Concrete: Microstructure, Properties, and Materials. *Aggregates for concrete*
- A. E. B. CABRAL, V. S. (2008, June 2). Influence of the type of recycled aggregate from construction and demolition waste on the module of deformation of recycled aggregate concrete. *IBRACON STRUCTURES AND MATERIALS JOURNAL*, 171-192.
- D. Tavakoli; A. Heidari and M. Karimian. (2013). PROPERTIES OF CONCRETES PRODUCED WITH WASTE CERAMIC TILE AGGREGATE. *ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC)*, 14, 369-382.
- Hye-Yang Kim, B.-S. C.-H.-S. (2011). An investigation on the recycling of waste concrete on cementitious material. *Journal of Ceramic Processing Research*, 202-206.
- Siddesha, H. (2011). Experimental Studies on the Effect of Ceramic fine aggregate on the Strength properties of Concrete. *International Journal of Advances in Engineering, Science and Technology (IJAEST)*.
- L. J Murdock, K. M. Brook and J. D. Dewar (1991), *Concrete Materials and practice*, 6th Edition; London Melbourne Auckland, London.
- Sudarsana Rao hunchate, G. V. (2013, November 11). Influence of Water Absorption of the Ceramic Aggregate on Strength Properties of Ceramic Aggregate Concrete. *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 2.
- R. Kamala, B. Krishna Rao. (October, 2012). *International Journal of Engineering and Advanced Technology (IJEAT)* ISSN: 2249 – 8958, Volume-2, Issue-1.

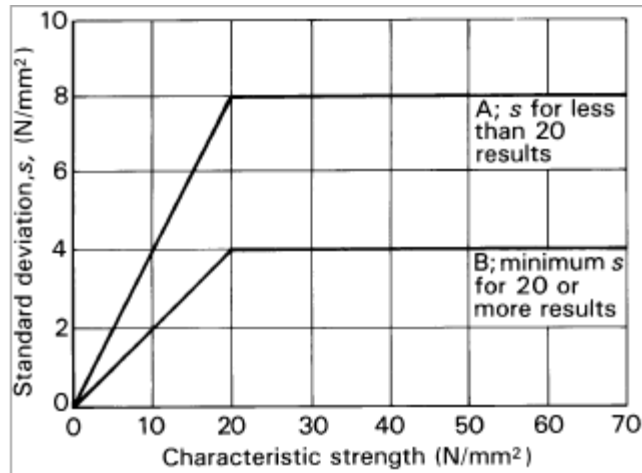
BS 812: 102:1989

BS EN 12620:2002 (E)

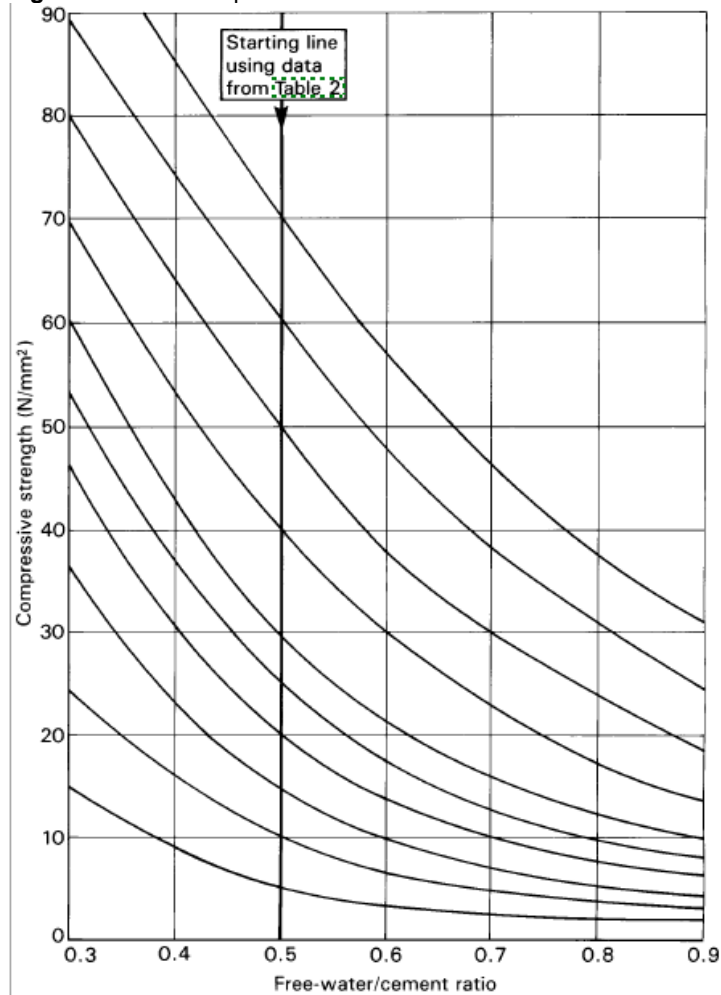
BS 5328: 1990: part 4 Table 1



**APPENDIX  
APPENDIX A: THE MIX DESIGN PROCESS**



**Figure 3:** Relationship between standard deviation and characteristic strength



**Figure 4:** Relationship between compressive strength and free-water/cement ratio

**The margin; Equation C1**

The margin may be derived from the calculation below;

$$M = k \times s \dots\dots\dots C1$$

Where;  $M$ = The margin.

$k$ = A value appropriate to the 'percentage defectives' permitted below the characteristic strength.

$s$ = The standard deviation

**The target mean strength; Equation C2**

$$f_m = f_c + M \dots\dots\dots C2$$

Where;  $f_m$ = The target mean strength

$f_c$ = The specified characteristic strength

$M$ = The margin

**Cement content; Equation C3**

$$\text{Cement content} = \frac{\text{free - water}}{\text{cement Ratio}} \dots\dots\dots C3$$

**Total Aggregate content; Equation C4**

$$\text{Total aggregate content (saturated surface - dry)} = D - WC - WFW \dots\dots\dots C4$$

Where;  $D$ = The wet density of concrete ( $\text{Kg/m}^3$ )

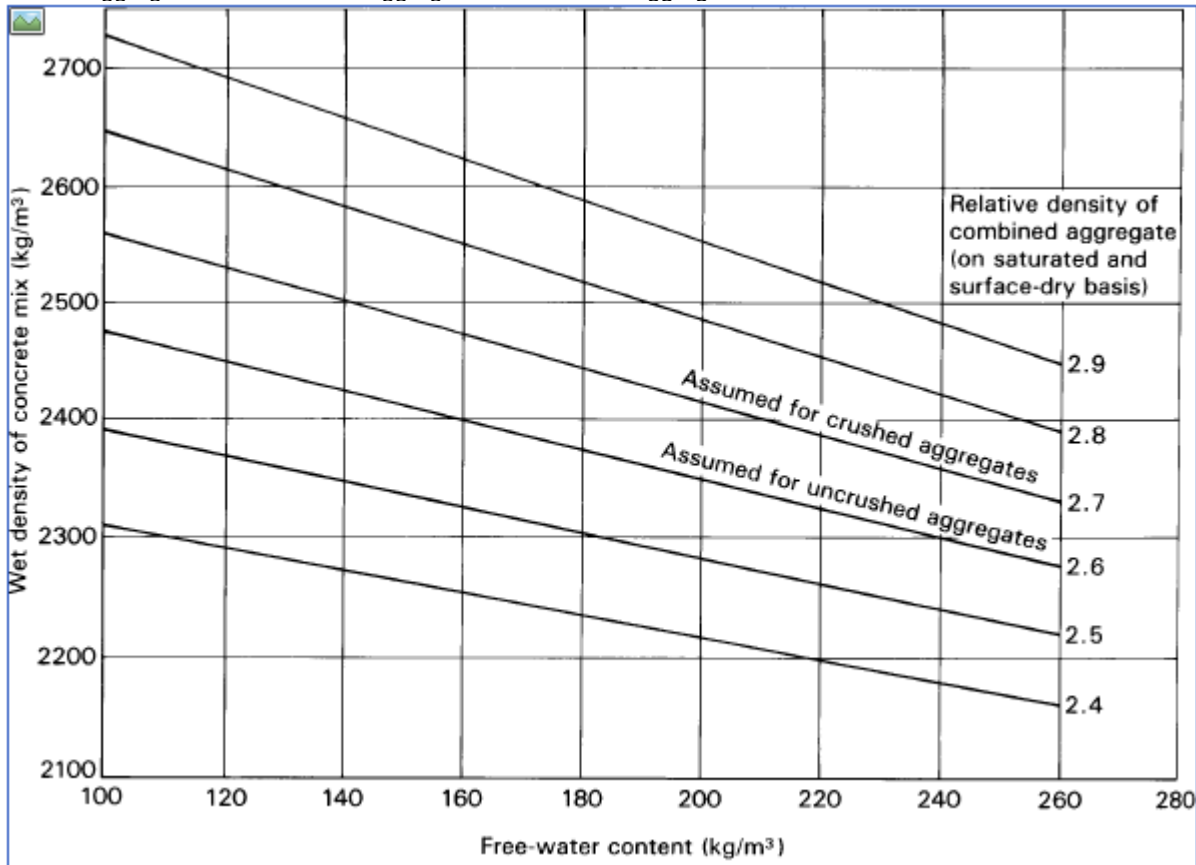
$WC$ = The cement content ( $\text{Kg/m}^3$ )

$WFW$ = The free - water content ( $\text{Kg/m}^3$ )

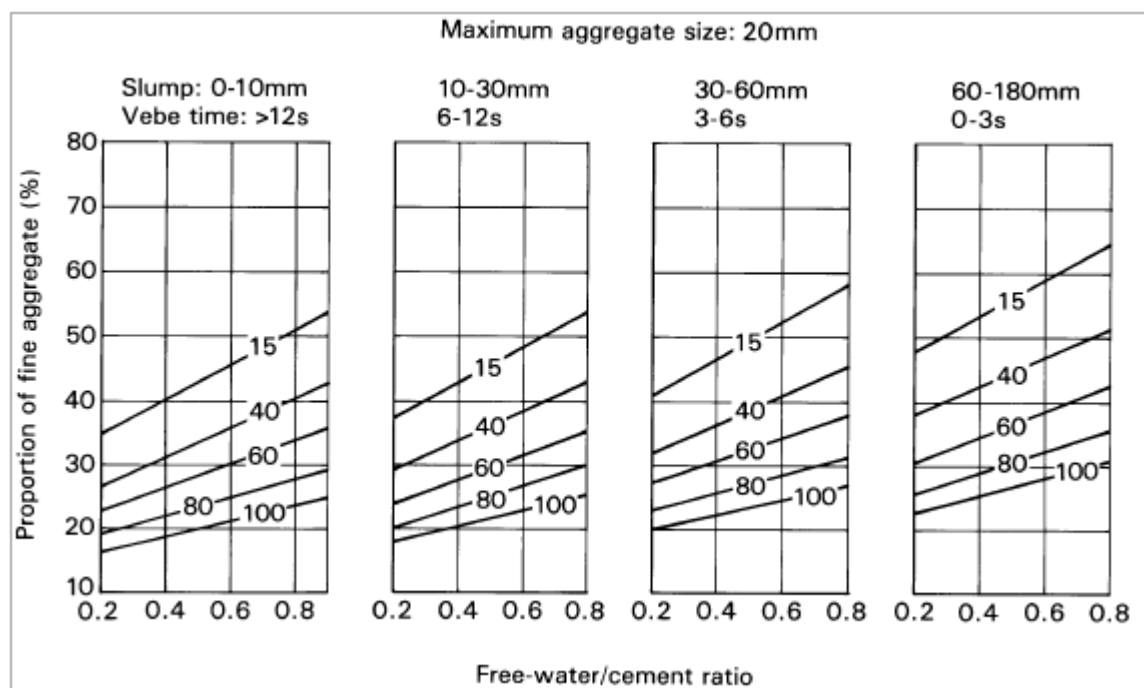
**Fine and coarse aggregates contents; Equation C5**

Fine aggregate content = Total aggregate content  $\times$  Proportion of fines

Coarse aggregate content = Total aggregate content - fine aggregate content  $\dots\dots\dots C5$



**Figure 5:** Estimated wet density of fully compacted concrete



**Figure 6:** Recommended proportions of fine aggregate according to percentage passing a 600  $\mu\text{m}$  sieve

Standard sieve (mm)	Percentage by weight passing standard sieves			
	Grading zone 1	Grading zone 2	Grading zone 3	Grading zone 4
10	100	100	100	100
5	90-100	90-100	90-100	95-100
2.36	60-95	75-100	85-100	95-100
1.2	30-70	55-90	75-100	90-100
0.6	15-34	35-59	60-79	80-100
0.3	5-20	8-30	12-40	15-50
0.15	0-10	0-10	0-10	0-15

**Table 22:** Grading limits for DOE mix design procedure

Type of cement	Type of coarse aggregate	Compressive strengths (N/mm <sup>2</sup> )			
		Age(days)			
		3	7	28	91
Ordinary Portland Cement (OPC)	Crushed	18	27	40	48
	Uncrushed	23	33	47	55
Rapid Hardening Portland Cement (RHPC)	Crushed	25	34	46	53
	Uncrushed	30	40	53	60

**Table 23:** Approximate compressive strengths (N/mm<sup>2</sup>) of concrete mixes made with a free- water/cement ratio of 0.5

Slump (mm) Or V – B (s)		0 – 10 >12	10 – 30 6 – 12	30 – 60 3 – 6	60 – 180 0 – 3
Max. size of aggregates (mm)	Type of aggregate				
10	Uncrushed Crushed	150 180	180 205	205 230	225 250
20	Uncrushed Crushed	135 170	160 190	180 210	195 225
40	Uncrushed Crushed	115 155	140 175	160 190	175 205

**Table 24:** Approximate free – water contents (Kg/m<sup>3</sup>) required to give various levels of workability.

28-Day Compressive Strength in MPa (psi)	Water-cement ratio by weight	
	Non-Air-Entrained	Air-Entrained
41.4 (6000)	0.41	–
34.5 (5000)	0.48	0.40
27.6 (4000)	0.57	0.48
20.7 (3000)	0.67	0.59
13.8 (2000)	0.82	0.74

**Source:** ACI, 2000 - Table 5.17

Flow chart of procedures

Concrete mix design form							
				Job title .....			
Stage	Item	Reference or calculation	Values				
1	1.1	Characteristic strength	Specified	{ ..... N/mm <sup>2</sup> at ..... days Proportion defective ..... %			
	1.2	Standard deviation	Fig 3	..... N/mm <sup>2</sup> or no data ..... N/mm <sup>2</sup>			
	1.3	Margin	C1 or Specified	(k = ..... ) ..... × ..... = ..... N/mm <sup>2</sup> ..... N/mm <sup>2</sup>			
	1.4	Target mean strength	C2	..... + ..... = ..... N/mm <sup>2</sup>			
	1.5	Cement strength class	Specified	42.5/52.5			
	1.6	Aggregate type: coarse Aggregate type: fine		Crushed/uncrushed Crushed/uncrushed			
	1.7	Free water /cement ratio	Table 2, Fig 4	} Use the lower value <input type="text"/>			
	1.8	<i>Maximum free-water / cement ratio</i>	<i>Specified</i>				
2	2.1	Slump or Vebe time	Specified	Slump ..... mm or Vebe time ..... s			
	2.2	Maximum aggregate size	Specified	..... mm			
	2.3	Free water content	Table 3	<input type="text"/> kg/m <sup>3</sup>			
3	3.1	Cement content	C3	..... ÷ ..... = ..... kg/m <sup>3</sup>			
	3.2	<i>Maximum cement content</i>	<i>Specified</i>	..... kg/m <sup>3</sup>			
	3.3	<i>Minimum cement content</i>	<i>Specified</i>	..... kg/m <sup>3</sup>			
	3.4	Modified free water /cement ratio		use 3.1 if ≤ 3.2 use 3.3 if > 3.1 <input type="text"/> kg/m <sup>3</sup>			
4	4.1	Relative density of aggregate (SSD)		..... known/assumed			
	4.2	Concrete density	Fig 5	..... kg/m <sup>3</sup>			
	4.3	Total aggregate content	C4	..... - ..... - ..... = ..... kg/m <sup>3</sup>			
5	5.1	Grading of fine aggregate		Percentage passing 600 µm sieve ..... %			
	5.2	Proportion of fine aggregate	Fig 6	..... %			
	5.3	Fine aggregate content	C5	{ ..... × ..... = <input type="text"/> kg/m <sup>3</sup> ..... - ..... = <input type="text"/> kg/m <sup>3</sup>			
	5.4	Coarse aggregate content					
Quantities		Cement (kg)	Water (kg or litres)	Fine aggregate (kg)	Coarse aggregate (kg) 10 mm    20 mm    40 mm		
per m <sup>3</sup> (to nearest 5 kg)		.....					
per trial mix of ..... m <sup>3</sup>		.....					

Items in italics are optional limiting values that may be specified (see Section 7).  
 Concrete strength is expressed in the units N/mm<sup>2</sup>. 1 N/mm<sup>2</sup> = 1 MN/m<sup>2</sup> = 1 MPa. (N = newton; Pa = pascal.)  
 The internationally known term 'relative density' used here is synonymous with 'specific gravity' and is the ratio of the mass of a given volume of substance to the mass of an equal volume of water.  
 SSD = based on the saturated surface-dry condition.

Figure 13: Mix design flow chart

<b>Table 1. Characteristic compressive strength compliance requirements</b>			
<b>Specified grade</b>	<b>group of test results</b>	<b>A</b>	<b>B</b>
		<b>The mean of the group of test results exceeds the specified characteristic compressive strength by at least:</b>	<b>Any individual test result is not less than the characteristic compressive strength less:</b>
C20 and above	first 2	N/mm <sup>2</sup> 1	N/mm <sup>2</sup> 3
	first 3	2	3
	any consecutive 4	3	3
C7.5 to C15	first 2	0	2
	first 3	1	2
	any consecutive 4	2	2

BS 5328: 1990: part 4 Table 1



APPENDIX B: PICTURES.



Figure 14: Collection of ceramic waste from a construction site in Ruaka



**Figure 14:** Crushing ceramics to fine aggregate in JKUAT.



**Figure 15:** Ceramic Waste Crushed to fine aggregate.



**Figure 16:** Curing of concrete cubes in the lab.





**Figure 17:** Performing compressive and tensile strength test in the lab



**Figure 18:** Performing compressive strength test in the lab



Figure 19: Tensile Splitting Test