UNIVERSITY OF NAIROBI

DEPARTMENT OF CIVIL ENGINEERING

FINAL YEAR PROJECT REPORT

Investigating the effect of partial replacement of aggregates by clay waste products in concrete

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This project is submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Science in Civil Engineering

DECLARATION

I, Waleed Esmail, do declare that this report is my original work and to the best of my knowledge, it has not been submitted for any degree award in any university or institution.

Signed ____________________ Date ___________________

CERTIFICATION

I have read this report and approve it for examination.

Signed ____________________ Date ___________________

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I cannot forget my family and friends for their support and motivation throughout this project.

DEDICATION

My dedication goes to my lecturer, family members and fellow students for their support and guidance in this project.

ABSTRACT

The author intends to investigate the performance clay based aggregates in concrete with a view of achieving the target compressive strengths specified in concrete mix design. The author will also explore the performance of clay based aggregates in comparison with the normal granitic aggregates. Particular emphasis being recovery of clay waste from the manufacturing industries such as Kenya Clay Products LTD etc.

Clay waste products have in the past been disposed by either land dumping or filling depressions on roads. The scenario is common among the manufacturing industries. The land dumping disposal method is expensive as it involves excavation of land, transportation of waste product to the disposal site and compaction of the material in layers.

Furthermore, the production of normal aggregates and building stones through quarrying is an expensive process. Quarrying involves deep excavation and blasting of rocks. This has created an unpleasant environment by leaving scars on land. The author developed interest on noticing land degradation in Ndarugu area in Thika district where mining of machine cut stones are extensively produced.

Clay waste products chips when crushed to the required nominal sizes such as 10mm, 14mm, 20mm, 40mm etc. provide a rough and irregular surface which aids in bonding of cement paste and the aggregate. Therefore the bond strength of concrete is likely to be increased when these aggregates are used. Careful consideration of the water absorption of clay based aggregates will be taken in the mix design to ensure that the workability of the mix is achieved.

This project tries to encourage the recovery of waste materials to be used in production of aggregates for concrete hence conserving the environment.

CHAPTER 1
1.0 INTRODUCTION

1.1 Background

Use of waste material as aggregates in civil engineering applications is beneficial because it reduces the environmental impact and economic cost of quarrying operations, processing, and transport. Reuse of construction and demolition waste is becoming increasingly desirable due to rising hauling costs and tipping fees for putting this material into landfills (Robinson et al. 2004). In recent years, sustainable construction initiatives have also made reuse of construction and demolition debris (as aggregates and otherwise) an appealing option when considering design alternatives for many types of structures (Desai 2004). Incorporating these aggregates into cementitious materials is practical, as cementitious materials are non-homogeneous composites that allow material of different sizes and compositions to be bound in a cementitious matrix.

Typical structural clay products are building brick, paving brick, terra-cotta facing tile, roofing tile etc. These products are made from commonly occurring natural materials, which are mixed with water, formed into the desired shape, and fired in a kiln in order to give the clay mixture a permanent bond. With the large amount of brick masonry or ceramic waste produced in the country, this material may provide a significant source of aggregates that can be used to produce more sustainable concrete. In addition to reducing the amount of waste that is landfilled (and become an environmental hazard), other benefits can be realized as well. Brick aggregates are lighter than normal weight aggregates, and would provide haul cost savings. Concrete that incorporates brick aggregates is also lighter than normal weight concrete, would also be cheaper to transport, and can significantly reduce the self-weight of a structure. Brick aggregates also have the potential to enhance the fire performance of concrete due to their thermal expansion and conductivity properties.

The study will majorly deal with clay products such as kilned bricks, roofing tiles etc. One of the waste products' of clay products industries and brick producing industries (e.g. Kenya Clay Products, KCP) are the waste chips which can be utilized as aggregates in concrete. This research project will try to investigate the properties of these clay products waste chips and their possibility of being used as aggregates in production of concrete economically. This research will be aiming at provision of economically and locally available aggregates for the production of low cost concrete for use in low cost housing. The research will be limited to studying the clay products waste chips properties.

Figure 1 (a): Clay products waste aggregate (size<20mm)

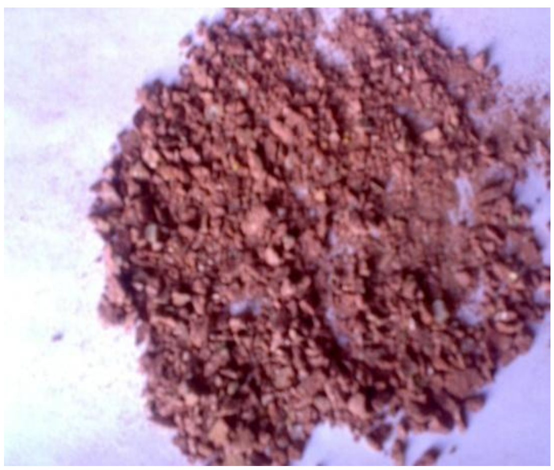


Figure 1 (b): Clay products waste aggregate (size<4mm)

1.2 Problem statement

Concrete is the most important building material used in the construction industry globally. Concrete production has become expensive over the years due to increased demand of construction. This has led to an increase in the rates of the materials used to make concrete i.e. aggregates and cement.

One of the development goals of Kenya's vision 2030 is to provide affordable housing to all citizens especially those in the slums and shanties. This may be accomplished by provision of quality alternative building materials such as clay aggregates. Thus from economical point of view, a research on the production of cost effective concrete to meet demand is the most important step in the right direction in concrete technology. Therefore, the provision of locally available aggregates from the utilization of clay products waste chips to be used in concrete production will help in lowering the cost of construction of housing units (low cost housing) for human dwelling.

Furthermore, production of common granitic aggregates and building stones (rough and machine cut stones) by quarrying is very expensive economically. Quarrying creates an unfriendly environment by leaving land excavated and rocks blasted which can lead to subsidence and in some cases earth tremors due to disturbance of the rock strata. For instance the *Ndarugu* area in *Thika district* where production of machine cut building stones by mining is the common activity; this has led to degradation of environment. Reclaiming land degraded by quarrying is also an expensive process and takes time to salvage its glory.

Hence the provision of alternative aggregates from clay products waste chips is likely to lower the cost of producing concrete as well as protecting the environment by reusing the waste chips as aggregates which would have otherwise been disposed.

1.3 Problem justification

Since it is clearly known and understood that the rising cost of concrete production has impaired the construction industry, a study on the alternative readily available alternatives (like clay products waste chips) to aggregates justifies the research. Also from environmental point of view, recycling of these wastes would help in the protection of environment i.e. exploitation of normal granitic aggregates through quarrying would be significantly reduced.

1.4 Objectives

The key objective of this work was to develop concrete mixtures, using crushed clay products waste as a partial replacement for normal granitic aggregates, which exhibit acceptable properties comparable to that of structural coarse aggregates.

Specific objectives

- To determine the properties of clay products waste chips.
- To design concrete mixes using clay products waste chips as aggregates.
- To establish the availability and economic feasibility of the use of clay products waste chips as aggregates.

1.5 Research hypothesis

Clay products waste chips may be suitably used as an alternative (partial replacement) to normal granitic aggregates in structural concrete.

1.6 Scope and limitations of study

In concrete mix design, it is necessary to analyse experimentally and practically all the components of the concrete mix i.e. cement, aggregates, additives and water. Due to the limited time available, it wasn't possible to investigate the properties of the above mentioned components. Long term behaviour study of clay aggregate concrete use in reinforced concrete under weather exposure was also not possible due to time constraints.

In this project, power max cement (42.5) was used assuming its properties hold for other types of cement. The research will be majorly dealing with the analysis of the properties of clay products waste chips to be used as coarse aggregates in concrete. The crushed clay waste was obtained from Kenya Clay Products. Prior to developing mix designs, grading was done to obtain the required particle size distribution and tests were performed to characterise the aggregate. The compressive and tensile strengths at 14 and 28 days of curing of concrete cubes/cylinders will be analysed. Six trial mixes were prepared, namely;

- Normal mix (control) i.e. cement + water + sand + coarse aggregate (granitic).
- Special mix 1 i.e. cement + water + sand + blended coarse aggregate (5% clay waste chips + 95% granite)
- Special mix 2 i.e. cement + water + sand + blended coarse aggregate (10% clay waste chips + 90% granite)
- Special mix 3 i.e. cement + water + sand + blended coarse aggregate (15% clay waste chips + 85% granite)
- Special mix 4 i.e. cement + water + sand + blended coarse aggregate (20% clay waste chips + 80% granite)
- Special mix 5 i.e. cement + water + sand + blended coarse aggregate (25% clay waste chips + 75% granite)

CHAPTER 2
2.0 LITERATURE REVIEW

2.1 Overview

In concrete technology, aggregates have been depicted as hard, inert material incorporated in concrete mixes to serve as reinforcement to add strength to the overall composite material. In a typical medium-strength concrete mix, aggregates account for up to 75% of the total volume of concrete. Aggregates are incorporated into concrete mixes to serve the following functions;

- They reduce the heat of hydration of concrete since they are normally chemically inert and act as a heat sink for hydrating cement.
- They reduce the shrinkage of concrete since they do not swell and they restrain shrinkage of the hydrating cement.
- They also reduce the cost of concrete since they are mostly derived from natural materials and they occupy a greater percentage in concrete.

Use of waste as aggregates in new concrete has gained increased interest in recent years for reasons related to both economics and environmental sustainability. Demolition waste materials used for production of recycled aggregates can include crushed concrete, crushed brick and crushed mixed rubble from various sources including demolished buildings and roadways. Concrete that contains recycled aggregates is called recycled aggregate concrete (RAC).

Use of recycled/waste materials as aggregates in concrete can provide a number of advantages to stakeholders including owners, contractors, and the ready-mixed concrete and precast concrete industries. From an economic standpoint, these aggregates can be cheaper than conventional (natural and manufactured lightweight) aggregates. Use of aggregates made from crushed construction and demolition debris may become an increasingly attractive alternative due to rising landfill tipping fees, diminishing landfill space, and rising cost of virgin natural aggregate material (Tam and Tam 2006).

From the standpoint of sustainability, use of recycled materials as aggregates provides several advantages. Landfill space used for disposal is decreased, and existing natural aggregate sources are not as quickly depleted (Kutegeza and Alexander 2004).

2.2 Clay based aggregates

Clean broken brick of good quality can provide satisfactory aggregates, the strength and density of concrete depending on the type of brick; engineering and allied bricks when crushed make quite good concrete of medium strength (Leonard John Murdock 1991). In using second hand bricks, it is essential to remove all plaster otherwise calcium sulphate present is liable to prevent or delay setting and cause disintegration in a short time. Bricks containing soluble sulphates in excess of 0.5% should be avoided. Brick aggregates should be saturated before use because of its relatively high absorbency (K.M Brook 1990). Porous type of brick should not be used as aggregates in reinforced concrete work owing to the danger of penetration of moisture which may lead to corrosion of steel reinforcement (Leonard John Murdock 1991).

2.2.1 Early history

The earliest use of crushed brick in cementitious materials using Portland cement occurred in Germany in 1860 (Devenny and Khalaf 1999, Hansen 1992). In Europe, many of the buildings damaged or destroyed by bombs during World War II included brick masonry. As part of rebuilding the damaged cities in Germany, rubble recycling plants were created, producing crushed recycled brick masonry aggregate (RBMA) that was used in new concrete construction. Crushed brick masonry was also used as aggregates in concrete in Great Britain after World War II.

Economic conditions and lack of suitable natural aggregates seems to have resulted in brick being used as aggregate in developing nations before being used in developed ones. Khan and Choudhry (1978) discuss how in Bangladesh, brick chips have been used as aggregate. They describe the manufacturing processes used for making brick in Bangladesh and discuss the large variation in quality and mechanical properties of bricks made from these methods. General batching processes are described, and data for several brick aggregate concrete mixtures (compressive strengths ranging from 3,950 to 6,260 psi, or 27.2 to 43.2 MPa) is presented.

2.2.2 China clay products as aggregates

China clay (kaolin) is formed by the hydrothermal alteration and decomposition of the feldspars within the parent rock. The material *insitu* takes the form of a weakened rock structure consisting predominantly of kaolin, quartz sand and mica. The `rock` is broken out by high pressure water jetting and the kaolin is separated from the resulting slurry.

The by-products resulting from the process are;

- Stent – largely unaltered rock material often appearing as overburden or in isolated locations within the rock mass.
- Sand – material consisting predominantly of quartz having a particle size grading from fine sand to coarse gravel.
- Mica – sub-sand sized material.

China clay is largely produced in the southwest of England and in particular in Cornwall. Approximately nine tones of by-product results for every one ton of kaolin produced.

The uses of china clay products are:

The crushed and graded stent has been used as a substitute for primary aggregate in highways construction. Using crushing and grading techniques it is possible to meet the majority of the required engineering properties. These include drainage filter media, pipe bedding and Type 1 sub-base. It is also possible to use the material as special fill and as an aggregate for concrete in accordance with BS 882. Adjustments are necessary in some specifications, particularly for structural fill due to the wide range of 10% fines values (http//.clay waste products aggregates).

Crushed stent was used as Type 1 sub-base in the A30/A39 Indian Queens and Fraddon Bypass in Cornwall, England. This was a major trunk road scheme comprising of 7 km of new dual carriageway which was constructed in 1993/4. China Clay by-products have properties similar to primary aggregates. In particular the better quality stent has properties not dissimilar to crushed granite. These materials are abundant in the south west of England and are available for exploitation. High road transport costs coupled with limitations in the existing rail link renders their transport to other parts of the UK uneconomic at present (http//.clay waste products aggregates).

Figure 2 (a)

Figure 2 (b)

Figure 2 (a): A30/A39 Indian Queens and Fraddon Bypass (Cornwall, England) during construction.

Figure 2 (b): Embankment constructed using china clay waste in China.

Approximately 150 thousand tons of crushed stent was provided from the Indian Queens Quarry. This material was tested both by the contractor and Cornwall County Council and was found to be generally compliant to the specification with only occasional oversized material being present. China clay sand was also used as the fine aggregate in concrete for the by-pass. This was supplied by CAMAS Aggregates from the Black pool Pit. Testing again demonstrated high compliance rates with occasional instances of marginally high silt content. The concrete mixes incorporated both OPC and ground granulated blast furnace slag with a plasticizer admixture (http//.clay waste products aggregates).

2.2.3 Expanded clay aggregates

LECA (Lightweight Expanded Clay Aggregate)

LECA is a special type of clay that has been palletized and fired in a rotary kiln at a very high temperature. As it is fired, the organic compounds in the clay burn off forcing the pellets to expand and become honeycombed while the outside surface of each granule melts and is sintered. The resulting ceramic pellets are lightweight, porous and have a high crushing resistance. It is a natural product containing no harmful substances. It is inert with a neutral pH value, resistant to frost and chemicals, will not break down in water, is non-biodegradable, non-combustible and has excellent sound and thermal insulation properties.

LECA is an incredibly versatile material, and is utilized in an ever-increasing number of applications. In the construction industry, it is used extensively in the production of lightweight concrete blocks as well as both a sound and thermal insulation material, and flue & chimney lining material. It is used in structural backfill against foundations, retaining walls, bridge abutments etc. It can reduce earth pressure by 75% compared with conventional materials, and also increases stability while reducing settlement and land deformation.

Two methods have been adopted in the preparation of raw material before burning: the wet process and the dry process. The wet process has been widely used in the manufacture of LECA. The clay minerals from the clay quarry are homogenized and crushed into very fine powder by passing through grinding mills. Water and expanding agents are then added. The fine and plastic paste of clay is then forced through perforated plates in extrusion press. The holes' diameters are chosen according to aggregate diameter required. The extruded clay paste is then cut into pieces of required length. The pellets obtained are first dried in a rotary kiln giving them rounded shapes. The burning process is mainly done in rotary kilns at 11500 degrees Celsius to 12000 degrees Celsius. The resulting products are cooled, crushed if necessary for fines and screened in different particle sizes fractions (The Concrete Society Ci80, 1980). The aggregates are brownish to reddish in colour, light, hard, rounded with honeycomb interior. Since LECA are porous, they absorb considerable quantities of water. The amount of water absorbed by LECA or Lytag (Pulverized Fly Ash, PFA) can exceed 20% by volume and the ultimate water absorption is of the order of 30% by volume. There is therefore, a considerable amount of water present within these aggregates and this can have a considerable influence on the thermal insulation, shrinkage and creep of concrete which is made with them (Leonard John Murdock 1991)

Figure 2 (c) *Figure 2 (d)*

Figure 2 (c): Asphalt bituminous surface treatments using clay lightweight expanded clay chip (seal coat), East Ohio.

Figure 2 (d): LECA lightweight blocks used as hollow masonry blocks in UK.

The bulk densities of LECA according to size fractions are as follows (The Concrete Society 1980);

- Less than 3mm: 600-750 kg/m^3
- 3-10 mm: 400-500 kg/m^3
- 10-20mm: 350-450 kg/m^3

Lightweight chip seal and other uses with Asphalt on road surfaces;

When bonded to asphalt, structural lightweight aggregate chip seal creates a significantly improved asphalt bituminous surface treatment that is safer, more economical and longer lasting than conventional aggregates. Wet or dry, road surfaces of lightweight chip seal provide superior skid resistance that is maintained throughout the surface life. Lightweight aggregate does not polish as it wears. Because it is light in weight there are trucking and handling cost advantages to the contractor. Also, windshield damage and damage to headlights, and paint caused by "flying" stones is virtually eliminated with structural lightweight aggregate, thus avoiding costly insurance claims and motorist complaints. (Expanded clay, shale and slate institute (ECSI), East Ohio)

2.3 Natural aggregates

These 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 gabbro's. 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 quartzite's are usually massive, dense and adequately tough thus provide good aggregates. However schist's and slates are often thinly laminated and are therefore unsuitable.

Other rocks such as shale, sandstones etc. are rarely available. Shale's 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.

Figure 2 (e)

Figure 2 (e): Normal granitic aggregates

2.4 Artificial aggregates

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

Pulverised 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^{0}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^{0}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^{3}/g Blaine. Before grinding, 2.5% of calcium carbonate (CaCO3) 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^{0}C and passed quickly through a rotary kiln at 800^{0}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.

2.5 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^3 may be considered as the upper limit of a true lightweight aggregate although this value may sometimes be exceeded. (K.M Brook, 1991)

2.6 Normal weight aggregates

Many natural aggregates e.g. from granites, gravels, basalts, limestone's etc. 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^3 depending on the mix proportions.

2.7 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^3 – 4500Kg/m^3 are obtained. Example of these aggregates is Barytes (a barium sulphate ore). Steel shots can produce concrete of about 7000Kg/m^3 density (J.M Illston 1994).

CHAPTER 3
3.0 METHODOLOGY

3.1 Preparation of aggregates

It is important to determine the properties of different types of aggregates through effective testing and measurement.

The properties of a good aggregate are:

- **Particle shape and texture**

  Particle size, shape and texture can have considerable effects on various design properties and are generally specified within certain limits. Rounded aggregate can lead to instability in a bituminous mixture yet be ideal as a concrete aggregate where good workability of the mix is essential for placing and compaction. The shape and surface texture of aggregates influence considerably the strength of concrete, especially the flexural strength. This is because they both influence the bonding between the aggregate and the cement paste. A rougher texture surface such as those of crushed particles results in greater adhesion between the particles in the cement matrix. Smooth surfaced particles have very poor bond thus gives concrete of lower strength which are unsatisfactory. Shape of aggregate can be depicted as regular, irregular, angular, rounded or flaky. Surface texture is depicted as smooth or rough.

  The shape and surface texture of aggregate especially of fine aggregates have a strong influence on the water requirement of the mix. If these particles are expressed indirectly by their packing i.e. by the percentage voids in a loose condition, the water requirement is quite definite. More water is required when there is a greater void content of the loosely packed aggregate. Flakiness and the shape of coarse aggregate have an appreciable effect on the workability of concrete. An increase in angularity of aggregate from minimum to maximum would reduce the compacting factor of fresh concrete considerably (Kaplan's paper).

- **Toughness and Hardness**

  Toughness is defined as the resistance of an aggregate to failure by impact. Hardness is the resistance of the aggregate to wear. Hardness is an important property of concrete used especially in roads and floor surfaces subjected to heavy traffic.

- **Cleanliness and deleterious substances**

  Organic impurities: The aggregates to be used should clean and free from organic impurities which interfere with the chemical reactions of hydration. The organic matter found in aggregate usually consists of products of decay of vegetable matter appearing in form of humus or organic loam. Such materials are likely to be found in sand than in coarse aggregates. Washing of fine aggregates should be done to remove organic impurities.

  Silt, clay and other fine materials: They interfere with the bond between aggregate and cement paste. Since a good bond is essential to ensure satisfactory strength and durability of concrete, the problem of clay and silt coatings must be addressed. Silt and fine dust may foam coatings or may be present in form of loose particles not bonded to the coarse aggregate. Silt and fine dust should not be present in excessive quantities because owing to their fineness and therefore large surface areas, silt and fine dust increase the amount of water necessary to wet all the particles in the mix thus lowering the strength of concrete. The aggregates should therefore be washed to remove these impurities. Washing should not be thorough so as not to remove the fines passing BS 410 sieve of 300µm. This is because deficiency of these fines leads to harshness in the mix.

- **Sieve analysis and grading**

  This is the process of screening a sample of aggregate into size fractions each consisting of particles of the same range size i.e. particle size distribution. Sieve analysis is done by passing the dried aggregate through a series of standard test sieves beginning with the one sufficiently coarse to pass all the material. The diameters of test sieves and mesh apertures are given in BS 410: 1976.

  Having completed the sieving, the weights of aggregate retained in each sieve in turn are recorded. The weights and percentages of aggregate passing each test sieve are then computed. The results of sieve analysis are represented graphically in charts known as grading curves/charts. By using these charts, it is possible to see at a glance if the grading of a given sample conforms to that specified or it is too fine or coarse or deficient on a particular size. In the curves, the ordinates represent cumulative percentages passing and the abscissa the sieve sizes plotted in a logarithmic scale.

Grading is of importance as it affects the workability of concrete. The development of strength corresponding to a given water/cement ratio requires full compaction and this can only be achieved with a sufficiently workable mix. It is necessary to produce a mix that can be compacted to a maximum density with a reasonable amount of work. The main factors governing the desired aggregate grading are;

1. Surface area of aggregate. This determines the amount of water necessary to wet all the solids/particles.
2. The relative volume occupied by the aggregate.
3. The workability of the mix. The aggregate must contain a sufficient amount of material passing 300mm sieve to improve workability.
4. The tendency to segregation. It is essential for the voids in the combined aggregate to be sufficiently small to prevent the cement paste from passing through and separating out.

3.2 Laboratory testing of the properties of aggregates

3.2.1 Particle size distribution

Introduction

This test consists of dividing up and separating by means of a series of test sieves, a material into several particle size classifications of decreasing sizes. The mass of the particles retained on the various sieves is related to the initial mass of the material. The cumulative percentages passing each sieve are reported in numerical and graphical form.

Objective

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

Apparatus

- Sieves with openings of different sizes

Procedure

The test sieves were arranged from top to bottom in order of decreasing aperture sizes with pan and lid to form a sieving column. The aggregate sample was then poured into the sieving column and shaken thoroughly manually.

Sieves were removed one by one starting with the largest aperture sizes (top most), and each sieve shaken manually ensuring no material is lost. All the material which passed each sieve was returned into the column before continuing with the operation with that sieve.

The retained material was then weighed for the sieve with the largest aperture size and its weight recorded. The same operation was carried out for all the sieves in the column and their weights recorded.

The screened material that remained in the pan was weighed and its weight recorded.

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.

Figure 3 (a)

Figure 3 (a): Arrangement of the test sieves to form a sieving column

3.2.2 Specific gravity

Introduction

There are several types of specific gravities of aggregates;

Absolute specific gravity: It refers to the ratio of the weight of the solid referred to vacuum, to the weight of an equal volume of gas – free distilled water both taken at stated temperature. The volume of solid referred is the volume excluding all the pores. Thus in order to eliminate the effect of totally enclosed impermeable pores, the material has to be pulverized. This test is both laborious and sensitive and it is not normally required in concrete technology.

Apparent specific gravity: This is the ratio of the weight of the aggregate dried in an oven at 100°C – 110°C for 24 hours to the weight of the water occupying a volume equal to that of the solid including the impermeable pores. The latter weight is determined using a vessel (pycnometer) which can be accurately filled with water to a specified volume. The apparent specific gravity of aggregate depends on the specific gravity of the minerals of which the aggregate is composed and on the amount of voids.

Gross specific gravity: This is the specific gravity obtained on saturated surface - dry condition of aggregate. Calculations with reference to concrete are generally based on the saturated surface - dry condition of the aggregate because the water contained in all the pores in the aggregate does not take part in chemical reactions of cement and can therefore be considered as part of the aggregate. This specific gravity is most frequently used and easily determined and necessary for calculation of yield of concrete or the quantity of aggregate required for a given volume of concrete.

Objectives

- To determine the gross and apparent specific gravities for the specified coarse and fine aggregates.

Apparatus

- A weighing balance accurate to 0.01g.
- Test sieve with mesh apertures 10mm as specified.
- Thermometer accurate to 0.1°C.
- A drying oven capable of maintaining temperatures of 110°C and above.
- A wire basket preferably 3mm mesh, 200mm diameter and 400mm height.
- A water tight tank containing water at $22\pm3^{\circ}$C.
- A dry absorbent cloth.

Procedure for coarse aggregates

Approximately 2Kg of a representative sample of aggregate retained on a 10mm test sieve was taken and the sample was thoroughly washed with water to remove dust on the surface of the grains. This was followed by soaking in water at $22\pm3^{\circ}$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 were removed. Large particles were wiped individually. The sample was weighed and recorded as W_{SD}.

The sample was then placed in a wire basket, immersed in water at room temperature and tapped to remove entrapped air on the surface and between the grains and weighed the sample while immersed. This weight was recorded as W_W.

The sample was later removed from water; dried in a drying oven to a constant weight at a temperature of $105^{\circ}C – 110^{\circ}C$ and cooled to room temperature, weighed and recorded as W_{OD}.

Analysis

Specific gravity on saturated surface-dry basis, $S_{SD} = W_{SD} \div (W_{SD}-W_W)$

Absolute dry specific gravity, $S_{AP} = W_{OD} \div (W_{SD}-W_W)$

3.2.3 Flakiness index

Introduction

This test is used to determine the quantity of aggregate particles that are elongated, instead of cubicle, in shape. It is important in certain applications, such as concrete, where an elongated shape has a larger surface area and therefore will require greater quantities of cement in order to produce concrete of the required strength.

Objectives

- To determine the flakiness index of coarse aggregate

Apparatus

- A metal thickness gauge as shown below
- Weighing balance accurate to 0.5% of the sample mass

Procedure

Approximately 1kg of aggregate was taken and each particle of the 7/8 in. (22.4 mm) to 5/8 in. (16.0 mm) sample was passed through the 3/8 in. (9.5 mm) slot of the thickness gauge. The particles passing through the gauge were separated from those retained on the gauge.

Each particle of the 5/8 in. (16.0 mm) to 3/8 in. (9.5 mm) sample was passed through the 1/4 in. (6.3 mm) slot of the thickness gauge. The particles passing through the gauge were separated from those retained on the gauge.

Each particle of the 3/8 in. (9.5 mm) to 1/4 in. (6.3 mm) sample was passed through the 5/32 in. (4.0 mm) slot of the thickness gauge. The particles passing through the gauge were separated from those retained on the gauge.

All particles retained on the gauge were combined and counted. The total is the Retained Sample. The particles passing through the appropriate slots were combined and counted; this is the total passing sample.

Analysis

Flakiness index = Sample passing ÷ (sample passing + sample retained) x 100%

3.2.4 Aggregate Crushing Value (ACV)

Objective

To determine the relative measure of the resistance of an aggregate to crushing under gradually applied compressive load.

Apparatus

- An open ended steel cylinder of nominal 150mm internal diameter with plunger and base plate.

- Round ended steel tamping rod 16mm diameter and 600mm long.
- A weighing balance.
- BS Test sieves 14mm, 10mm and 2.36mm.
- A compressive testing machine capable of applying 400KN, at a uniform loading rate.
- A cylindrical metal measure of internal dimensions; 115mm Ø by 180mm deep.

Procedure

The surface-dry aggregate was sieved through 14mm and 10mm sieves and the material retained on 10mm sieve adopted for test. The retained material was placed in the cylindrical measure and its weight determined and recorded as Wt (A).

The cylinder of the test apparatus was put in position and the test sample placed in three layers each layer being subjected to 25 strokes of the tamping rod. The surface of the aggregate was then leveled and the plunger inserted and ensured it rested horizontally on the surface of the aggregates.

The apparatus with the test sample and plunger were then placed in position between the platens of the testing machine and loaded at a uniform rate to the required load. After loading, the crushed material was removed from the cylinder and sieved through 2.36mm sieve. The fraction passing the 2.36mm sieve was then weighed and recorded as Wt (B).

Analysis

Aggregate crushing value = Wt (A) / Wt (B) x 100%

3.3 Design of concrete mixes

This is the process of selecting the correct proportions of cement, fine and coarse aggregate, water and sometimes admixtures to produce concrete having the properties specified and desired i.e. workability, compressive strength, density and durability requirements by means of specifying the minimum or maximum water/cement ratio.

3.3.1 Principles of design

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

The workability of the concrete mix was determined by the slump test which is more appropriate for higher workability mixes.

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 the mixes must comply with specific grading curves of the 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 will be with reference to the weights of materials in a unit volume of fully compacted concrete. This approach will require 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 will result in the mix being specified in terms of the weights in kilograms of different materials required to produce $1m^3$ of finished concrete.

3.3.2 Stages in mix design

STAGE 1: Selection of target water/cement (w/c) ratio

STAGE 2: Selection of free water-content

STAGE 3: Determination of cement content

STAGE 4: Determination of total aggregate content

STAGE 5: Selection of fine and coarse aggregate content

STAGE 6: Mix proportioning

3.4 Batching of concrete materials

Following the mix design process, concrete materials (Cement, Fine and Coarse Aggregates) should be prepared early enough before the concrete works begins. This allows the smooth running of the project. Batching of materials was done by weight basis. The advantage of weight method is that bulking of aggregates (especially fine aggregates) does not affect the proportioning of materials by weight unlike batching by volume method. Bulking of sand results in a smaller weight of sand occupying a fixed volume of the measuring container thus the resulting mix becomes deficient in sand and appears stony and the concrete may be prone to segregation and honeycombing. Concrete yield may be reduced.

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

3.5 Production of trial mixes

The main objective to make trial mixes is to check whether or not the particular aggregates or cement selected for use will behave as anticipated. Adjustments may be made to the original mix proportions, if necessary, will differ according to how much the results of the trial mixes differ from the design values. Based on these, the courses of actions which may be contemplated 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

The mix design adopted gave the weights in kilograms of the different materials required to produce one cubic metre of compacted concrete. The batch weights for the trial mix were obtained directly by multiplying each of the constituents contents by the volume of the mix required. For instance, in the production of the normal mix;

- Six cubes of 150mm each were required
- Volume of one cube; 0.15m x 0.15m x 0.15m = $0.003375m^3$
- Wastage = 15%. Therefore, total volume = 1.15 x 0.003375 = $0.00388125m^3$
- Volume of mix required; 6 x 0.00388125 = $0.0232875m^3 \cong 0.0233m^3$

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 following moisture conditions;

- Oven – dry conditions
- Air – dried conditions
- Saturated surface – dry conditions
- Saturated by soaking in water for at least 24 hours

The aggregates used were first brought to saturated surface – dry conditions as specified in BS 1881 – 125: 1983.

During the mixing process of the trial mixes, adjustments to the water contents were done by inspection of the workability of the mix. Initially, a small proportion of the mix water (approximately 10% of the initially designed value) was withheld as the mixing process continued. When by visual assessment of the workability, the mix required addition of water; water was added with great care. Furthermore, when at the designed water content, the workability of the mix appeared below that required, additional water was added to until the required workability was achieved.

3.6 Testing the properties of fresh concrete

3.6.1 Slump test

Introduction

Slump test has been used extensively in site work to detect variations in the uniformity of mix of given proportions. It is useful on the site as a check on the variations of materials being fed to the mixer. An increase in slump may mean that the moisture content of aggregate has increased or a change in grading of the aggregate, such as the deficiency of fine aggregate. Too much or too low slump gives an immediate warning and enables the mixer operator to remedy the situation.

The test was done according to BS 1881 – 102:1983 which describes the determination of slump of cohesive concrete of medium to high workability. The slump test is sensitive to the consistency of fresh concrete. The test is valid if it yields a true slump, this being a slump in which the concrete remains substantially intact and symmetrical.

Objective

- To determine the slump of fresh concrete mix

Apparatus

- A standard mold which is a frustum of a cone complying with BS 1881 – 102: 1983
- A standard flat base plate preferably steel.
- A standard tamping rod.
- Standard graduated steel rule from 0 to 300mm at 5mm intervals.
- A scoop approximately 100mm wide.

Procedure

The inside surfaces of the mould were cleaned and oiled to prevent adherence of fresh concrete on the surfaces. The mould was placed on the base plate and firmly held.

The cone was then filled with fresh concrete in three layer with each layer compacted with 25 strokes of the tamping rod. After filling the mould, the top surface was struck off by means of rolling action of the tamping rod.

Immediately after filling, the cone was slowly and carefully lifted and after removal of the mold the slump of the unsupported concrete was measured and recorded.

Figure 3 (b)

Figure 3 (c)

Figure 3 (b): Fresh concrete filled in the mould and rolled flat.

Figure 3 (c): Slump after removal of mould.

3.6.2 Workability

Workability may be described as the consistence of a mix such that the concrete can be transported, placed and finished sufficiently easily and without segregation. Workability may also be specifically defined as the amount of useful work necessary to obtain full compaction i.e. the work done to overcome the internal friction and the surface friction between the individual particles in concrete and also between the concrete and the surface of the mould or of the reinforcement. The concrete should have sufficient cohesiveness in order to resist segregation and bleeding.

The main factor affecting workability is the water content of the mix expressed in Kilograms per cubic metre of concrete. If the water content and other mix proportions are fixed, workability is governed by the maximum size of aggregate, shape and texture. The free – water required to produce concrete of a specified slump depends upon the characteristics of the aggregate. The grading of coarse aggregates, provided it complies with the requirements of BS 882, has little effect on water requirement of a concrete mix. The grading of fine aggregate has a considerable effect on the water requirement of the concrete.

3.7 Determination of compressive strength

3.7.1 Casting cubes

The specimens were cast in iron moulds generally 150mm cubes. This conforms to the specifications of BS 1881 – 3:1970. The moulds surfaces were first cleaned and oiled on their inside surfaces in order to prevent development of bond between the mould and the concrete. The moulds were then assembled and bolts and nuts tightened to prevent leakage of cement paste.

After preparing trial mixes, the moulds were filled with concrete in three layers, each layer being compacted using a poker vibrator to remove as much entrapped air as possible and to produce full compaction of concrete without segregation. The moulds were filled to overflowing and excess concrete removed by sawing action of steel rule. Surface finishing was then done by means of a trowel. The test specimens were then left in the moulds undisturbed for 24 hours and protected against shock, vibration and dehydration.

3.7.2 Curing cubes

Curing may be defined as the procedures used for promoting the hydration of cement, and consists of a control of temperature and of the moisture movement from and into the concrete. The objective of curing was to keep concrete as nearly saturated as possible, until the originally water – filled space in the fresh cement paste was filled to the desired extent by the products of hydration of cement. The temperature during curing also controls the rate of progress of the reactions of hydration and consequently affects the development of strength of concrete. The cubes were placed in a curing pond/tank at a temperature of $20 \pm 2^{\circ}C$ for the specified period of time.

Figure 3 (d)

Figure 3 (d): Cubes and cylinders in a curing tank

Before placing the cubes into a curing tank they must be marked with a water proof marker. Details to be marked on the cubes are mainly; type of mix, date of casting, duration for curing and crushing day.

3.7.3 Compressive test

After curing the cubes for the specified period, they were removed and wiped to remove surface moisture in readiness for compression test. The cubes were then placed with the cast faces in contact with the platens of the testing machine that is the position of the cube when tested should be at right angles to that as cast. The load was applied at a constant rate of stress of approximately equal to 15 N/mm^2 to failure. The readings on the dial gauge were then recorded for each cube.

Figure 3 (e)

Figure 3 (e): Compressive test machine

The crushing strength is influenced by a number of factors in addition to the water/cement ratio and degree of compaction. These are;

The type of cement and its quality – both the rate of strength gain and the ultimate strength may be affected.

Type and surface of the aggregate – affects the bond strength.

Efficiency of curing – loss in strength of up to 40% may result from premature drying out.

Temperature – in general, the initial rate of hardening of concrete is increased by an increase in temperature but may lead to lower ultimate strength. At lower temperatures, the crushing strength may remain low for some time, particularly when cements of slow rate of strength gain are employed, but may lead to higher ultimate strength, provided frost damage does not occur.

Age – when moisture is available, concrete will increase in strength with age, the rate being greatest initially and progressively decreasing over time. The rate will be influenced by the cement type, cement content and internal concrete temperature.

Moisture condition – concrete allowed to dry will immediately exhibit a higher strength due to the dry process but will not gain strength thereafter unless returned to and maintained in moist conditions. Dry concrete will exhibit a reduced strength when moistened.

3.8 Determination of tensile strength

3.8.1 Casting cylinders

The method adopted was the indirect tensile splitting test of cylindrical concrete specimens. Concrete mixes were prepared and the fresh concrete cast in 150mm 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 smoothened using a plasterer's float and the outside of the moulds wiped clean.

3.8.2 Curing cylinders

The specimens were then stored in an undisturbed environment for 24 hours then cured in a curing tank for the required number of days.

3.8.3 Tensile test (Splitting test)

The test specimen after curing for the required age were 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 increased gradually till failure. The readings observed on the machine were then recorded.

Figure 3 (f)

Figure 3 (g)

Figure 3 (f): Tensile cylinder splitting test

Figure 3 (g): Cylinder specimen after splitting

The tensile strength was calculated as shown below:

$$\sigma = {}^{2F}/_{\pi\, d\, l}$$

Where;

F = Load at failure (N)

d = diameter of cylinder

l = length of cylinder

Tensile strength is of crucial importance in resisting cracking due to changes in moisture content.

3.9 Cost of concrete

The cost analysis of 1m^3 of concrete was done for both cases (i.e. normal aggregates and clay aggregates).

From the concrete mix design, 1m^3 concrete requires 420kg cement, 585kg fine aggregate (sand) and 1190kg normal aggregate.

The prices of the various materials are:

1 tonne sand = Ksh. 1800

1 tonne normal aggregate = Ksh. 1600

50kg cement = Ksh. 900

Clay aggregates are obtained as waste material and are therefore not accounted for.

The price of $1m^3$ of concrete was calculated from the weight ratios of cement, fine aggregate and coarse aggregate.

CHAPTER 4
4.0 DATA COLLECTION AND ANALYSIS

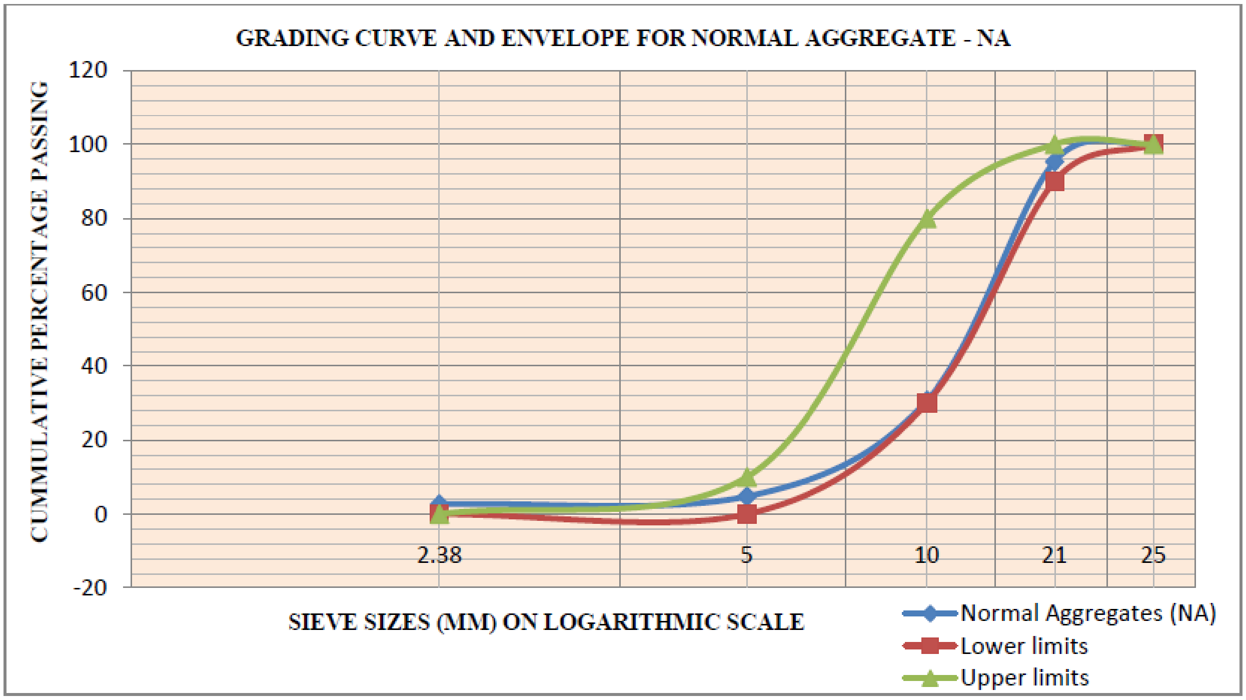
4.1 Laboratory test results

4.1.1 Sieve analysis

Particle size distribution to BS EN 933 – 1: 1997

Table 1: Normal (granitic) aggregates

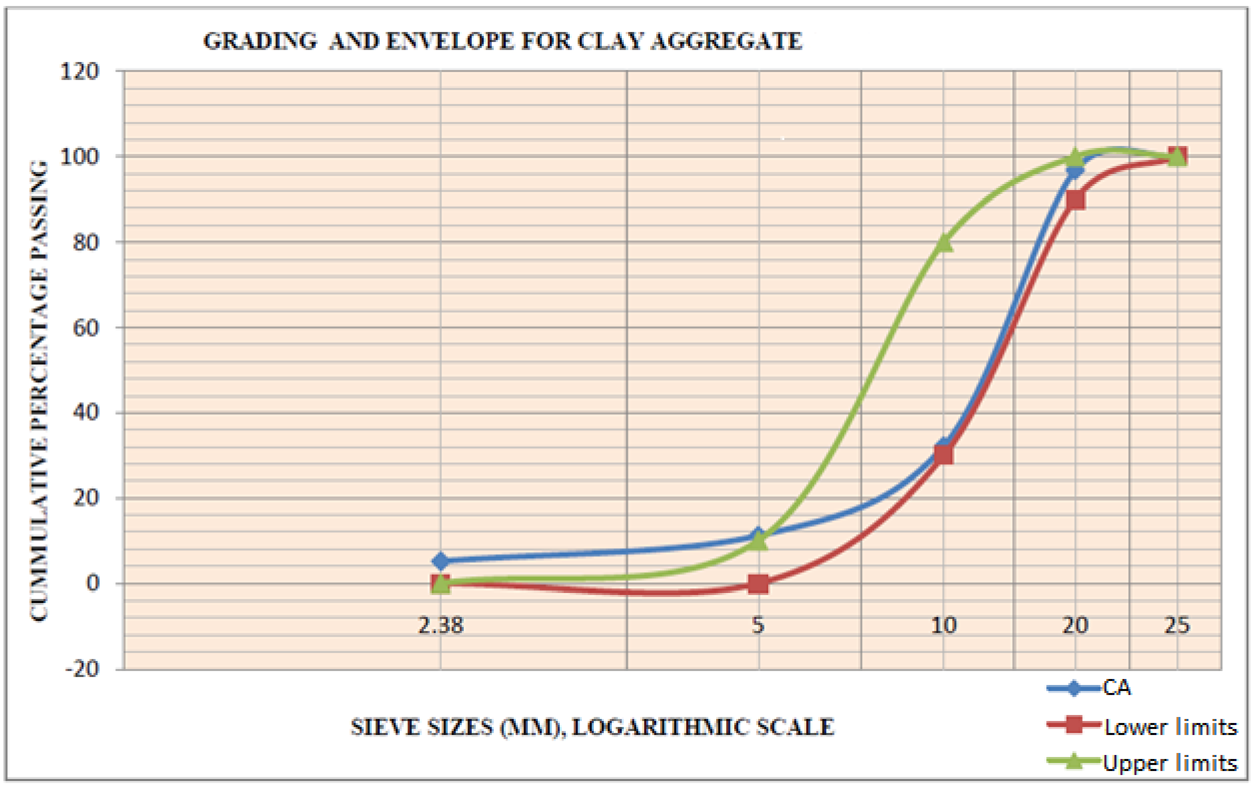
Sieve sizes (mm)	Retained mass (g)	Mass passing (g)	% Retained	Cumulative passed Percentage (%)
37.5	0.0	2638	0	100
25	0.0	2638	0	100
20	123.0	2515	4.7	95.3
10	1705.5	809.5	64.6	30.7
5	682.5	127.0	25.9	4.8
2.38	56.0	71.0	2.1	2.7
Pan	71.0		2.7	
Total	**2638**		**100**	



Mass of dry sample was **2640g**. The grading of the normal aggregate was within the specified limits.

Table 2: Clay aggregates

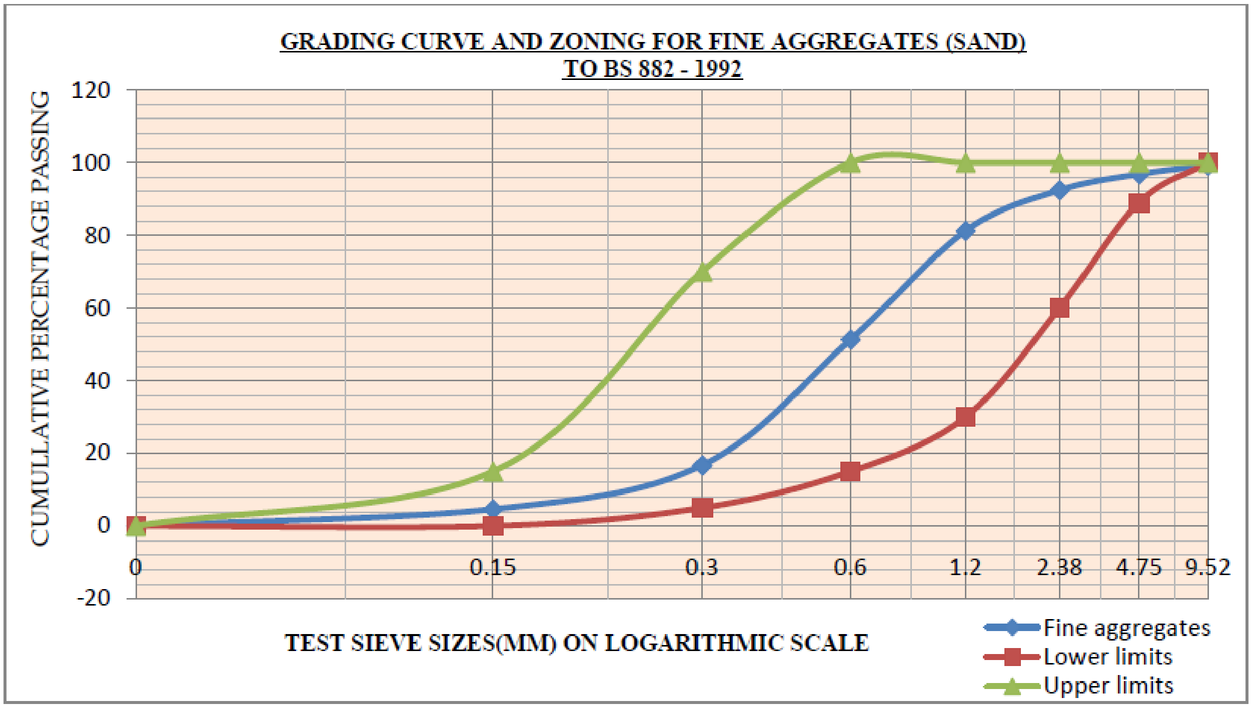
Sieve sizes (mm)	Retained mass (g)	Mass passing (g)	% Retained	Cumulative passed Percentage (%)
37.5	0	1800	0	100
25	0	1800	0	100
20	57.5	1742.5	3.2	96.8
10	1164.0	578.5	64.6	32.2
5	377.5	201	21	11.2
2.38	107.5	93.5	6	5.2
Pan	93.5		5.2	
Total	**1800**		**100**	



Dry sample mass was **1800g**. Grading of the clay aggregate deviated slightly in the 2.38 and 5mm sieve sizes but was within the specified limits thereafter.

Table 3: Fine aggregates

Sieve sizes (mm)	Retained mass (g)	Mass passing (g)	% Retained	Cumulative passed Percentage (%)
9.52	14	1850.5	0.8	99.2
4.75	45	1805.5	2.4	96.8
2.38	82.5	1723.0	4.4	92.4
1.20	208.0	1515.0	11.2	81.2
0.6	558.5	956.5	29.9	51.3
0.3	644.5	312.0	34.6	16.7
0.15	226.0	86.0	12.1	4.6
Pan	86.0		4.6	
Total	**1864.5**		**100**	



Original mass of sample was **1865.0g**. The grading of the fine aggregates was within specified limits.

4.1.2 Flakiness index

Table 4: Flakiness Index for the clay aggregate

Sieve size (inches)	Weight retained (g)	Weight passing (g)
1	95	40
0.75	475	40
0.5	285	35
0.375	25	5
0.25	0	0
∑	**880**	**120**

Total mass of sample taken was **1000g**

Therefore;

FI = (120 ÷ 1000) × 100%

= **12%**

4.1.3 Specific gravity

Table 5: Determination of specific gravity and water absorption to BS EN 1097 – 6: 2000

Item	Normal aggregate	Clay aggregate
Average specific gravity on saturated – surface dry basis (gross) $S_{SD} = \frac{W_{SD}}{W_{SD} - W_W}$	2.6	2.3
Average absolute dry specific gravity (Apparent) $S_{AP} = \frac{W_{OD}}{W_{SD} - W_W}$	2.5	2.2
Average water absorption (% of dry weight) $W_A = \frac{W_{SD} - W_{OD}}{W_{OD}}$	2.9	4.7

4.1.4 Aggregate crushing value

Table 6: Aggregate crushing value for clay aggregate

	Mass Passing (g)	Mass retained (g)
Sieve No. 7 (2.36mm)	890	1110
- Container mass (g)	340	340
Resultant Mass (g)	**550**	**770**

ACV = 550 ÷ (550+770)

= 0.4167 × 100%

= **41.67%**

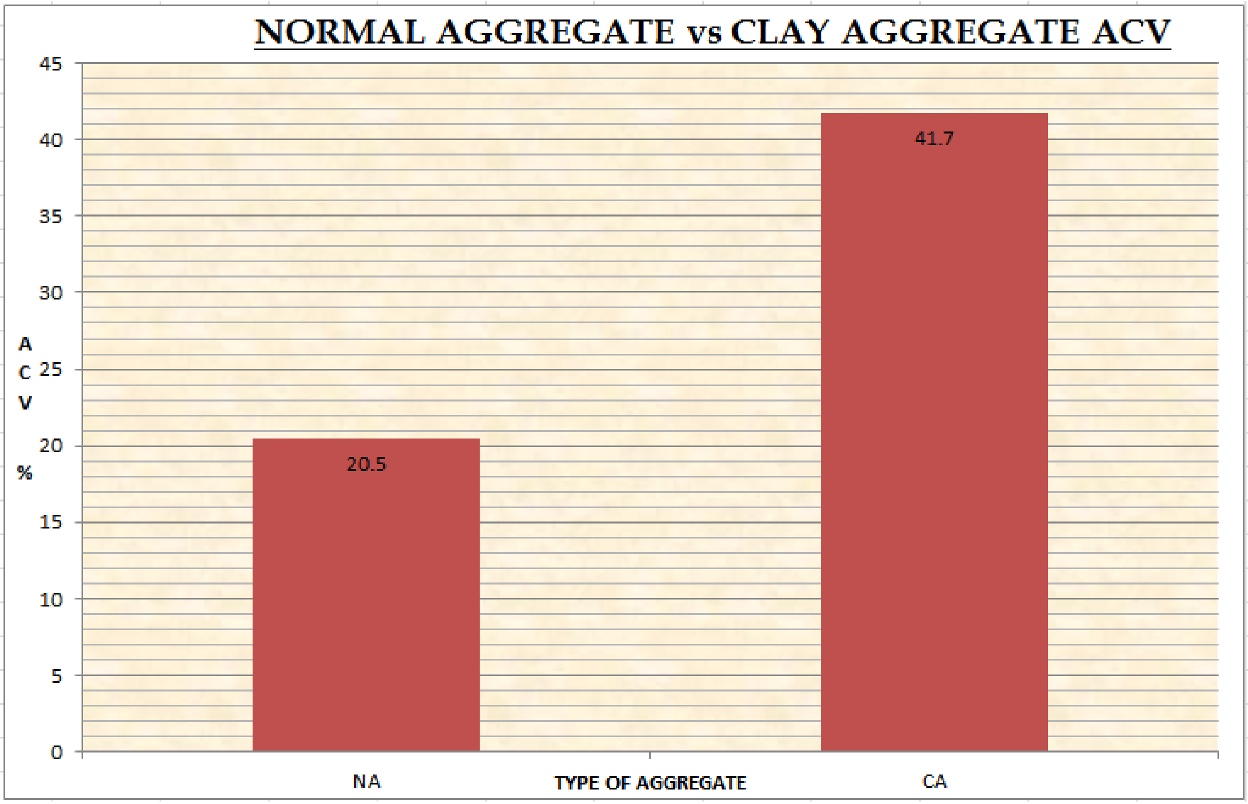
Table 7: Aggregate crushing value for normal aggregate

	Mass passing (g)	Mass retained (g)
Sieve No. 7 (2.36mm)	610	1390
- Container mass (g)	340	340
Resultant mass (g)	**270**	**1050**

ACV = 270 ÷ (270+1050)

= 0.205 × 100%

= **20.5%**

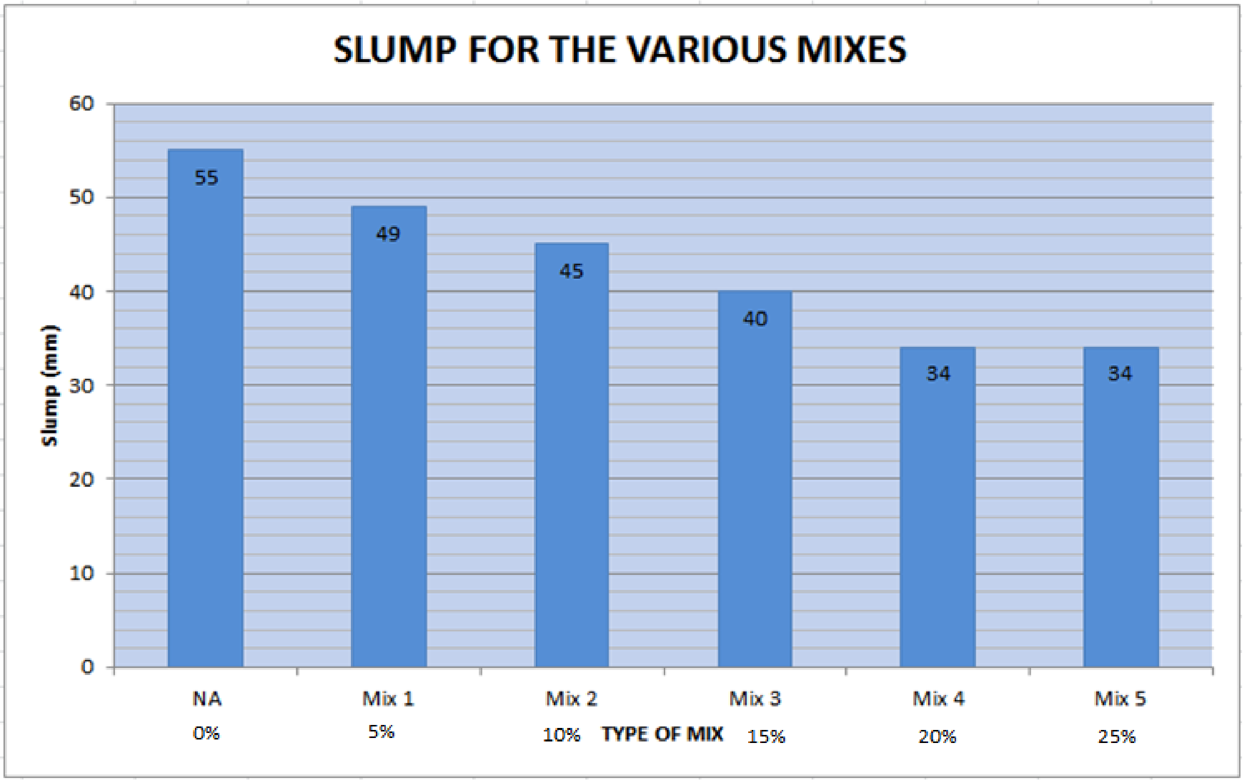


The aggregate crushing value of the clay aggregates was twice as much as that of the normal aggregates due to its porous nature.

4.1.5 Slump

Table 8: Slump for different types of mixes

Type of mix	Slump (mm)
Normal mix (Control mix)	55
Special mix 1 (5% replacement)	49
Special mix 2 (10% replacement)	45
Special mix 3 (15% replacement)	40
Special mix 4 (20% replacement)	34
Special mix 5 (25% replacement)	34

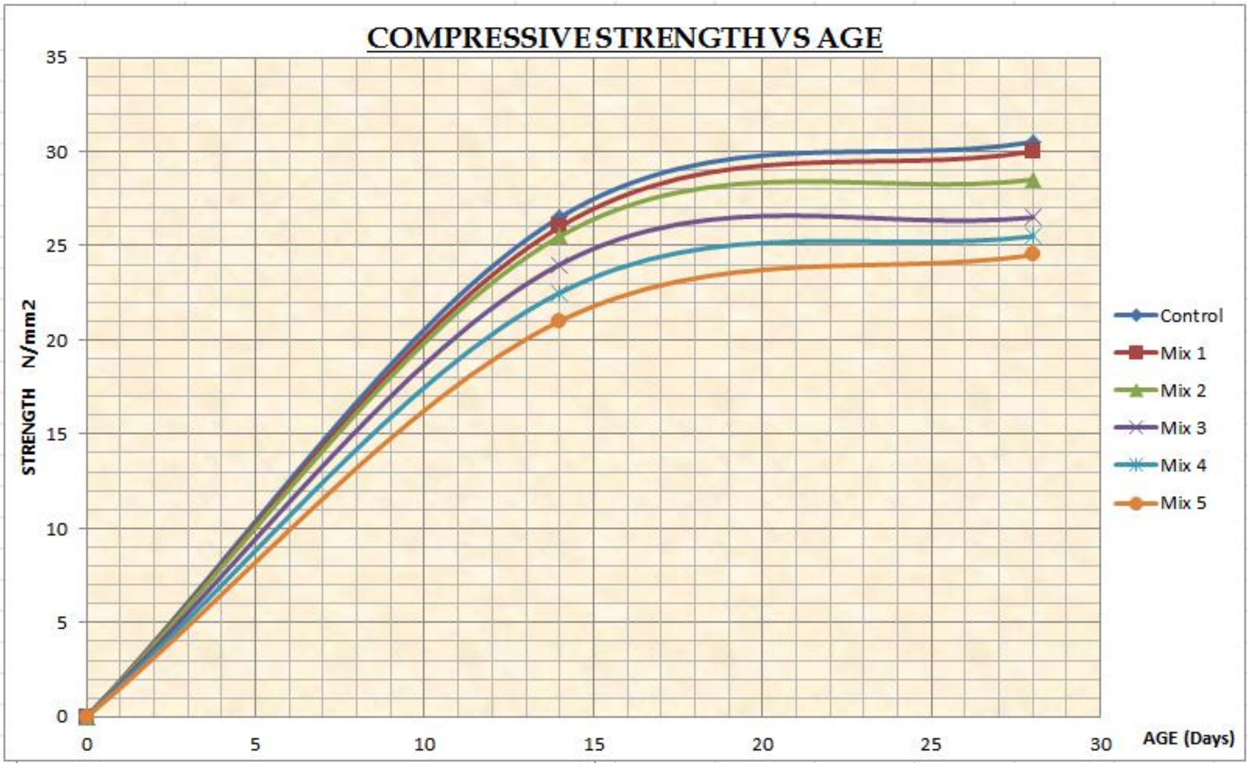


The slump of the normal aggregate concrete was found to be 55mm. Slump decreases as the percent replacement of aggregates increases.

4.1.6 Compressive strength

Table 9: Compressive strength results

Type of mix	Concrete class (N/mm^2)	Age of curing (days)	Average compressive strength (N/mm^2)
Normal mix (Control)	25	14	26.5
		28	30.5
Mix 1 (5% replacement)	25	14	26.0
		28	30
Mix 2 (10% replacement)	25	14	25.5
		28	28.5
Mix 3 (15% replacement)	25	14	24.0
		28	26.5
Mix 4 (20% replacement)	25	14	22.5
		28	25.5
Mix 5 (25% replacement)	25	14	21
		28	24.5



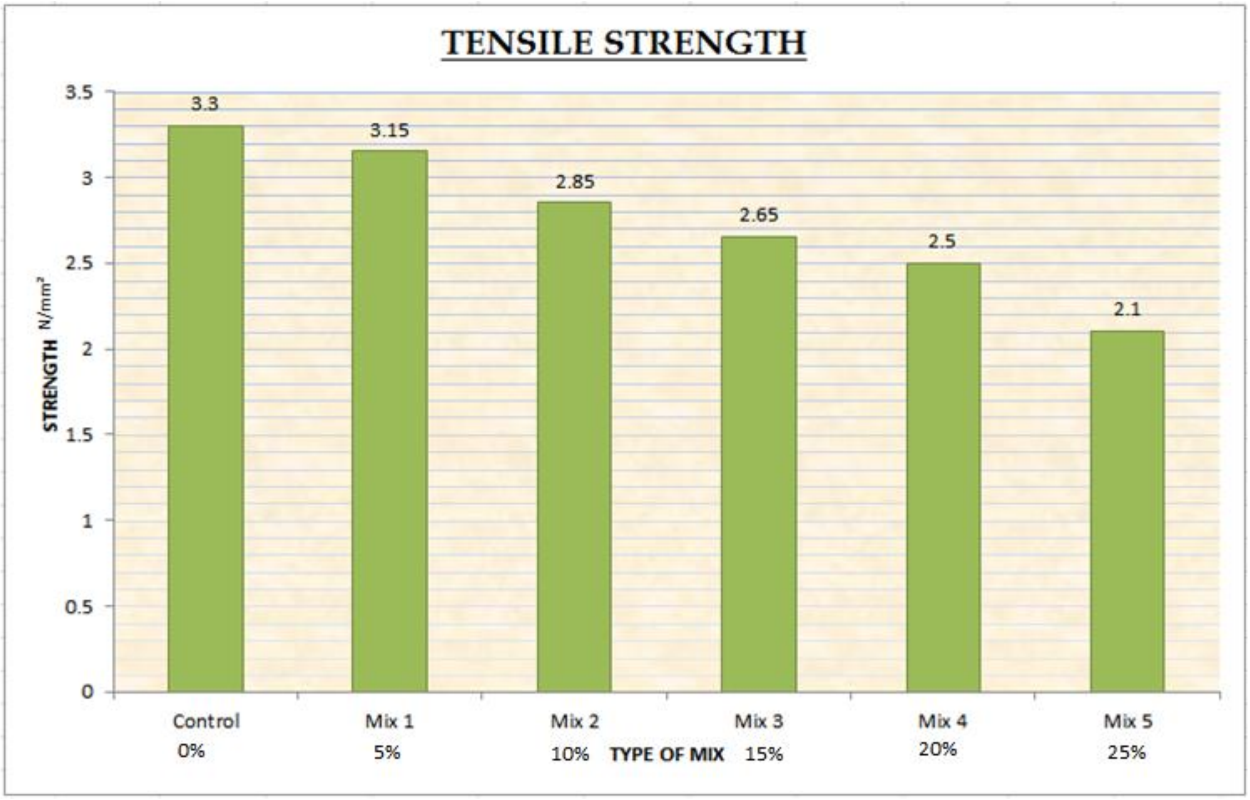
It was found out that the compressive strengths of the concrete mixes increased as the number of days increased.

There was a marked decrease of compressive strength as percent replacement increased. At 25% replacement, concrete had lost up to 20% of the strength.

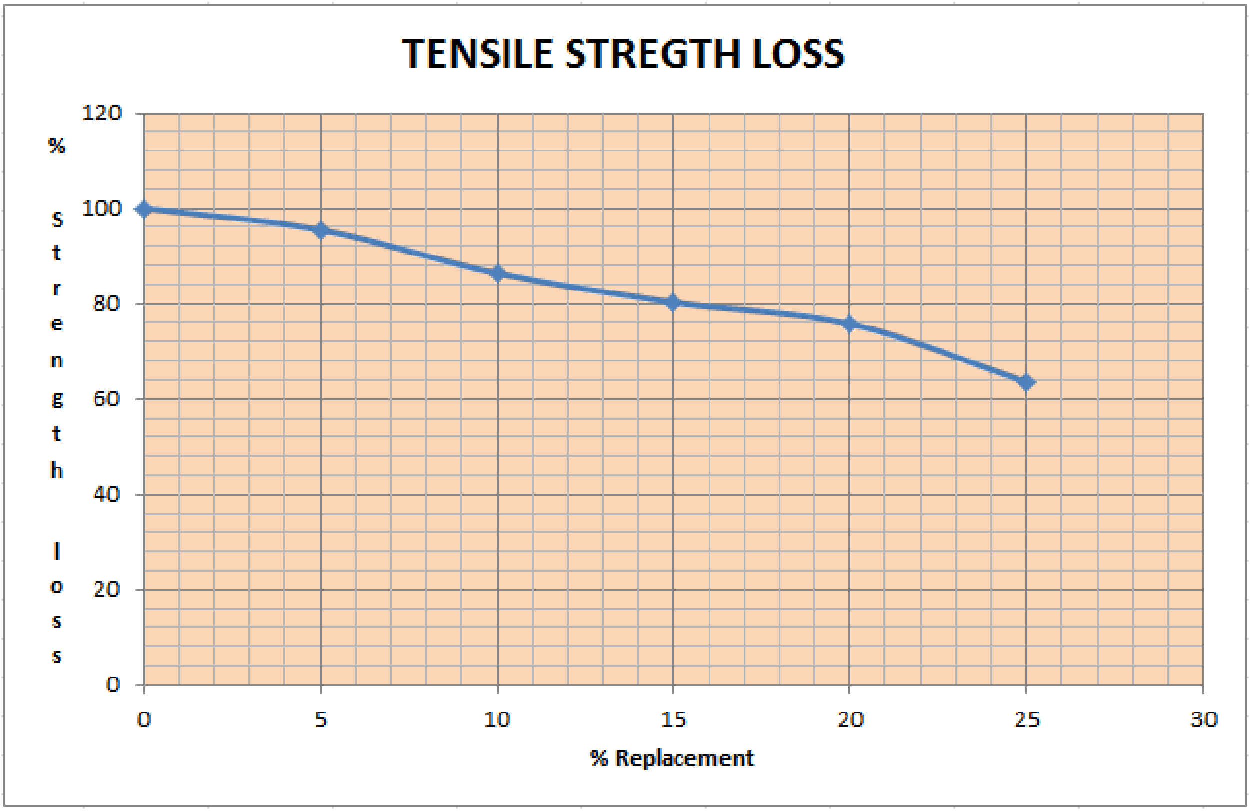
4.1.7 Tensile strength

Table 10: Tensile strength results

Type of mix	Concrete class (N/mm^2)	Age of curing (days)	Average tensile strength (N/mm^2)
Normal mix (Control)	25	28	3.3
Mix 1 (5% replacement)	25	28	3.15
Mix 2 (10% replacement)	25	28	2.85
Mix 3 (15% replacement)	25	28	2.65
Mix 4 (20% replacement)	25	28	2.5
Mix 5 (25% replacement)	25	28	2.1



It was found that tensile strength of concrete decreases as the percent replacement increased. The tensile strength at 25% replacement was gotten as 2.1N/mm^2.



Tensile strength decreased up to 36% as the percent replacement increased.

4.1.8 Cost of concrete

Table 11: Cost of concrete per m^3

Material	Normal aggregate concrete cost (Ksh.)	Clay aggregate concrete cost (Ksh.)
Cement	7560	7560
Fine aggregate	1053	1053
Coarse aggregate	1904	-
Total	**10517**	**8613**

CHAPTER 5
5.0 DISCUSSION

5.1 Grading

Sieve analysis was done using the standard sieve sizes meeting the requirements of BS 410: 1986 – specification for test sieves. Sieve analysis results were represented graphically in grading curves. From the grading curves, fine aggregates were found to lie within zone two while the normal granitic aggregates and crushed clay aggregates were within the limits given in BS 882: 1992. Grading is of importance in concrete mix design in the determination of the fine aggregate content hence the determination of the amount of coarse aggregate required. Grading affects the workability of concrete. Well graded aggregates enhance the workability of concrete by minimising the voids in the mix.

5.2 Flakiness index

Flakiness index was carried out using the specifications of BS 812-105.1: 1989. The flakiness index of crushed clay aggregate was found to be 12%. This was within the requirements of BS 812-105.1: 1989 (specifies a maximum of 25%). Flaky aggregates may have adverse effects on concrete. For instance, flaky particles tend to lower the workability of the mix which may impair the long-term durability of concrete.

5.3 Specific gravity

Gross and apparent specific gravities were done for the coarse aggregates. Gross specific gravity was a pre requisite in the concrete mix design. This specific gravity was necessary for calculation of the yield of concrete and the total aggregate content required for a given volume of concrete. The specific gravities and water absorption are shown below.

TYPE OF AGGREGATE	SPECIFIC GRAVITY	WATER ABSORPTION
Normal aggregate (NA)	2.6	2.9
Clay aggregate (CA)	2.3	4.7

Calculations with reference to concrete mixes were generally based on the saturated surface dry condition of aggregates because the water contained in all the pores in the aggregate does not take part in chemical reaction of cement and therefore considered as part of the aggregate.

Water absorption mainly depends on the porosity of the aggregates. Clay aggregates were found to have a higher water absorption compared to normal aggregates due to their porosity.

5.4 Aggregate crushing value

Aggregate crushing value of the aggregates was done to determine their relative resistance to crushing under a gradually applied compressive load. The test yields a fraction that passes 2.36 mm sieve which was weighed and divided by the fraction retained on a 10mm sieve after sieving through 14mm sieve before test. From the analysis, ACV for the normal aggregates was found to be **20.5%** while the ACV for clay aggregates was **41.67%**. Clay aggregates were found to have a lesser ability to resist crushing.

5.5 Concrete mix design

This was done based on the procedure given by the department of environment and Transport and Road Research Laboratory TRRL, London. Mix design was done to determine the concrete mix proportion that is water-cement ratio, cement content, fine and coarse aggregate content. The method adopted for identifying mix proportions was in reference to the weights of materials in a unit of fully compacted concrete. The method resulted in specifying mix constituents in terms of weights in kilograms necessary to produce the required volume of concrete. The mix proportions should be selected in such a way as to provide a balance between economy and requirements of place ability, strength, durability and appearance.

5.6 Workability

Slump test was used to determine workability, which is the amount of useful work required to obtain full compaction. Slump test does not measure workability directly, but it is commonly used in site work to detect variations in the consistency of mix of given proportions. Slump test is a means of assessing the consistency of fresh concrete.

The control mix gave a slump of 55mm while the slump results of the other mixes are as follows;

5% replacement = 49mm

10% replacement = 45mm

15% replacement = 40mm

20% replacement = 34mm

25% replacement = 34mm

This gives an indication of the water absorption and slightly elongated nature of the clay aggregate, which affect workability of concrete. The porous nature of clay aggregates results in medium to high rapid water absorption hence if the aggregate is used dry at mixing time, it will rapidly absorb water leading to harsh mixes with very low workability. Aggregates should be brought to saturated surface dry condition before mixing process by the addition of the required amount of water according to BS 1881 – 125:1983.

Slump results for all the mixes were within the design limits (30-60mm).

5.7 Compressive strength

Cubes were subjected to compression test after 14 and 28 days of curing. Analysis of the compressive strengths at 28 days of curing shows that 25% replacement of clay aggregate gains up to **80%** of the strength gained by normal granitic aggregate while 5% replacement of clay aggregate gains up to **97%** of the strength. The compressive strength curve shows that compressive strength increases with age.

From analysis of the results, compressive strength decreases as the percent replacement increases but the results are within acceptable limits. The 25% clay aggregate replacement concrete achieves strength of **26.5N/mm^2** compared to the normal aggregate concrete which achieves strength of **30.5N/mm^2**.

The type of cube failure was satisfactory and conforming to the specifications of BS 1881-116: 1983.

Some of the satisfactory types of failure are shown below;

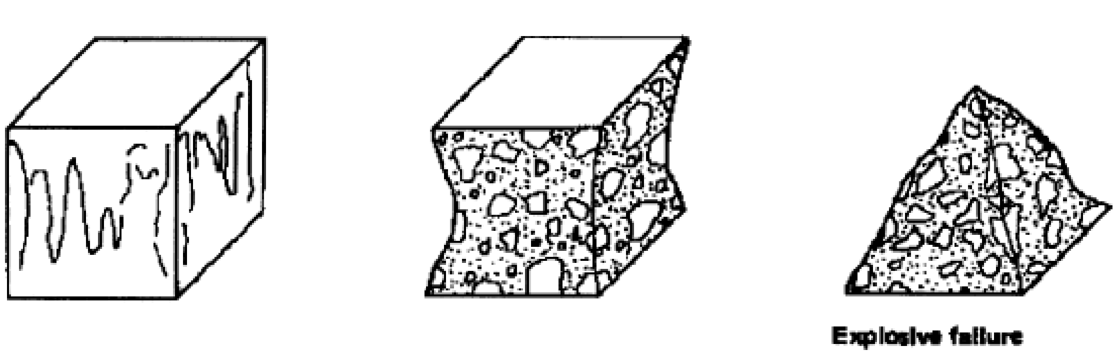


Figure 5 (a and b)

Figure 5 (a, b): Satisfactory failure

Apart from the compressive strengths observed, clay aggregates produced concrete with significantly reduced weight and densities as compared with normal concrete. Use of clay aggregates is thus advantageous in concrete production as the dead loads (self-weight) of concrete elements are substantially reduced in a structure.

5.8 Tensile strength

Cylindrical specimens were subjected to indirect splitting test after 28 days of curing. Tensile strength for the normal aggregate was found to be **3.3N/mm^2** while that of 5% replacement of clay aggregate was **3.15N/mm^2** and 25% replacement was **2.1N/mm^2**. It was observed that tensile strength decreased as percent replacement increased; however, the boundaries of deviation were marginal.

Wooden strips were placed above and below the cylinder, which was placed centrally, during loading. This was done to ensure that the load was distributed evenly along the cylinder specimen.

Figure 5 (c)

Figure 5 (c): Splitting test (wooden strips visible).

Tensile strength is not usually taken into account in reinforced concrete design (except in water retaining structures) because concrete is poor in tensile strength. It is however of considerable importance in resisting cracking due to changes in moisture content or temperature.

CHAPTER 6

6.0 Conclusion

Clean, crushed clay waste products provide satisfactory aggregates which can be used to produce good quality concrete of medium to high strength depending on the source of aggregate. It is found that compressive strengths of up to 24.5N/mm^2 can be attained by blending 25% of clay aggregates with normal aggregates. Compressive strengths for blended aggregates ranging from 80% to 97% of concrete made with normal aggregate can be achieved. This significant strength is attributed to the particle shape and roughness of the clay aggregates which provides satisfactory bond strength.

Clay aggregates produce concrete with comparatively lower densities. This indicates that there can be significant reduction of dead loads (self-weight) of fully compacted concrete. Weight reduction of up to **9%** of normal aggregate concrete can be attained.

The concern in the use of clay aggregates is their water absorption characteristic. This affects the workability of concrete. Therefore; these aggregates must be saturated for some time and surface dried before they can be used in concrete making. Another disadvantage is the production of too much dust particularly during crushing. This is due to their high crushing values. When using clay aggregates, grading should be done impeccably.

The use of these aggregates can offer benefits associated with both economy (cost savings of up to Ksh. 1900 per m^3) and sustainability.

6.1 Recommendation

From the laboratory test results and study, I would like to commend the use of clay aggregates in the production of concrete with medium to high compressive and tensile strengths especially for low cost construction.

One of the key objectives of Kenya's vision 2030 is to deliver affordable housing to all especially in the shantytown areas, hence the need to provide cheaper building materials. The use of clay aggregates in concrete production would significantly lessen the high cost of concrete because these aggregates can be gotten as a waste from clay products manufacturing industries. These aggregates would also provide haul cost savings since they are lighter than the normal aggregates.

The recycling and use of the aggregates will reduce environmental degradation in two aspects:

I. Reduction of overdependence on natural sources of aggregates i.e. granitic aggregates. This will reduce quarrying for normal aggregates.
II. The clay waste products can be put into a more beneficial use as aggregates in concrete, other than dumping and land filling.

Hence, the use of these aggregates will endorse environmental sustainability and sustainable development.

I would like to recommend further research on the behaviour of clay aggregates in reinforced concrete i.e. its suitability in RC beams etc. and also in the use in pre-cast elements. Further investigation should be done on the long term behaviour of clay aggregate concrete under moderate weather exposure that is external exposure.

APPENDIX

Appendix A: The mix design process

(Based on the procedure given by the Department of Environment – Transport and Road Research Laboratory, London)

The margin: Equation C1

The margin may be derived from the calculation below;

$M = k \times s$.....................**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

$fm = fc + M$................**C2**

Where;

fm = the target mean strength.

fc = the specified characteristic strength.

M = the margin.

Cement content: Equation C3

Cement content = $\frac{Free - water\ content}{Free{-}water\ /cement\ ratio}$.....................**C3**

Total Aggregate content: Equation C4

Total aggregate content (saturated surface – dry) = $D{-}W_C{-}W_{FW}$....................**C4**

Where;

D= the wet density of concrete (Kg/m3)

W_C= the cement content (Kg/m^3)

W_{FW}= the free – water content (Kg/m^3)

Fine and coarse aggregates contents: Equation C5

Fine aggregate content = Total aggregate content × Proportion of fines

Coarse aggregate content = Total aggregate content – fine aggregate content……………….**C5**

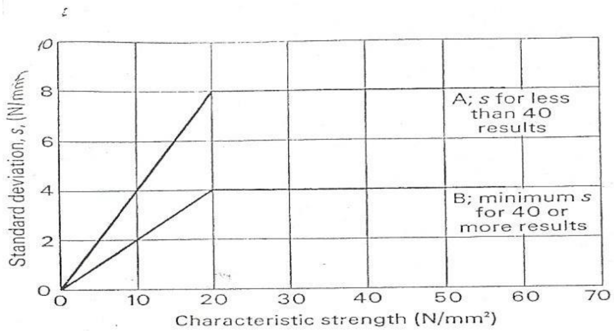


Figure 3 Relationship between standard deviation and characteristic strength

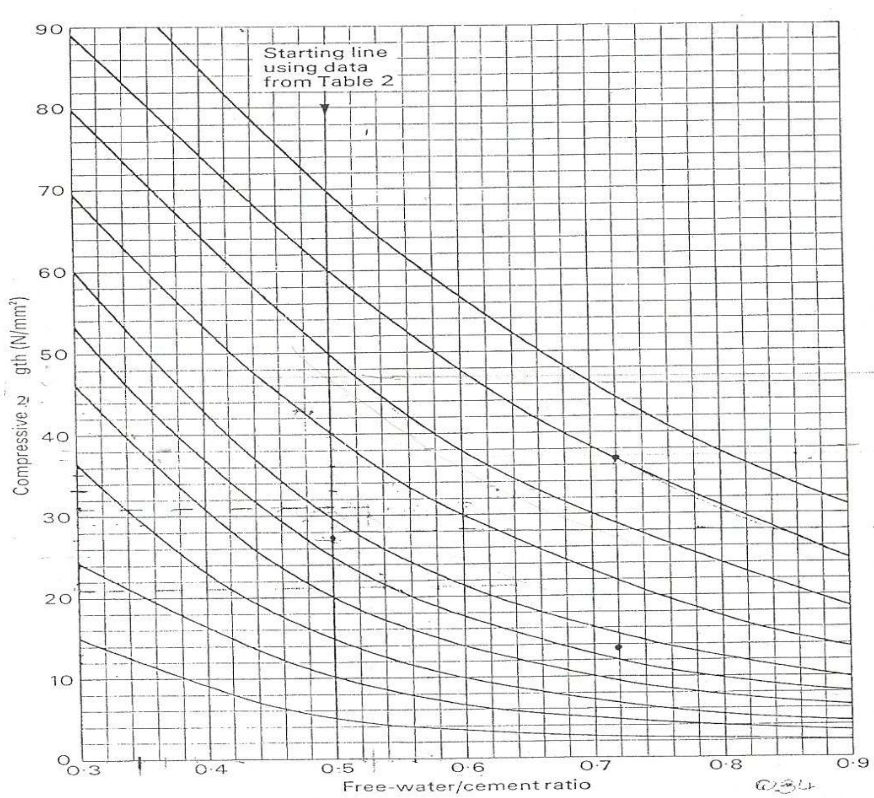


Figure 4 Relationship between compressive strength and free-water/cement ratio

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Figure 3: Relationship between standard deviation and characteristic strength.

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

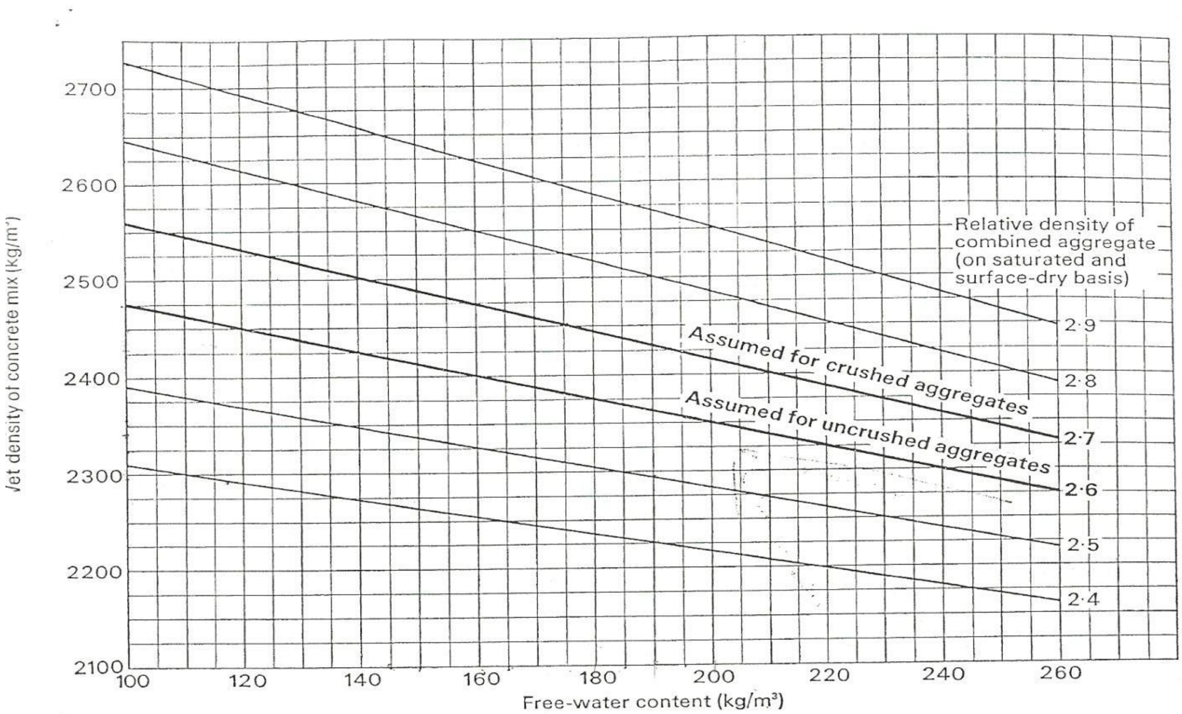

Figure 5 Estimated wet density of fully compacted concrete

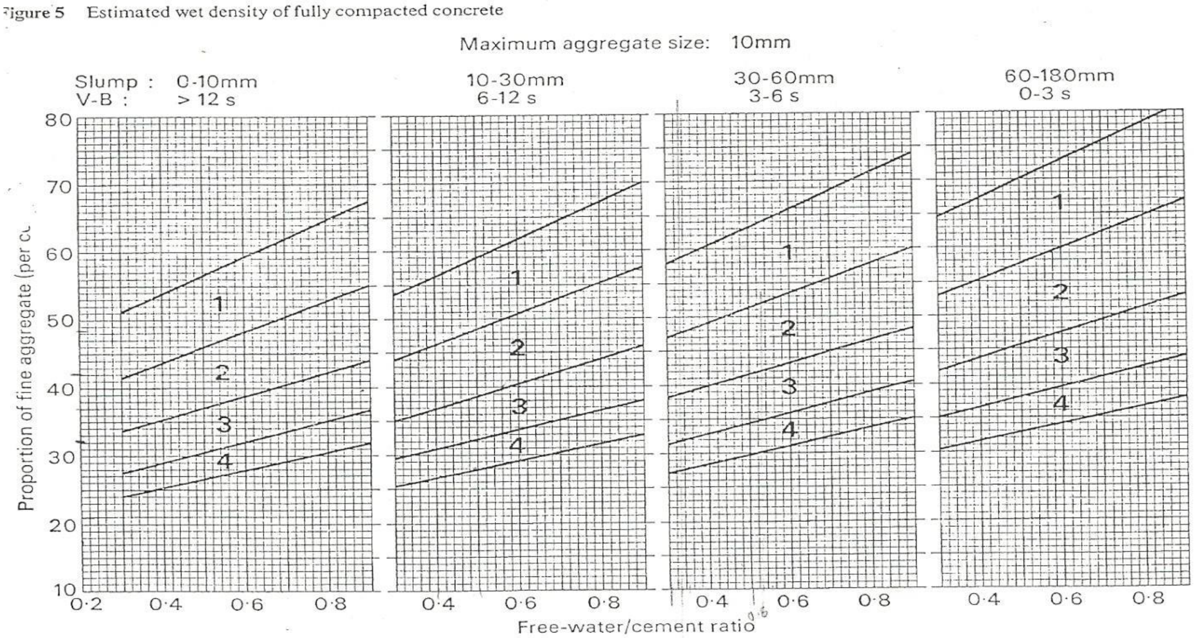

Figure 6 Recommended proportions of fine aggregate for BS 882 grading zones 1, 2, 3 and 4

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Figure 5: Estimated wet density of fully compacted concrete.

Figure 6: Recommended proportions of fine aggregate for BS 882 grading zone 1, 2, 3 and 4.

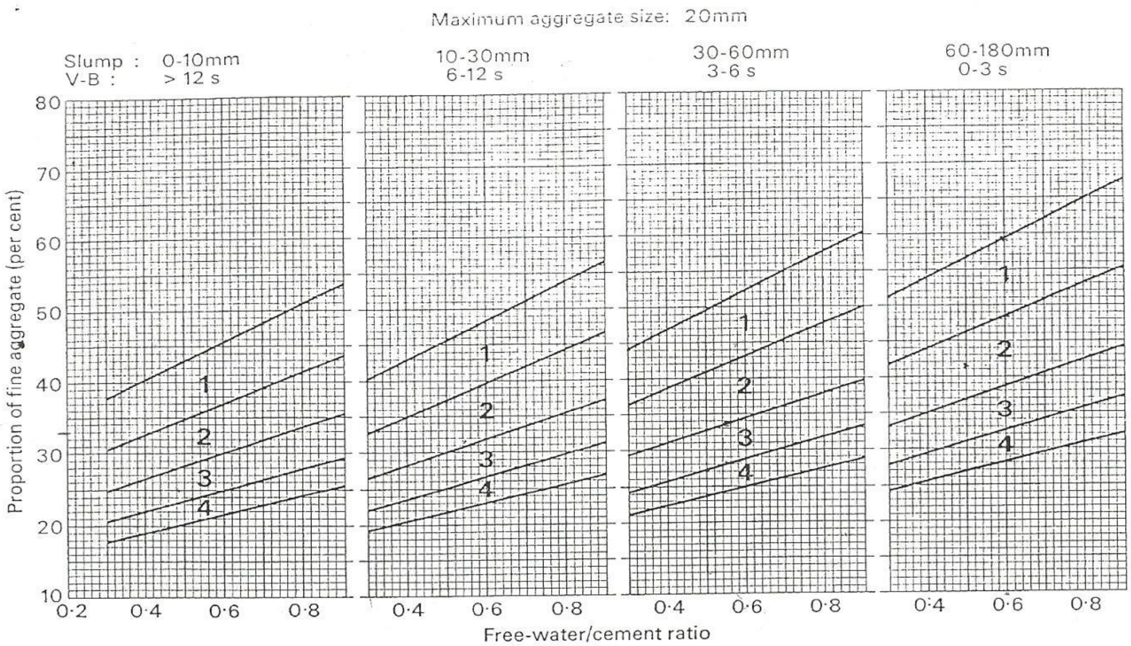

Figure 6 *(continued)*

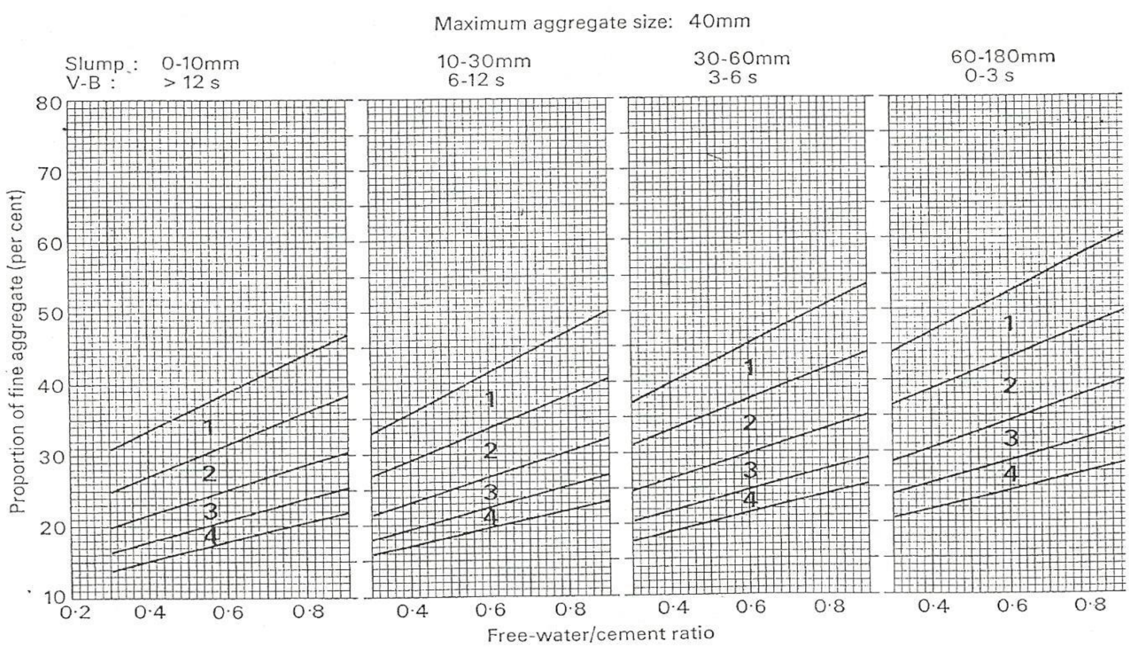

Figure 6 *(continued)*

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Figure6: *(Continued)*

Table 2: Approximate compressive strength (N/mm^2) of concrete mixes made with free-water/cement ratio of 0.5

Type of cement	Type of coarse aggregate	Compressive strengths (N/mm^2) Age (days)			
		3	7	28	91
Ordinary Portland Cement (OPC) or Sulphate Resisting Portland Cement (SRPC)	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 3: Approximate free-water contents (kg/m^3) required to give levels of workability

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	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Concrete mix design: Normal aggregates

Stage	Item	Reference	Values
1	1.1 Characteristic strength 1.2 Standard deviation 1.3 Margin 1.4 Target mean strength 1.5 Cement type 1.6 Aggregate type: Coarse Fine 1.7 Free water/Cement ratio 1.8 Maximum free water/cement ratio	Specified Fig…**3**…… ……**C1**….. ……**C2**….. Specified Table…**2**…/ Fig…**4**… Specified	**25** N/mm² at **28** days Proportion defective **5** % **-** N/mm² or no data **8** N/mm² (k =**1.64)** X **8** = **13** N/mm² **25** + **13** = **38** N/mm² **Power max 42.5** **Crushed** **Crushed** **0.56** Use lower value **0.5**
2	2.1 Slump or V – B 2.2 Maximum aggregate size 2.3 Free – water content	Specified Specified Table …**3**…	Slump **30-60** or V – B …………. **20** mm **210** Kg/m³
3	3.1 Cement content 3.2 Maximum cement content 3.3 Minimum cement content 3.4 Modified free – water cement	……**C3**……. Specified Specified ………….	210 ÷ 0.5 = **420** kg/m³ 200 kg/m³
4	4.1 Relative density of aggregate 4.2 Concrete density 4.3 Total aggregate content	DETERMINED Fig …**5**……. …………	**2.6 Known**/assumed **2400** Kg/m³ **2400** – **420** – **210** = **1770** Kg/m³
5	5.1 Grading of fine aggregate 5.2 Proportion of fine aggregate 5.3 Fine aggregate content 5.4 Coarse aggregate content	**BS 882** Fig …**6**……. …**C5**…… …………..	**Zone 2** **33%** 1770 × 0.33 = **584** kg/m³ 1770 – 584 = **1186** kg/m³

Quantities	Cement	Water	Fine aggregate	Coarse aggregate
Per m³ (5kg)	**420** Kg	**210** Kg	**585** Kg	**1190** Kg
	1		**1.4**	**2.8**
Mix ratios per trial mix of 0.0233m³	**9.8 Kg**	**4.9Litres**	**13.6 Kg**	**27.6 Kg**

Coarse aggregate replacement:

Trial mix per $1m^3$

TYPE OF MIX	CLAY AGGREGATE CONTENT (kg)	NORMAL AGGREGATE CONTENT (kg)
Mix 1 (5% replacement)	59.5	1130.5
Mix 2 (10% replacement)	119.0	1071.0
Mix 3 (15% replacement)	178.5	1011.5
Mix 4 (20% replacement)	238.0	952.0
Mix 5 (25% replacement)	297.5	892.5

Appendix B: Raw data

Sieve analysis

Normal aggregates

Test sieve sizes (mm)	Weight of sieve (g)	Weight of sieve + retained material (g)	Weight retained (g)	Weight passing (g)	Percentage retained (%)	Percentage passing (%)
37.5	517.5	517.5	0.0	2638.0	0	100
25	538.5	538.5	0.0	2638.0	0	100
20	588.0	711.0	123.0	2515.0	4.7	95.3
10	497.5	2203.0	1705.5	809.5	64.6	30.7
5	482.5	1165.0	682.5	127.0	25.9	4.8
2.38	463.0	519.0	56.0	71.0	2.1	2.7
Pan	515.5	586.5	71.0		2.7	
Total			**2638**		**100**	

Clay aggregates

Test sieve sizes (mm)	Weight of sieve (g)	Weight of sieve + retained material (g)	Weight retained (g)	Weight passing (g)	Percentage retained (%)	Percentage passing (%)
37.5	517.5	517.5	0.0	1800	0	100
25	538.5	538.5	0.0	1800	0	100
20	588.0	645.5	57.5	1742.5	3.2	96.8
10	497.5	1661.5	1164.0	578.5	64.6	32.2
5	482.5	860.0	377.5	201	21	11.2
2.38	463.0	570.5	107.5	93.5	6	5.2
Pan	515.5	609.0	93.5		5.2	
Total			**1800**		**100**	

Fine aggregates

Test sieve sizes (mm)	Weight of sieve (g)	Weight of sieve + retained material (g)	Weight retained (g)	Weight passing (g)	Percentage retained (%)	Percentage passing (%)
9.52	521.0	535.0	14.0	1850.5	0.8	99.2
4.75	470.0	515.0	45.0	1805.5	2.4	96.8
2.38	463.5	546.0	82.5	1723.0	4.4	92.4
1.2	450.5	658.5	208.0	1515.0	11.2	81.2
0.6	529.5	1088.0	558.5	956.5	29.9	51.3
0.3	389.0	1033.5	644.5	312.0	34.6	16.7
0.15	356.5	582.5	226.0	86.0	12.1	4.6
Pan	511.5	597.5	86.0		4.6	
Total			**1864.5**		**100**	

Specific gravity

ITEM	NORMAL AGGREGATE		CLAY AGGREGATE	
	NA1	NA2	CA1	CA2
Weight of saturated surface dry sample (W_{SD}), g	646.5	655.0	973.5	992.5
Weight of sample when immersed in water (W_W), g	397.0	401.0	555.0	566.0
Weight of oven dry sample at 105-110°C (W_{OD}), g	628.5	636.5	930.0	948.0
Specific gravity on saturated-surface dry basis (gross) $S_{SD} = \frac{W_{SD}}{W_{SD}-W_W}$	2.591	2.578	2.326	2.327
Average specific gravity on saturated surface dry basis	2.6		2.3	
Absolute dry specific gravity (apparent) $SAP = \frac{W_{OD}}{W_{SD}-W_W}$	2.52	2.51	2.222	2.223
Average apparent specific gravity	2.5		2.2	
Water absorption (% of dry weight)	2.86	2.91	4.68	4.69
Average water absorption	2.9		4.7	

Compressive strength

Cube mark	No. of cubes	Class (N/mm^2)	Age (days)	Mass (kg)	Density (kg/m^3)	Compressive strength (N/mm^2)	Average strength (N/mm^2)
NA 1	3	25	14	8.1	2400	26.6	26.5
				8.0	2370	27.1	
				8.1	2400	26.2	
NA2	3	25	28	8.1	2400	29.8	30.5
				8.1	2400	33.3	
				8.1	2400	27.6	
CA1 (5%)	3	25	14	7.9	2340	26.2	26.0
				7.9	2340	25.8	
				7.9	2340	26.2	
CA2 (5%)	3	25	28	7.9	2340	31.6	30.0
				7.9	2340	28.9	
				7.8	2311	29.3	
CA3 (10%)	3	25	14	7.8	2311	25.3	25.5
				7.8	2311	25.8	
				7.8	2311	24.9	
CA4 (10%)	3	25	28	7.8	2311	27.1	28.5
				7.8	2311	31.1	
				7.8	2311	27.6	
CA5 (15%)	3	25	14	7.8	2311	24.4	24.0
				7.7	2281	23.1	
				7.7	2281	24.0	
CA6 (15%)	3	25	28	7.7	2281	26.2	26.4
				7.7	2281	26.7	
				7.7	2281	26.2	

CA7 (20%)	3	25	14	7.6	2252	21.3	22.5
				7.6	2252	22.7	
				7.6	2252	23.1	
CA8 (20%)	3	25	28	7.6	2252	24.4	25.5
				7.6	2252	25.8	
				7.6	2252	25.8	
CA9 (25%)	3	25	14	7.5	2222	20.9	21
				7.5	2222	22.2	
				7.5	2222	20.4	
CA10 (25%)	3	25	28	7.5	2222	24.0	24.5
				7.4	2193	23.6	
				7.4	2193	25.3	

Tensile strength

Cylinder mark	No. of cylinders	Class (N/mm^2)	Age (Days)	Tensile strength (N/mm^2)	Average tensile strength (N/mm^2)
NA1	3	25	28	3.4	3.30
				3.8	
				2.8	
CA1 (5%)	3	25	28	3.7	3.15
				2.6	
				3.2	
CA2 (10%)	3	25	28	3.2	2.85
				2.5	
				2.8	
CA3 (15%)	3	25	28	2.8	2.65
				2.3	
				2.8	
CA4 (20%)	3	25	28	2.6	2.50
				2.6	
				2.2	
CA5 (25%)	3	25	28	2.0	2.10
				2.1	
				2.1	

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