INVESTIGATIONS INTO THE PROPERTIES OF CONCRETE MADE WITH CRUSHED BRICKS AS COARSE AGGREGATE

BY

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A Thesis submitted to the Post-graduate School, Ahmadu Bello University, in partial fulfilment of the requirements for the Award of MASTER OF SCIENCE (CONSTRUCTION TECHNOLOGY)

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November, 1988.

D E C L A R A T I O N

I, Garba Muhammad Magaji declare that this thesis is solely the record of my work and has never been submitted anywhere for any degree.

All literature cited have been duly acknowledged in the references.

Garba Muhammad Magaji Date.....

APPROVAL STATEMENT

This project thesis entitled "INVESTIGATIONS INTO THE PROPERTIES OF CONCRETE MADE WITH CRUSHED BRICKS AND COARSE AGGREGATE" by Garba Muhammad Magaji meets the regulations governing the award of the degree of Master of Science (Construction technology) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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D E D I C A T I O N

This work is specially dedicated to my father Alhaji Garba Iyalu and my mother Mrs. Garba Magajiya and the entire Mallam Halliru family.

ACKNOWLEDGEMENT

I am very grateful to the following people for their honest advice/help during the progress of the work:

(i) Dr. A. A. HUSSEINI
Lecturer in the Department of Building and the Supervisor of this work.

(ii) Dr. T. O. MOSAKU
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(iv) Mr. U. K. AIMIUWU
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(v) Mr. DAVID ATABO
Works Manager, Nigerian Clay and Ceramic Product Ltd., Kaduna.

(vi) And finally to the entire staff and students of this department for their co-operation, which created a conducive atmosphere for learning. But above all, I am grateful to Ahmadu Bello University, Zaria for sponsoring me for this degree.

A B S T R A C T

This thesis investigated the properties of coarse aggregate made by manually crushing bricks from the Nigerian brick and clay product Ltd. Kaduna, and the properties of the concrete produced using this aggregate. The average compressive strength of bricks used was 30 N/mm^2. Three concrete mixes were made. The maximum compressive strength obtained for 7 - days was 13 N/mm^2 while for 28-days 18 N/mm^2 was obtained. The tensile strength was about $\frac{1}{12}$th to $\frac{1}{9}$ of the cube compressive strength while the modulus of elasticity was about 48% lower than that of normal concrete of the same strength.

From the investigations, brick aggregate produce concrete of adequate strength and of "medium weight". The unit weight being about 1870 to 2183 Kg/m^3 as compared to a range of 2354.9 to 2563.2 Kg/m^3 for normal weight concrete and 400.5 to 1762.2 Kg/m^3 for light weight concrete.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Whenever one visits any of the clay brick factories in this country, there is every likelyhood of coming across heaps of deformed and broken bricks. These spoilt bricks constitute a great disposal problem as the factories do not recycle them. At the moment, spoilt bricks are mostly used in filling up badly weathered road and also as hardcore filling materials. Mckay (1973) reported that old bricks from demolished buildings can be used as coarse aggregate in concrete after crushing to aggregate size.

Although bricks can be used as aggregate, the properties of the concrete made with this type of aggregate will definately depend on many variables arising from the nature of the bricks used. Thus for any factory bricks to be used satisfactorily, the properties of the aggregate as well as the concrete must be investigated and certified adequate. It is in this direction that the study was carried out. Work reported here is the investigation into the properties of concrete made with crushed bricks as coarse aggregate.

Spoilt bricks from the Nigerian Brick and Clay Products Ltd. Kaduna factory were used for this study. The bricks were manually crushed to aggregate

sizes. The physical properties (specific gravity, density, porosity, absorption capacity and moisture content) were determined. The aggregate was then used to produce concrete which was tested for density, ultimate crushing strength, cylinder splitting strength and static modulus of elasticity.

1.2 Objectives

The objectives of the investigations were:

1. To determine the properties of brick aggregate and compare it with those of normal aggregate.
2. To make concrete with this aggregate and determine its properties which would be compared with those of normal concrete.
3. To establish the weight group of the brick concrete and its suitability for construction.

1.3 Scope and Limitations

Of the properties of coarse aggregate and concrete, only the basic ones were investigated. This was mainly due to equipment constraints. The properties of the aggregate determined were the bulk density, specific gravity, absorption capacity and moisture content. The aggregate was then used to produce concrete properties like the compressive and tensile strengths, modulus of elasticity and density were determined.

Properties like aggregate's abration and impact values, flakiness and sphericity indices were not investigated. The permeability, durability, creep and shrinkage properties of the concrete were also not investigated and the reason being as mentioned earlier.

1.4 Methodology

The investigation started by manually crushing bricks to produce 20mm maximum aggregate size. The physical properties of the aggregate were determined. Concrete mixes were then made with this aggregate and certain of its properties determined. The results of the investigation were compared with those of normal concrete in order to enable objectives assessment of the brick concrete.

CHAPTER TWO

2.0 LITERATURE REVIEW

Introduction

In order to enable objective assessment of the properties and qualities of brick concrete, the properties of normal aggregates and concrete are discussed in this chapter. The review starts by first discussing the properties of normal aggregates (e.g. stones and gravels) and then that of the concrete made with these aggregates.

2.1 THE AGGREGATES

Mineral aggregates as defined by George and Harmer (1956) is "the relatively inert filler material in a portland-cement concrete".

Aggregates are used in concrete to voluminise it. They also increase strength, reduce shrinkage, creep and overall cost of concrete.

Some of the materials used as aggregates are: gravels, crushed rocks, iron shots, barytes and scrap iron. According to Ochard (1973) any material provided it satisfies the under-listed criteria can be used as aggregate:

(i) chemically inert

(ii) strong

(iii) can be obtained with required size and grading.

(iv) clean.

2.1.1 Classification of Aggregates

Concrete aggregates can be broadly classified into natural and artificial. This classification as stated by Ochard (1973), can be further sub-divided according to the petrological characteristics, specific gravities, shape and texture of the aggregate.

Figure 2.1 depicts the classifications of aggregates pictorially.

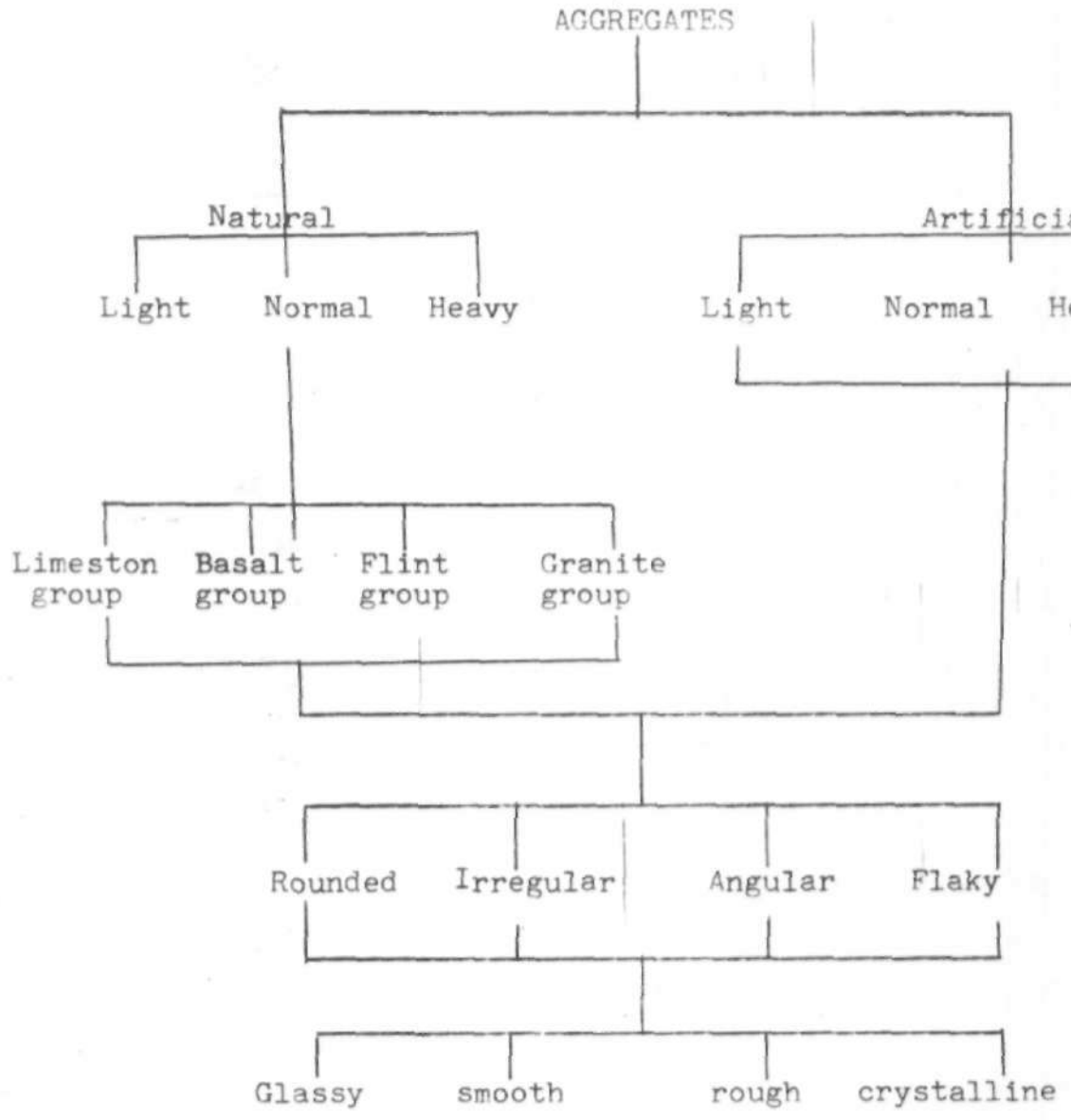


Fig. 2.1 - Classification of aggregates.

Natural Aggregates

These consists of gravels obtained from natural sources like pits, river and ocean beds where they have been deposited by alluvial or glacial action. They could also be found on shores where they have been deposited by sea action.

Often aggregates obtained from the above sources must be cleaned to remove harmful impurities like clay, silt or salt in the case of on-shore deposits.

Gravels can consist of flint, quartz, chert and igneous rocks. Some deposits contain a large proportion of calcium carbonate which according to Elvery (1963) are quite satisfactory.

Gravels are usually obtained with required particle sizes. When a gravel deposit contains too much over-size material, it must be crushed and screened to required size.

Another source of natural aggregates is rocks outcrop. Rock outcrops are lasted and crushed to required size. Crushed rocks provide a good coarse aggregate although the cost is higher than a naturally occuring gravels. Crushed rock used as concrete aggregate include granites, dolerites, diorites, syenites and limestones. Crushed rocks are frequently referred to commercially as granite although only a small proportion of these are really granites in geological sense.

Artificial Aggregates

These are usually the by-products of some industrial process. However plants for producing artificial aggregate like the expanded clay foamed slag etc. have been made. Many of these aggregates produce light weight concrete of adequate strength and good heat insulation properties. Examples of artificial aggegates that produce light weight concrete include; blast-furnace slag, foamed slag, furnace clinker and expanded clays. Those that produce heavy weight concrete are iron shots, barytes, scrap iron and ball bearings.

Sub-division of Aggregates

As depicted on figure 2.1, natural and artificial aggregates can be sub-divided into groups based on petrological characteristic, specific gravities, particle shape and texture. Each of these sub-division has its advantage and use.

(i) Sub-division based on specific gravities

Here, aggregates are grouped into three classes depending on their specific gravities. These are heavy weight, normal weight and light weight aggregates. According to Ochard, (1973), heavy-weight aggregates are those having specific gravity of 4.0 and above. Example of these are scrap iron, ball bearings, ilmenite, magnetite and barytes.

They are used in producing concrete for radiation shielding and/or concrete for counter weight. Normal aggregates are those with a specific gravity of about 2.6. Examples include; sandstones, limestones, granite and syenite. Normal weight aggregates are used for making ordinary structural concrete. Light weight aggregates are those that have S.G. less than 2.6. These aggregates have high porpsity which results in low apparent specific gravity. Light weight aggregate occur naturally and some are manufactured. Examples of light weight aggregates are; pumise, scoria, asbestos and saw dust.

(ii) Sub-division based on petrological characteristics.

In this subdivision, aggregates are grouped based on their mineral and chemical composition, texture and structure. Crushed natural rock is classified in B.S. 812, "sampling and testing of mineral aggregates, sands and fillers" into their groups. Some of these are the basalt group, granite group, gritstone group and limestone group.

(iii) Sub-division based on shape and texture

The shape and texture of aggregates affect many properties of the concrete made with them. Properties like workability, compaction and strength to mention a few are greatly affected by shape and texture of aggregates. It is for this reason that it was found convenient to classify aggregates in accordance to shape and texture. Under

aggregate shape, we can have; rounded, irregular, angular and flaky shapes. Aggregates texture are classified as being, smooth, glassy, rough crystalline etc.

2.1.2 Properties of Aggregates

One of the principles of concrete mix design is to use as much aggregate as possible. This is because aggregate is cheaper than cement and is a more satisfactory structural material than cement paste. Apart from the amount of aggregates in concrete, another very important factor to be considered is that the aggregate must be of good quality. To assess the quality of aggregate, its properties must be determined as described in B.S. 812 (1960).

Physical properties of aggregates

Of the various physical properties of aggregates, the following are the most important:

(i) Particle-size distribution,
(ii) Fineness modulus,
(iii) Particle shape and texture,
(iv) Specific gravity,
(v) Moisture content,
(vi) Absorption and,
(vii) Bulk density.

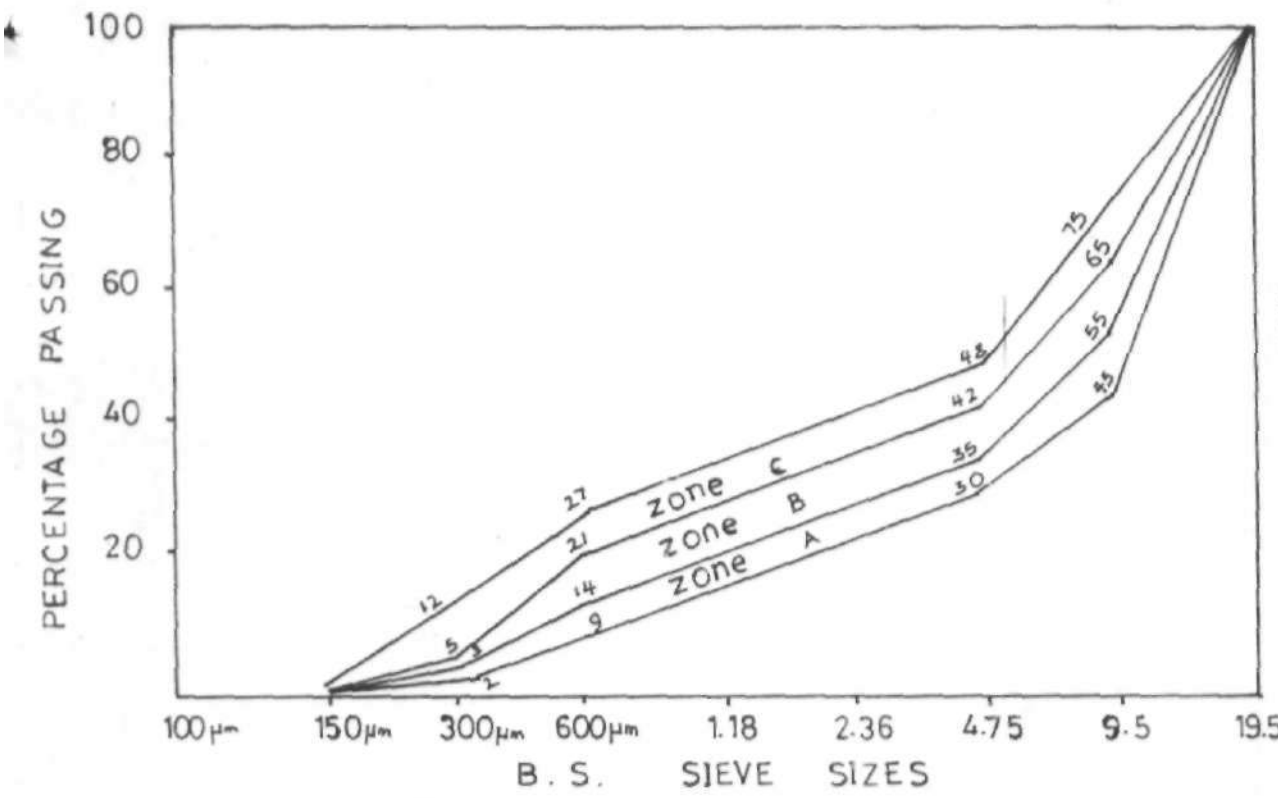
(i) Particle-size Distribution

This is the distribution of the various particle sizes in an aggregate sample. The particle-size distribution or grading is very important as it affects many properties of the finished concrete. Properties

like workability, compaction, density, permeability, durability and cost of the mix are affected by the aggregate's grading.

The particle-size distribution is determined by the method of sieve analysis as described in B.S. 812 (1960). It involves passing a sample of the aggregate through a series of sieves each having appertures half the size of those in the previous sieve. The sieve sizes used for the analysis of coarse aggregate are 38mm, 20mm, 10mm, 5mm, and 2.36mm. The amount of material retained on each of the sieves is weighed and the weights expressed as percentage of the total weight of the sample. From these figures, the cumulative percentages by weight passing each of the sieve is calculated and the result plotted against the sieve size as shown in figure 2.2.

Figure 2.1 shows the standard grading curves for 20mm maximum aggregate size as given in Road Research Laboratory (1950). The grading curve of any coarse aggregate that falls in zone A is very coarse while zone B is for aggregates that are neither fine nor coarse.



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Figure 2.2. Type grading curve for 20mm aggregate (According to Road Research Laboratory: 1950).

(ii) Fineness Modulus

Apart from the use of grading curves for expressing the fineness or coarseness of an aggregate, another method is the use of fineness modulus. The fineness modulus of an aggregate is the cumulative percentage of the aggregate retained on each of a series of sieves, each having a clear opening half that of the preceding one, the total being divided by 100. A normal coarse aggregate has fineness modulus ranging from 5.5 to 8.0 while that of sand is between 2.5 to 3.0 (according to Joseph: 1962).

(iii) Particle shape and Texture

The particle shape and texture of aggregate greatly

influences many of the properties of concrete although indirectly. Particle shape of an aggregate are grouped as rounded, irregular, flaky and elongated. The best shape according to Elvery (1963) being rounded and then irregular. Flaky and elongated shapes should whenever possible be avoided as they are a source of weakness when used in concrete making.

The textures of aggregates are classified as being; glassy, smooth, granular, rough and crystalline. The texture affects workability of concrete.

(iv) Specific gravity

The specific gravity of an aggregate is used in proportioning of materials for concrete. The specific gravity could be based on saturated surface dry basis or an air-dry bases - depending on the condition of the aggregate to be used.

The specific gravity of a material is the ratio of its weight to the weight of an equal volume of water. The average specific gravities of some common aggregates according to Ochard (1973) are:

Sand-stone, 2.5;
Sand and gravel, 2.65;
Limestone, 2.65;
and granite, 2.65.

The specific gravity of an aggregate could be deter-

mined as specified in B.S. 812.

(v) Aggregate moisture content

The aggregate moisture content may affect the amount of water that will ultimately be available for workability and hydration in concrete. This is because some aggregates are highly porous. They have vacant spaces or pores located between the individual mineral grains comprising the particles.

When porous aggregates are exposed to wetness, they start absorbing water into their pores. A dry aggregate used in a concrete mix will absorb some water from the mix. This causes the paste to be dehydrated which in turn will affect the workability, strength and durability. Because the absorbed water is not available to hydrate the cement, it is not included in calculating the mix's water-cement ratio.

On the other hand, when a saturated surface-dry aggregate is used in concrete mix, it could be assumed that the mix's water-cement ratio is unaffected.

As it is difficult to keep aggregates at saturated surface-dry condition, moisture corrections are done in order to overcome the difficulty.

According to portland cement association, the moisture conditions of an aggregate can be classified into:

(a) Oven-dry aggregate.
This is an aggregate that has been dried in an oven at 105 to 110°C on a hot plate or when heated with a burning alcohol.

(b) Saturated surface-dry aggregate.
This is an aggregate which was initially wet but now has been surface-dried with a towel or an aggregate that has been dried in air to the point of surface dryness.

(c) Air-dry aggregate.

(d) Wet aggregate.

Figure 2.3 is the classification of aggregate moisture conditions shown pictorially.

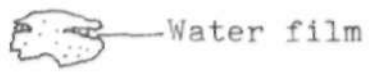
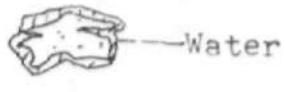
Oven-dry	
Air-dry	
Saturated surface-dry	
Wet or moist	

Fig. 2.2 - Schematic representation of moisture conditions of Aggregate.

(vi) Absorption Capacity

This is a measure of the water held in the pores of saturated surface-dry (S.S.D.) aggregrates after impersion for a specific time. The understanding of the absorption property of aggregate is important as it is used in calculating mix's water correction. Also a highly absorbent aggregate will produce a very permeable concrete which may not be durable.

Absorption capacity (A.C.) is expressed as a percentage of the oven-dry aggregate weight (A).

$$\% \text{ A.C.} = \frac{\text{Weight of total pore water}}{A} \times 100$$

$$= \frac{(\text{S.S.D.} - A)}{A} \times 100$$

Moisture content

This is a measure of the water held in the pores of an air-dry aggregate. Moisture content is also expressed as a percentage of the oven-dry aggregate weight. It is used for calculating mix's water correction.

$$\% \text{ M.C.} = \frac{\text{weight of water in pores}}{A} \times 100$$

$$= \frac{D - A}{A} \times 100$$

Surface Moisture

This is a measure of the free or surface moisture on aggregate surfaces. Surface moisture (% S.M.) is expressed as a percentage of S.S.D. aggregate weight.

It is also used in calculating the mix's water correction.

$$\% \text{ S.M.} = \frac{\text{Weight of surface moisture}}{\text{S.S.D.}} \times 100$$

$$= \frac{(W - \text{S.S.D.})}{\text{S.S.D.}} \times 100$$

Where W - is the weight of moist (wet) aggregate in air.

2.2 THE CONCRETE

Introduction

Concrete, an important construction materials is made by mixing cement, aggregate and water. Its strength development is as a result of a chemical reaction that takes place between the cement and water. The cement reacts with water (a process known as hydration) to form a number of complex chemical substances. The dominant product according to portland cement association (1975) consists of tiny particles suspended in liquid. This material is known as tobermorite get. Although other products are formed during hydration (crystalline calcium hydroxide, for example) all these products are often lumped together and called "cement get."

As the process of hydration proceeds, these gel particles continue to grow until they become interwined with each other. These interwined particles become rigid with time and form what is called hardened cement past (h.c.p.). This h.c.p. is the most fundamental material which provides the strength that allows concrete to

be used structurally. The aggregates which according to Illston J.M. (1979) forms 60 to 80% of volume of concrete, gives rigidity and dimentional stability.

By adjusting the constituent materials, concretes of differing properties could be made to suit various purposes. For instance a light weight concrete can be produced by using light weight aggregate which could result in low dead weight of a structure. Concretes for radiation shielding, high temperature or marine condition could be easily made by using other suitable materials.

The proportioning of concrete materials to achieve concrete of required quality is called mix design.

2.2.1 Concrete mix design

Concrete mix design as defined by Neville (1963) "is the process of selecting suitable ingredients of concrete and determining their relative quantities with the object of producing as economically as possible concrete of certain minimum properties".

Principles of mix design

The main objective of concrete mix design, as stated above, is to proportion materials which will produce concrete having required properties. Before a concrete is designed for a particular job, consideration must be taken of the site condition the concrete is to be made and placed.

Some of the important factors to be considered in mix design include water-cement ratio and compaction. The water-cement ratio of any mix is important because there is an optimum quantity of water needed for cement hydration and workability. If the quantity of water used exceeds the optimum, the excess water will dry out as the concrete hardens. This leaves voids within the concrete which could cause reduction in strength. Non-fully compacted concrete behaves in a similar manner with a concrete in which excess water has been used as regards to strength.

Concrete mix design procedures

Alot of concrete mix design procedures have been suggested based on different factors involved. Rene Feret found in 1892 that the compressive strength of concrete and mortar is proportional to the amount of cement in the mix, and that it increases as the volume of voids in the aggregate decreases.

Duff Abrams demonstrated in 1918 the relationship between strength and amount of water per unit volume of cement in the concrete. He found that the strength of concrete depends on the ratio of water to cement in the mix. The Abrams "water-cement law" in slightly modified form is used as the basis for some concrete mix design methods. However apart from giving consideration to water-cement ratio, other factors such as aggregate-cement ratio, grading, surface texture, shape and largest aggre-

gate size to be used must also be considered.

Other methods, not based on Abrams law include those based on proportioning materials for maximum density or minimum void contents such as Vallette's method, the Fuller ideal Curve (1907), Bolomey's formular (1926) and the Fineness modulus methods were used.

The above high-lighted methods of concrete mix design are sometimes cumbersome due to the fact that they involve the use of charts and tables which were arrived at using particular materials from a particular source. As in the case of the British method of mix design (based on Abram's principle), the graphs and tables are applicable only to London aggregates according to Murdok (1968). For this method to be used elsewhere, some form of modification is necessary.

For small jobs, the approximate method of design using the absolute volume method becomes very handy. In this method, the proportions of cement and aggregates are fixed and only the water content of the mix is varied. To achieve concrete of desired quality using this method, preliminary mixes are usually made and tested. The mix that satisfy the requirements is adopted. The use of the absolute volume method is easy due to the fact that its use has been practiced for quite sometime, thus making the characteristics of certain norminal mixes to be known. Some recommended norminal mixes include 1:1:2, 1:1½:3, 1:2:4, 1:3:6, and 1:4:8. The proportions are

for cement, sand and coarse aggregate respectively.

2.2.2 Properties of fresh concrete

The quality of hardened concrete can be said to be dependent on its properties at fresh stage. A fresh concrete that has many defects like segregation and bleeding will definately have low strength and durability. Thus fresh concrete must be checked and satisfied adequate before used. Some properties of fresh concrete that must be checked include; segregation, bleeding and workability.

Segregation

This as defined by portland cement association "is the separation of the constituents of a heterogeneous concrete mixture so that their distribution is no longer uniform." Because concrete is made of particles of different sizes and specific gravities, care must be taken in selecting and handling of materials otherwise segregation takes place.

Segregation is quite detrimental to concrete as it prevents proper compaction which results in rock pockets, porous layers, crazing and surface scaling.

Some occurences of segregation are due to poor mix design, poor handling. Harsh mixes, dry mixes under-sanded mixes, may segregate even with careful handling.

Bleeding

This is a type of segregation in which mix water tends to rise to the surface of fresh concrete as the solid constituents settle downward. Bleeding can produce porous and weak concrete which can easily disintegrate. It is caused by poor grading and use of excessive amount of water.

Workability

Of the various properties of fresh concrete, workability is the most important. Concrete mix must be sufficiently fluid to allow for easy transportation, placing and compaction. However it must not be so fluid that it segregates.

The fluidity of concrete is known as workability and as defined by Blanks et al. (1940) is "the ease with which a given set of materials can be mixed into concrete and subsequently handled, transported, and placed with minimum loss of homogeneity". Before deciding on the appropriate workability for a given mix, consideration must be given to the process of handling and compaction of the concrete. For highly congested reinforced sections, medium or high workability is necessary. This also applies to concrete that is transported by pumping or placed without compaction. For lightly reinforced sections of average size and when powerful vibration is available, low workability could be adequate.

The degree of workability of any mix plays an important role in determining the stregth of hardened concrete. Sufficient workability helps in adequate compaction of the concrete resulting in a concrete of high strength. Low workability on the other hand produces the opposite result unless heavy compacting equipment are used. Figure 2.3 shows the relationship between degree of compaction (which is influenced by workability) expressed as density ratio and corresponding strength as strength ratio.

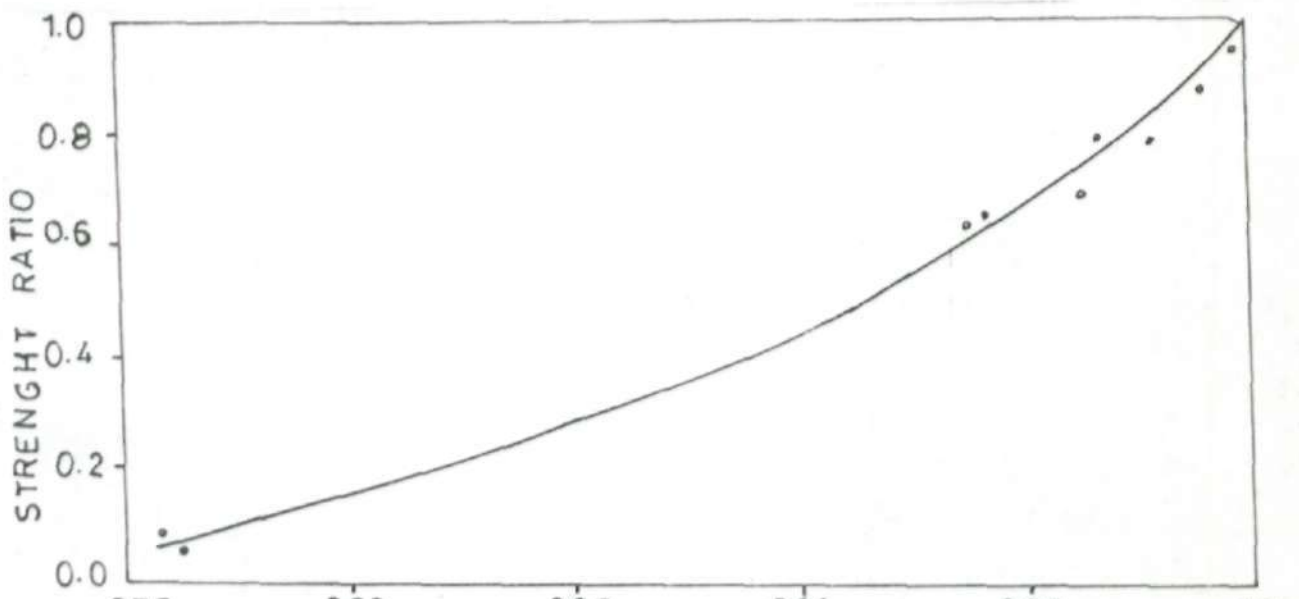


Fig. 2.3 Relation between strength ratio and density ratio.
(According to Glanville, W.H. et al. : 1974)

Factors Affecting Workability

The main factor that influences the workability of a given mix is the water content of the mix, expressed in kilogram per unit volume of concrete. Other factors are the amount and type of aggregate, cement and admixtures

used in the mix.

Effect of Aggregates

The type and characteristics of aggregates have a remarkable influence upon the workability of a concrete. According to Joseph (1962), aggregates of sub angular or subrounded shapes gives concrete of adequate workability other things being equal. Aggregates having large amount of flaky elongated pieces produce concrete of poor workability.

Apart from the shape and texture of aggregates, their grading especially that of sand and finer portion of the coarse aggregate affects the workability of a mix. The grading of sand should as far as possible, conform to the grading shown in table 2.1, according to Joseph (1962). Sand that fluctuates from high limit on one sieve to low limit on the adjacent should be avoided. Joseph further said that any sand that does not contain much of fractions passing No. 50 and No. 100 sieves is undesirable. The effect of coarse aggregate grading is less significant when compared with that of fine aggregate.

Table 2.1 sieve Analysis of sand
(According to Road Research Laboratory)

Sieve size (mm)	Cumulative percentage passing
9.2	100
4.75	95-100
2.36	75-90
1.18	50-75
600 um	30-65
300 um	10-30

150 um - - - - - - - - - - - 2-8
Fine ness modulus - - - - - 2.50-3.00

Effect of Cement

The quantity as well as the fineness of cement affect the workability of concrete mixes. A mix with low cement content (a lean mix) is harsh and thus not workable. High cement content results in a plastic mix that is plastic and workable. Similarly the fineness affects the workability. Cement ground to the upper limit of fineness makes more workable concrete because it is more cohesive and has less tendency to segregate and bleed. Coarse cement, on the other hand, reduces the stickiness of the mix and therefore is less workable.

Effect of Admixtures

Admixtures are used in concrete to improve certain of its properties. They consist of those which accelerate and those which retard hydration or setting of cement, those which improve workability, water proofness etc.

To improve workability, etrained air, pozzolana, fly ash or diatomaceous earth could be used. It should however be borne in mind that the use of a particular admixture could affect more than one property. Thus these materials must not be used without prior testing to guage their effect on strength and durability of a concrete.

Measurement of Workability

To date, no accurate and direct method of measuring the workability of a mix have been devised. However there are methods which measures workability indirectly. These methods include; the measurement of the penetration of a calibrated needle or plunger, the slump test, compacting factor method and many others.

The slump test together with observation of the behaviour of concrete is now the best means of assessing the workability of a mix. The consistency of a mix is measured by the slump test, plasticity, harshness, and cohesiveness is determined by noting the appearance of the slump specimen after the removal of the slump cone. A plastic mix (workable mix) will tend to stick together and subsides unbroken when the cone is removed. While a harsh mix behaves in an opposite manner.

The Slump Test

The details of the method of conducting this test is described in B.S. 1881. The test is done by filling a mould with a shape like the frustrum of a cone. The filling is done in three layers, each of the layers being tamped 25 times with a standard rammer of 25mm diameter.

The surface is then levelled off and the cone lifted vertically allowing the unsupported concrete to settle or collapse. The difference between the original and final heights represents the slump (which gives the measure of workability) of the mix.

With the slump test, a mix could produce true slump-meaning the mix is workable, shear slump-meaning the mix is harsh, collapse slump meaning the mix is highly workable. The various types of slumps are as shown in figure 2.4

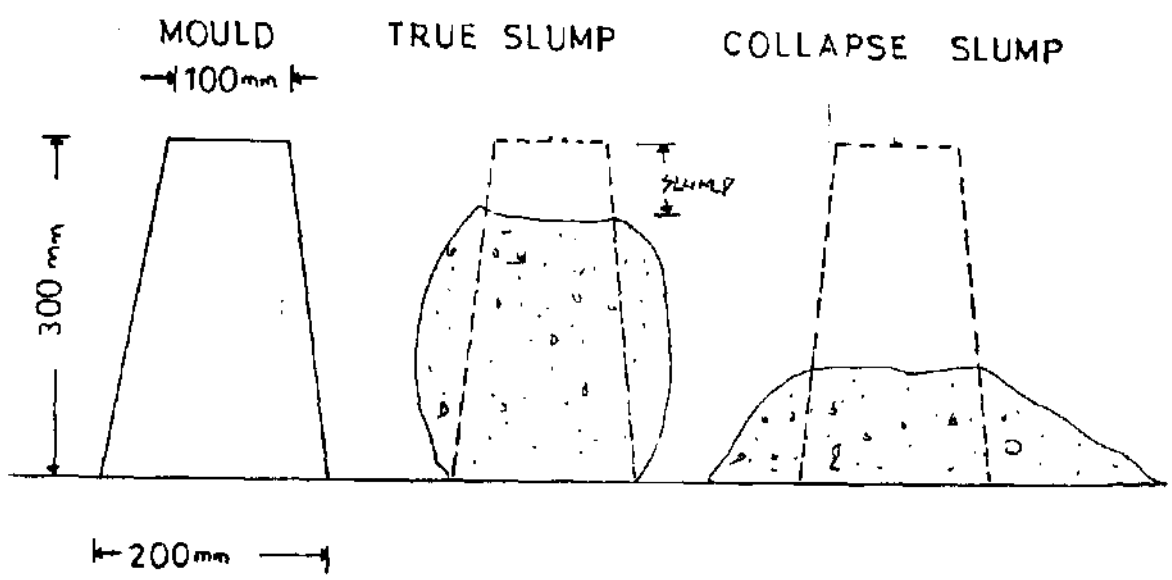


Fig. 2.4 Slump Mould and Slumps.

Compacting factor test

The slump test is only satisfactory for mixes of high workability. For concretes of low workability, the slump test cannot be used because in these mixes there may be zero slump. The compacting factor test in this case becomes the most appropriate. This testing method measures the degree of compacting achieved by a standard amount of work.

Murdock (1968) defined compacting factor as "the ratio of the weight of partially compacted concrete to the weight of fully compacted concrete, expressed to the nearest decimal place". The value of compacting factor lies between 0.75 to 1.0. Concrete with compacting

factor less than 0.75 cannot be compacted by hand satisfactorily.

The compacting factor test is conducted using the apparatus shown in figure 2.5. This consists of two rigid conical hoppers, which are mounted axially above a cylindrical mould.. The lower ends of the hoppers are closed with the aid of trap-doors as shown.

The upper hopper is filled with concrete, this is carried out gently so that no amount of work is done on the concrete (i.e. no compacting). The trap-door at the bottom of the hopper is then released and the concrete falls into the lower hopper. The door on the bottom is similarly opened so that the concrete falls into the cylinder. Excess concrete on the cylinder is levelled off gently and the sides cleaned. The cylinder and the concrete is weighed.

The cylinder is refilled with concrete from the same sample in layers of about 5cm deep and the layers rammed heavily or alternatively vebrated. The weight of this fully compacted concrete is determined and the compacting factor calculated.

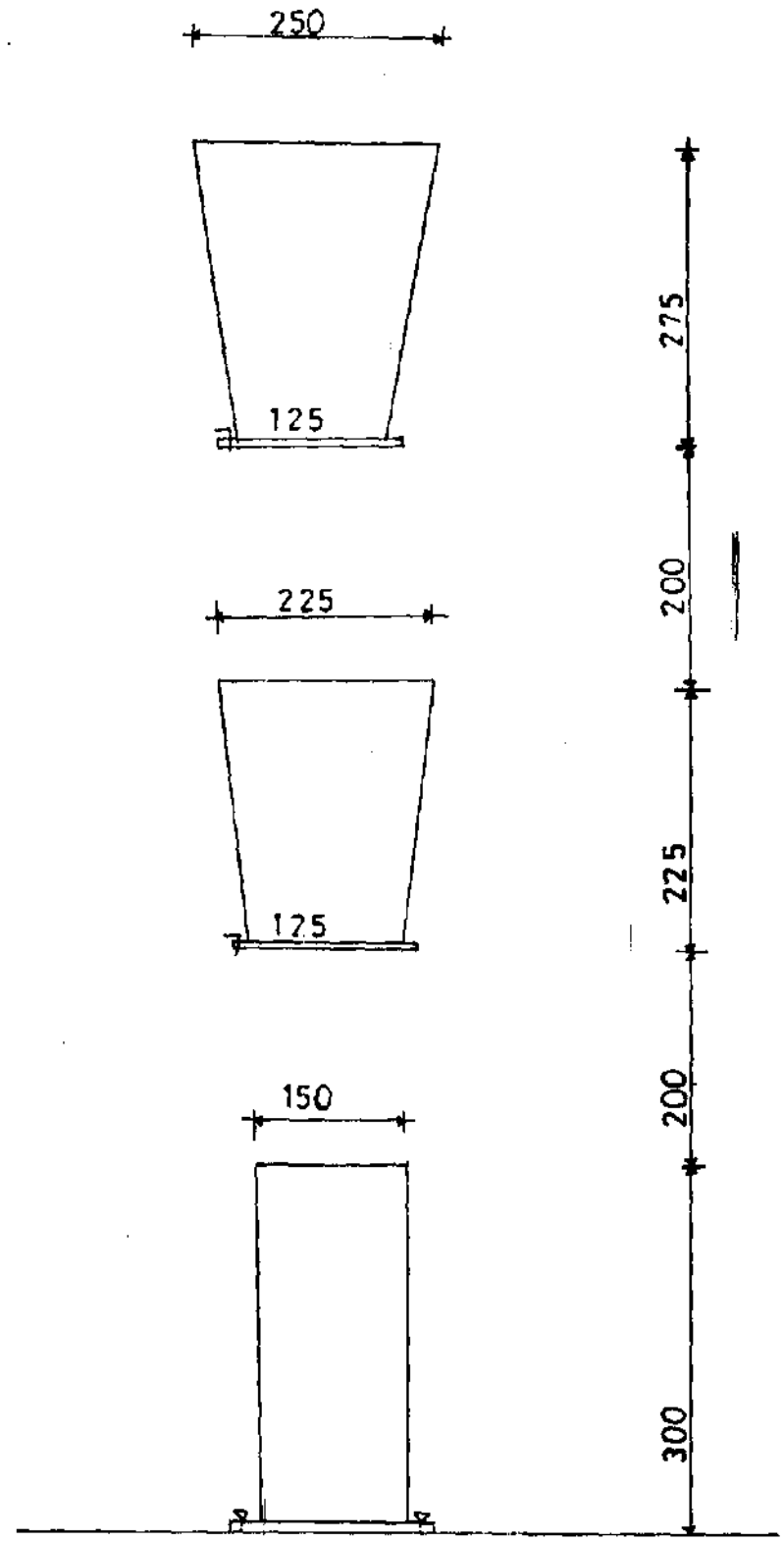


Fig. 2.5 COMPACTING FACTOR APPARATUS.

2.2.3 Properties of Hardened Concrete

The study and understanding of the properties of concrete is very important in predicting the performance of concrete in service condition. Because of the heterogeneous and complex nature of concrete, its properties might be remarkably affected by minor variation in either the mix proportions, curing methods, testing methods and/or the prevailing climatic conditions. The followings are some of the key properties of concrete:

Ultimate crushing strength
Tensile and lexural strength
Deformation characteristics
Density
Permeability
Durability

Investigations into the properties of concrete are sometimes made easier due to the closely related nature of some of these properties. For example a concrete of high crushing strength may have high tensile and flexural strengths, high durability, high density and low permeability.

Ultimate Crushing Strength

The ultimate crushing strength of concrete is of major importance as it is directly related to many other properties. A concrete having high compressive strength is likely to have a good durability when subjected to weathering and chemical attack according to Elvery (1963).

Concrete compressive strength is easy to determine and for this reason is the one most universally used in concrete practice. Concrete crushing strength tests are usually made on 150mm. or 100mm cubes. 150mm dia by 300mm cylinders are also used. It has been found that cylinders fail at lower compressive stress than 150mm cubes of the same quality concrete. According to Elvery (1963), the ratio of cube strength to cylinder strength is about 4:3. Elvery further said that the concrete cube crushing strength may be as high as 72N/mm^2, but the minimum strength required for ordinary reinforced concrete is about 21 N/mm^2.

The strength just as with other properties of concrete is influenced by certain factors. The factors are; type and quality of cement, degree of compaction, water/cement ratio, age, curing conditions etc.

The graphs overleaf depict the relationships between strength and these factors.

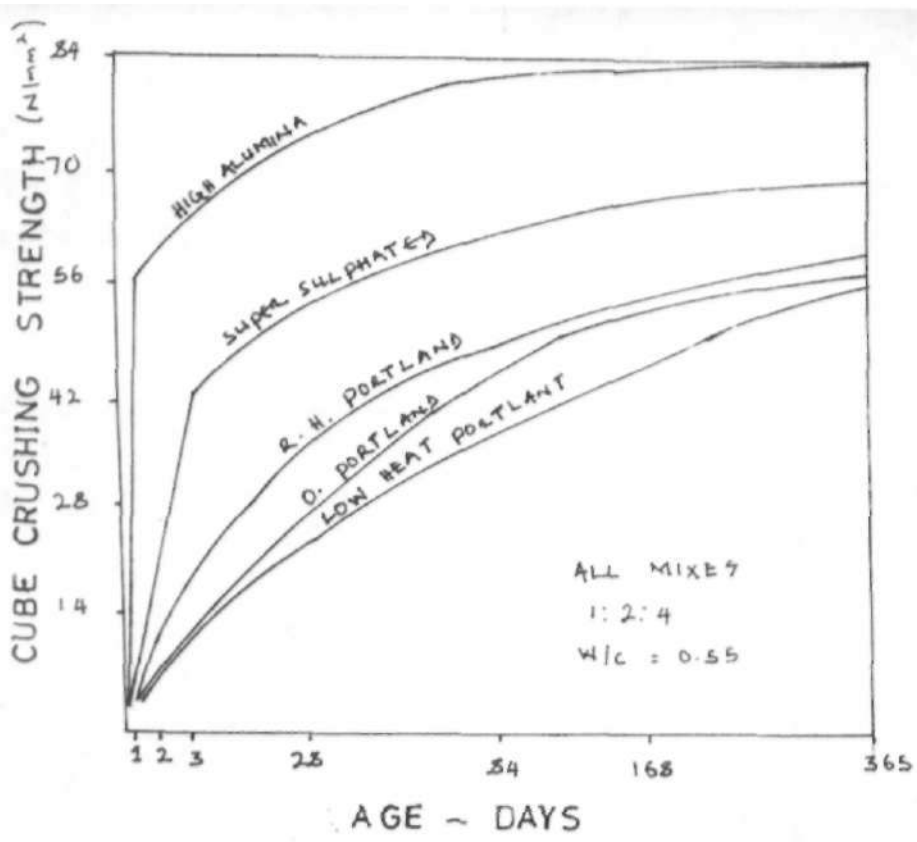


Fig. 2.6 Comparison of different cements used in concrete of constant mix proportions.
(According to Elvery, R.H. 1963)

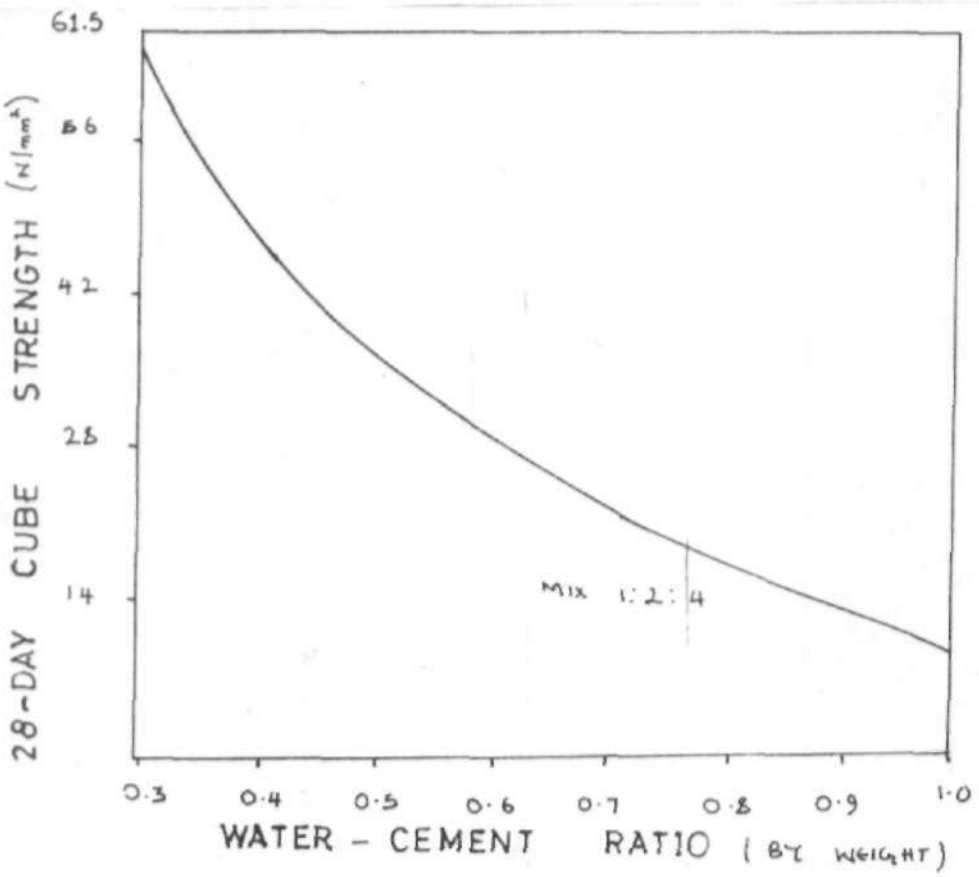


Fig. 2.7 Influence of water-cement ratio on compressive strength of concrete of given mix proportion.
(According to Elvery, R.H. 1963).

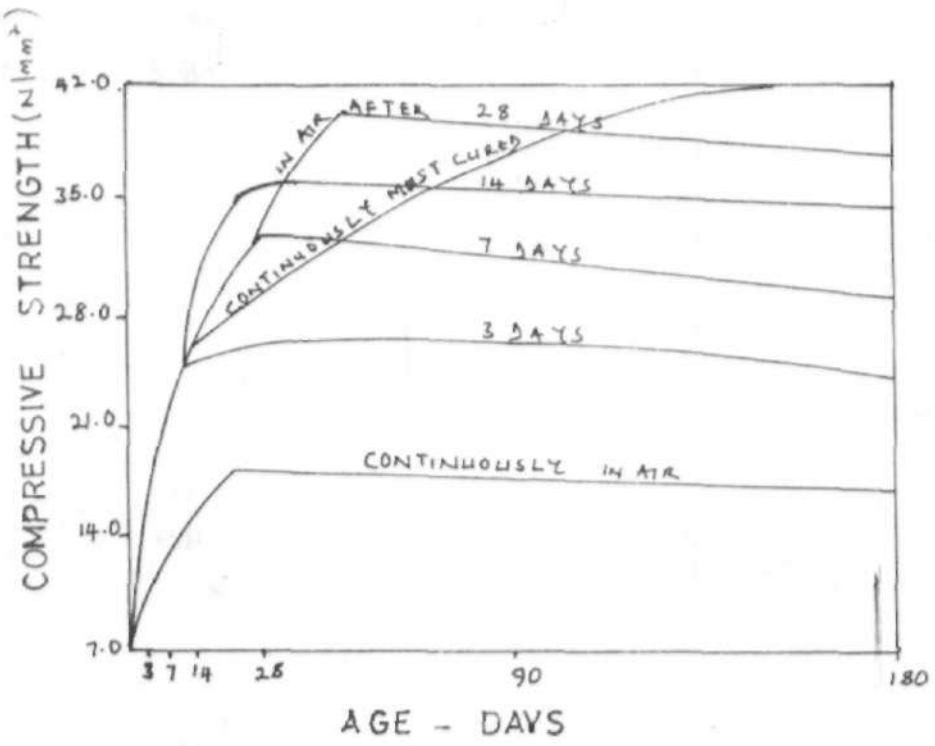


Fig. 2.8 The influence of moist curing on the strength of concrete with a water-cement ratio of 0.50.
(According to Price, W.H. : 1951)

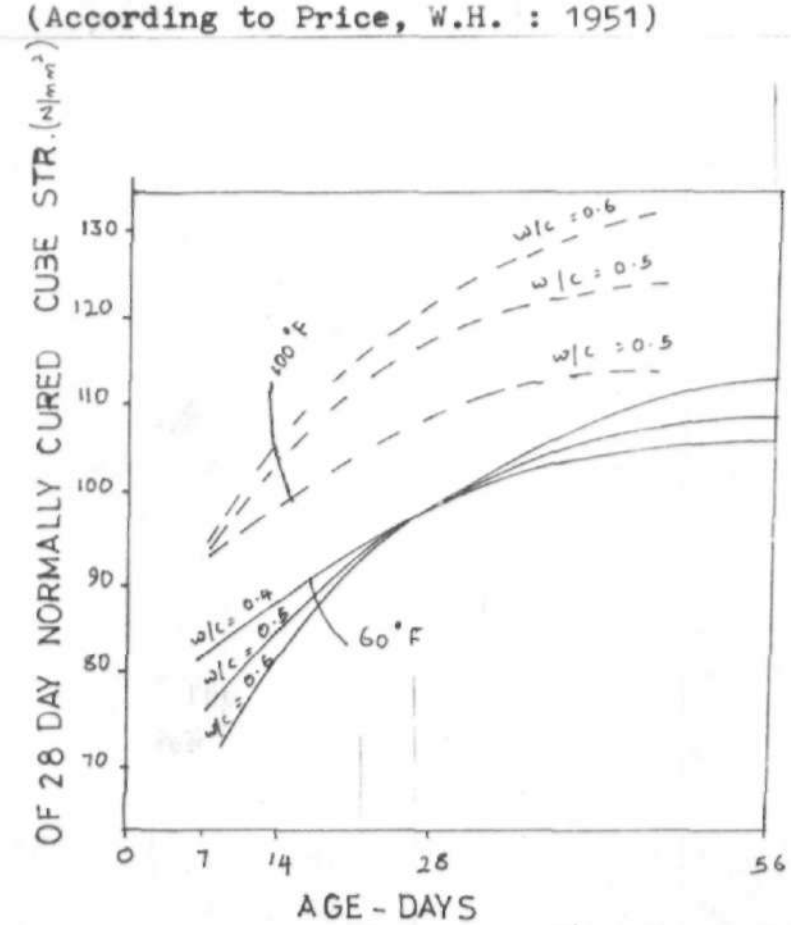


Fig. 2.9 Effect of curing temperature of 60 °F. and 100°F. on the relative strength development.
(According to Evans, E.P. : 1960)

Tensile and Flexural Strength

Although the tensile strength of concrete is very small when compared with its compressive strength (about $\frac{1}{12}$ to $\frac{1}{8}$ of compressive), it is important as it is the strength that mainly reduces cracks formation. Whereas the compressive strength depends, generally, to a certain extent on the compressive strength of coarse aggregate as mentioned by Illston (1979) the tensile strength depends mainly on the properties of the mortar between the coarse aggregate.

There are three different methods for measuring the tensile strength of concrete. These are:

(i) The direct tensile test,

(ii) The flexural (or bending) test on beam,

(iii) The indirect tensile test (split tensile test).

Of the above methods, the flexural and splitting tests are the most usual methods used. The flexural test is done as described in B.S. 1881.

The splitting test method was first suggested by Akazawa of Japan in 1942 and also by Carneiro of Brazil in 1947. This test involves loading cylinders along a generator. The loading arrangement is as shown in figure 2.10. The tensile strength (splitting strength) is calculated using equation (1).

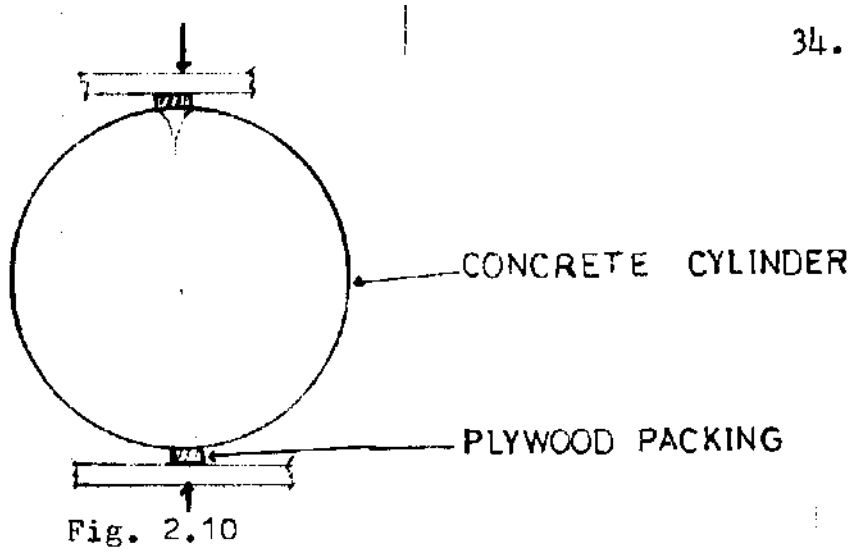


Fig. 2.10

$$\text{Tensile stress} = \frac{2P}{DL} \quad - - - - - \quad (1)$$

Where P = load at failure

D = diameter of cylinder and

L = is the length of the cylinder

Orchard (1962) said that the size of plywood packing has an unpredictable and irregular effect upon the splitting strength. For these reasons, the dimensions of the packing has been standardized at 12.5mm ($\frac{1}{2}$ in) wide by 3.13mm ($\frac{1}{8}$ in) thick.

The splitting test as investigated in Holland can also be conducted on cubes. The tensile strength when cube is used is given by the relation:

$$\text{Tensile stress (fct)} = 0.64 F_{cu}/a^2 \quad - - - \quad (2)$$

Where a = length of side of the cube

Fcu = failure load.

Although the tensile strength can be determined by three different methods, it has been found that the values of tensile strengths obtained using the different methods

are not the same. Wright (1955) found that the splitting test gave results which were about one and a half times those of the direct test and about two-thirds of the modulus of rupture for the same concrete.

As mentioned earlier (2.2.3.1), the tensile strength of concrete is related to its compressive strength. Figure 2.11 shows the relationship between tensile and compressive strengths as obtained by Evans, R.H. and Benette, J.D. (1958).

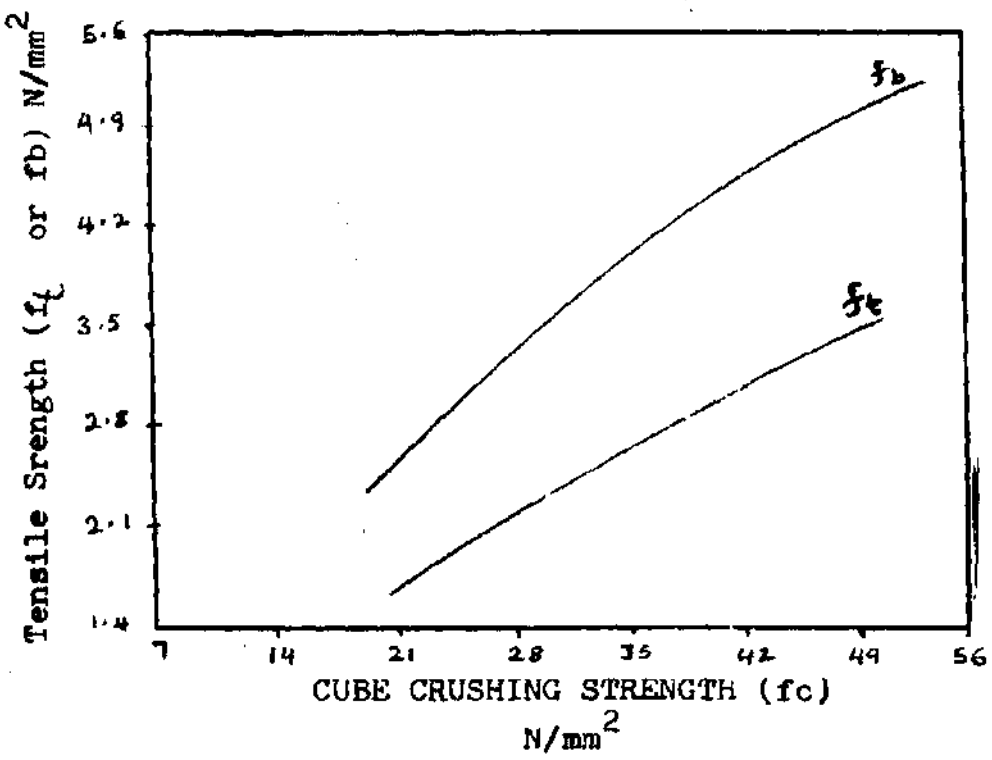


Fig. 2.11 Relation between tensile strength and crushing strength of typical gravel aggregate concrete.

(According to Evans, R.H. and Benette, J.D. : 1958)

Concrete Deformation Characteristics

Whenever concrete is loaded, it deforms. This deformation depends on the amount and rate of loading and the duration of the loading. The deformation of concrete consists of two parts; the initial elastic deformation and the non-elastic - time dependent deformation otherwise known as creep.

Although concrete deforms elastically as well as non-elastically, the elastic deformation in concrete is unlike that of metals. In concrete the load (stress) - deformation (strain) relationship is non-linear in character.

(i) Elastic deformation of concrete

Concrete behaves elastically to some extent. An elastic material is defined as any material that recovers its original shape when a deforming force has been removed. The stress-strain relationship of concrete greatly depends on the rate of loading. When the load is applied very quickly, the stress-strain graph is a straight line. However when the same concrete is loaded gradually, the graph is a curve. Figure 2.12 depicts the relationship between compressive strength and corresponsing strain.

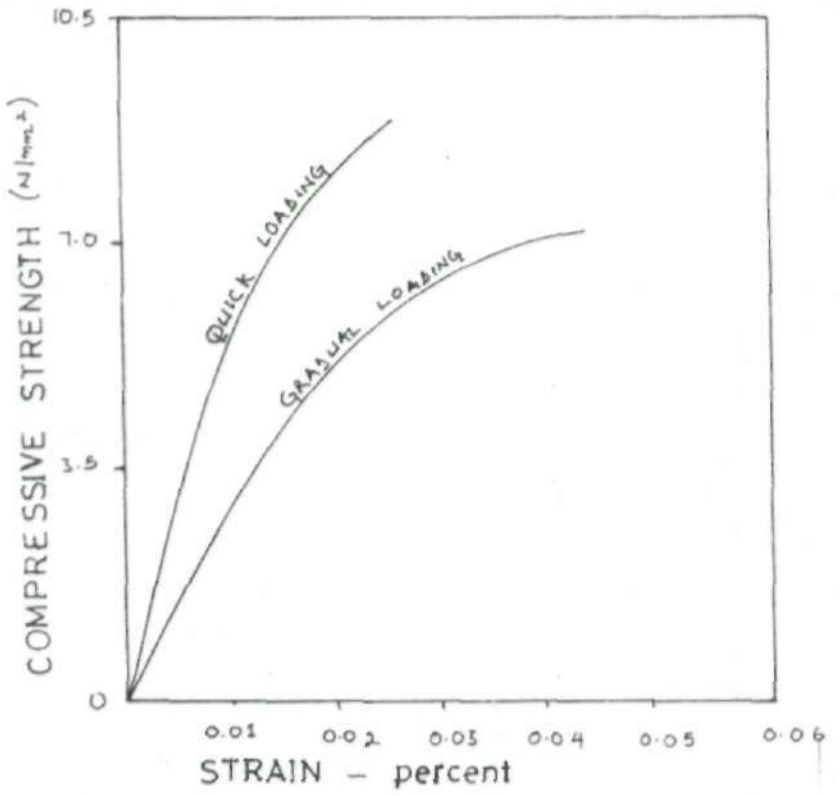


Fig. 2.12 TYPICAL STRAIN-STRESS CURVE FOR CONCRETE (33)

(ii) Modulus of Elasticity

This is defined as the ratio of the applied stress to the achieved strain.

Modulus of elasticity E = stress/strain = б/E

The modulus of elasticity is used when estimating the deformation, deflection or stresses under normal working loads. Because of the non homogeneity of concrete, it is not a properly elastic material and thus the modulus of elasticity depends on the particular defination adopted. With concrete, there are three possible moduli of elasticity as shown in figure 2.13. According to Elvery, R.H. the easiest to determine is the secant modulus of elasticity

and is the most realistic as it takes into account the total deformation at any one point. The average range of modulus of elasticity for most concretes at 28 days is from 15 to 40 KN/mm^2. This as pointed out by Elvery, R.H. may be assumed to be 3.8 $\sqrt{\quad}$ (concrete strength, N/mm^2)KN for normal concrete.

The most important factor that affects the value of the modulus is the stiffness of the aggregate. The stiffer the aggregate the higher the value according to Johnson (1967).

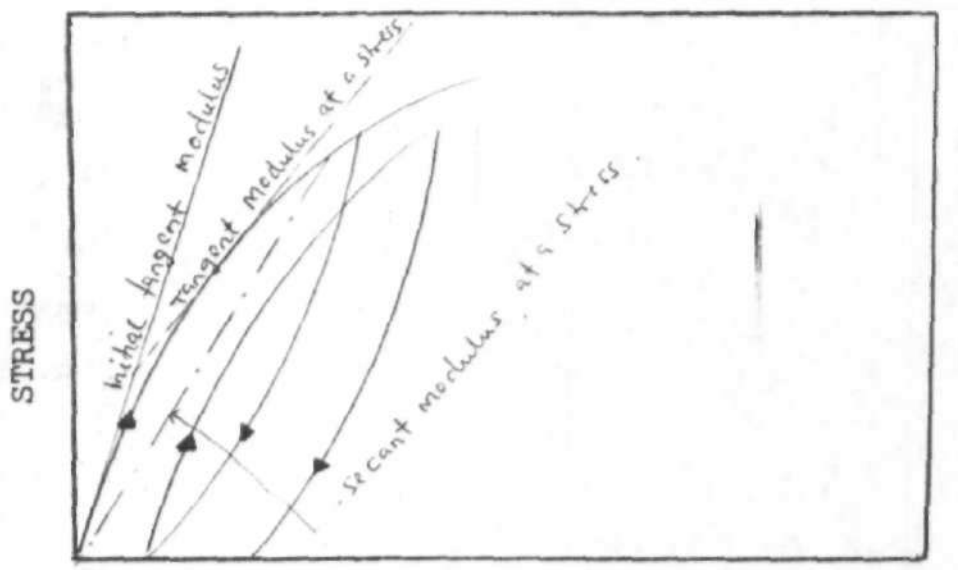


Fig. 2.13 A TYPICAL STRESS-STRAIN CURVE SHOWING DIFFERENT MODULI OF ELASTICITY

Density of Concrete

The density of a material is defined as its mass per unit volume and is calculated by the relation;

Density (Kg/m^3) = Mass (Kg)/volume (m^3).

There are a number of methods of determining the density of concrete. However the easiest is by finding the mass of a known volume of concrete and dividing by the volume. The density of normal concrete according to Ochard (1973) ranges from 2354.0 Kg/m^3 to 2563.2 Kg/m^3 while that of light weight concrete is between 400.5 Kg/m^3 to 1762.2 Kg/m^3.

The density of concrete depends on many factors due to the heterogeneous and porous nature of concrete. Factors that affects density of concrete include; the density of aggregate, grading, degree of compaction, water-cement ratio, moisture content of the concrete at the time of testing.

Because of density of concrete depends on its moisture condition, it is often specified in terms of its degree of dryness. Thus the density can be based upon; saturated surface dry, air-dry or oven-dry conditions. The most frequently quoted density of concrete is that based upon the air-dry condition.

CHAPTER THREE

3.0 MATERIALS AND TESTING

In order to minimize the number of variables, each of the materials used for this research were obtained from a single source. The coarse aggregate was solely made with bricks from a source. This also applies to the sand cement and water. The tests were carefully carried out as specified by the British Standards and the manufacturers of the machines used.

3.1 MATERIALS

The concrete whose properties were determined was made with coarse aggregate produced by manually crushing bricks. The bricks were obtained from the brick spoil heaps of Nigerian Brick and Clay Products Ltd. Kaduna factory. The spoil heaps contained the various types of bricks manufactured in the factory, this ranges from engineering bricks to decorative bricks. River sand obtained within the Zaria environment was used as the fine aggregate for all the mixes. This was however sieved to remove all particles retained on 5mm sieve. The cement type used was Ashaka ordinary portland cement. These were mixed with pipe borne water fit for drinking.

3.2 EQUIPMENT

The concrete was mixed with the revolving drum type concrete mixer. Well polished and oiled cast iron moulds comprising of 150mm X 150mm X 150mm cubes and 150mm diameter by 300mm cylinders were used in making the concrete

specimens. Vibrations applied through a vibrating table was used to compact the concrete.

3.3 PROPERTIES OF CRUSHED BRICK AGGREGATE

The physical properties of the manually crushed brick aggregate were determined based on air-dry and saturated surface dry (S.S.D.) bases. These were determined according to the appropriate sections of B.S. or A.S.T.M. codes.

3.3.1 Average Compressive Strength of Bricks

Although the bricks used were a combination of different types, the average compressive strength of the predominant trick type - the engineering brick was determined. The average strength was 30 N/mm^2.

3.3.2 Grading of the Aggregates

The crushed brick aggregate as well as the fine aggregate were graded in order to remove unwanted aggregate sizes and also to proportion the various aggregate sizes. The coarse aggregate (brick aggregate) was graded by passing it through sieve sizes 20, 10 and 5mm. It was proportioned by combining 65% and 35% of material retained on sieve sizes 10mm and 5mm respectively.

The fine aggregate was graded by sieve analysis as specified in B.S. 882. This was done by passing 8.0Kg of the aggregate through 5mm, 2.36mm, 1.18mm, 600 m, 300 m and 150 m sieve sizes. The sieves were shaken by mechanical vibration. The details of the calculations

of the sieve analysis are given in tables 3.1 and 3.2, while table 3.3 shows the calculations for finding the grading curve for the combined aggregate.

B.S. Sieve Sizes (MM)	Weight Retained (kg)	Percentage Retained (%)	Cumulative Percentage Passing(%)	Cumulative Percentage Retained(%)
20	0.00	0.00	100	0
9.5	32.50	65.00	35	65
4.75	17.50	35.00	0	100
Pan	0.00	0.00	0	
Total	50.00	100		

Table 3.1 Sieve Analysis details for the brick aggregate.

Total weight sieved = 50Kg.

B.S. Sieve Sizes (mm)	Weight Retained (Kg)	Percentage Retained (%)	Cumulative Percentage Passing(%)	Cumulative
4.75	0.412	5.15	94.85	5.15
2.36	1.045	13.07	81.78	15.22
1.18	2.900	26.26	45.52	54.48
600 m	2.550	31.89	13.63	86.37
300 m	0.430	5.38	8.25	91.75
150 m	0.435	5.44	2.81	97.19
Pan	0.225	2.81	0.00	100.00
Total	7.997			

Table 3.2 Sieve Analysis details for fine aggregate.

Total weight sieved = 8.0Kg

Table 3.3 - Calculations for combined grading curve

(1) Sieve Size (mm)	(2) Individual Percentage retained on for curve	(3) (4) (5) (6) Analysis of available aggregate				(7) ÷ 2 Coarse	(8) ÷ 2 fine	(9) X1¼ Coarse	(10) ( ) X ¾ fine	(11) Resultant % retained on (9)+(10)	(12) Resultant % Passi
		Percentage passing		Individual percentage retained on							
	3	Coarse	fine	Coarse	fine						
20	0	100	100	00	00	0	0	0	0		100
9.5	35	35	100	65	0	32.5	0	40	0	40	60
4.75	23	0	94.85	35	5.15	17.5	2.58	27	2.0	23	37
2.36	7	0	81.78	0	13.07	0	6.53	0	5.0	5	32
1.18	7	0	45.52		36.26	0	18.13		13	13	19
600μm	7	0	13.63		31.89	0	15.94		12	12	7
300μm	16	0	8.25		5.38	0	2.69		2	2	5
150μm	5	0	2.81		5.44	0	2.72		2	2	3
Pan		0	0		2.81	0	1.40	-	-	-	-

3.3.3. Particle Shape and Texture

The particle shape of the aggregate was determined by the visual method as equipment for conducting this test were not available. The crushed brick aggregate contained angular shape particles as the predominant particle shape with a few flaky shaped particles.

The surface texture of the aggregate could be described as a combination of smooth and rough. This is because the edges of the aggregate were rough while the tops and bottoms were smooth. Plate I shows the particle shape and texture of the brick sample.

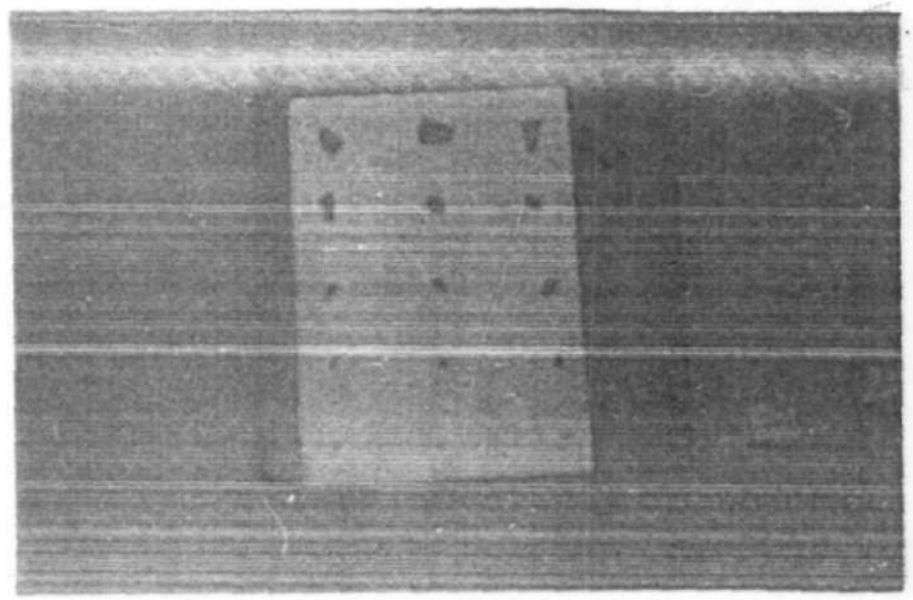


Plate I - Particle shape and texture of the brick aggregate sample.

3.3.4 Specific Gravity

This was determined according to B.S. 812. A quantity of the aggregate retained on 10mm sieve (5kg) was weighed. The sample was thoroughly washed and

immersed in water for 24hours, the weight of this wet aggregate was determined by weighing under water with the aid of a wire basket. The aggregate sample was then surface dried by spreading it on a hessian and gently blowing air from a ceiling fan. The weight of the saturated surface dry sample was determined. This was then dried for 24 hours in an oven at 100°C - 110°C, cooled and re-weighed.

Calculations:

Let A = weight of oven-dry sample
B = weight of saturated surface dry sample.
C = weight of saturated sample in water.
D = weight of aggregate in its natural state in air.

For the brick aggregate sample,

A = 4.78 Kg
B = 5.37 Kg
C = 2.62 Kg
D = 5.0 Kg

$$\text{Apparent specific gravity} = \frac{A}{A - C}$$

$$= \frac{4.78}{4.78-2.62}$$

$$= 2.21$$

$$\text{Specific gravity on dry basis} = \frac{A}{B-C}$$

$$= \frac{4.78}{5.37-2.62}$$

$$= 1.74$$

$$\text{Specific gravity on S.S.D. basis} = \frac{B}{B-C}$$

$$= \frac{5.37}{5.37-2.62}$$

$$= 1.95$$

3.3.5 Moisture Properties of Aggregate

The moisture properties of the aggregate (absorption capacity and moisture content) were determined using the readings obtained for the specific gravity calculations. The moisture properties calculations are shown below:

$$\text{Water absorption, per cent} = \frac{B - A}{A} \times 100\%$$

$$= \frac{5.37 - 4.78}{4.78} \times 100$$

$$= 12.34\%$$

$$\text{Moisture content, per cent} = \frac{D - A}{A} \times 100\%$$

$$= \frac{5.0 - 4.78}{4.78} \times 100$$

$$= 4.60\%$$

3.3.6 Bulk density

The bulk density of a material is defined as the weight of material held by a container of unit volume when filled and compacted under a defined condition.

The bulk density depends on the amount of moisture content of the aggregate, grading and the amount of compactive effort used in filling the container. For these reasons, the bulk density of the aggregate was determined on the bases of air-dry and saturated surface-dry conditions for both compacted and uncompacted situations. The procedure for its determination is as follows:

For the uncompacted situation, the bulk density was determined using 150mm X 150mm X 150mm container. The container was first weighed and then gradually filled with

the aggregate sample using a hand scoop. The top was then gently levelled off and the container with the aggregate weighed.

For the compacted situation, the container was filled in three equal layers. Each of the layers was tamped with 25 strokes of a 25mm standard rammer, the top was then levelled off and the weight of the compacted aggregate determined. Table 3.4 shows the calculations of bulk density of the brick aggregate sample.

Table 3.4 Bulk density Calculations

No.	Condition of sample	Weight of Container	Size of Container	Uncompacted weight (Kg)	Average uncompacted density (Kg/M^3)	Compacted weight (Kg)	Compacted density (Kg/M^3)
1	Air-dry		$(0.15)^3 M^3$	3.26		3.75	
2	"		"	3.29		3.29	
3	"		"	3.24	973.04	3.76	1110.52
4	"		"	3.25		3.77	
5	"		"	3.28		3.74	
1	SSD		"	3.66		4.26	
2	"		"	3.59		4.28	
3	"		"	3.68	1079.7	4.30	1269.9
4	"		"	3.64		4.30	
5	"		"	3.65		4.28	

3.3.7 Voids ratio

The void content of an aggregate indicates whether an aggregate is well graded or not. For a well graded aggregate, the void ratio is small.

The void content was calculated using the following relationship:

$$\text{Void ratio} = 1 - \frac{\text{Bulk density}}{\text{S.G x unit weight of water}}$$

$$\text{for uncompacted, void} = 1 - \frac{973.04}{1.74 \times 1000} \times 100$$

$$= 44\%$$

$$\text{for compacted, void ratio} = 1 - \frac{1110.52}{1.74 \times 1000} \times 100$$

$$= 36\%$$

The above values of void ratios show some elements of good grading in the aggregate.

3.4 CONCRETE EXPERIMENTAL DETAILS

The test specimens made comprises of cubes and cylinders. These were used to determine the concrete strengths and density.

In designing the concrete for these specimens, a constant mix proportion (1:2:4) was used. Three water-cement ratios were used. The details of concrete mix design principles and calculations are given under concrete mix design.

3.4.1 Specimens Identification

As stated earlier, one concrete mix proportion with three different water-cement ratios were used. The three

mixes were identified by letters A,B and C. The concrete specimens were tested at the ends of 7, 14, 21 and 28 days. A total of 70 cubes and 10 cylinders were made for each of the three mixes. For each concrete mix, three batches were made. Batch one was identified by A1, batch two by A2 and batch three by A3. Similarly the other mixes were identified by B1, B2, B3 and C1, C2, C3 respectively.

Table 3.5 depicts the specimens identifications as used in this research.

Table 3.5 - Specimens Identification

Mix / Batch	A	B	C
1	A1	B1	C1
2	A2	B2	C2
3	A3	B3	C3

3.4.2 Concrete mix design

The concrete was designed using the absolute volume design method (fixed proportion method). A mix proportion of 1:2:4 with three water-cement ratios was used.

The concrete mix design was based on the following data:

(i) Brick aggregate

Loose bulk density (air-dry)	-	973.04 Kg/m^3
" " " (S.S.D.)	-	1079.7 Kg/m^3
Specific gravity (air-dry)	-	1.74
" " " (S.S.D.)	-	1.95
% absorption capacity	-	12.34%
% moisture content	-	4.60%

(ii) Sand

loose bulk density (air-dry)	-	1660 Kg/m^3
specific gravity "	-	2.6

(iii) cement

loose bulk density	-	1440 Kg/m^3
specific gravity	-	3.15

(iv) water

bulk density	-	1000 Kg/m^3
specific gravity	-	1.0

3.4.2.1 Concrete mix A: (w/c - 0.70)

In this concrete, a water cement ratio of 0.70 was used. Some amount of water was added during the mixing to take care of the absorption of mixing water by the brick aggregate. The added amount of water was calculated using the percent moisture content and the percent absorption capacity of the aggregate.

Calculations:

Mix proportion - 1:2:4

Water/cement ratio - 0.70

Absolute volumes of materials

Absolute volume of brick aggregate = $\frac{4 \times 973.04}{1.74}$ = 223.68l

Absolute volume of sand = $\frac{2 \times 1660}{2.65}$ = 1252.8L

Absolute volume of cement = $\frac{1 \times 1440}{3.15}$ = 457.14L

Absolute volume of water = $\frac{0.70 \times 1440}{1.0}$ = 1008L

Total absolute volumes in litres =(2236.8+457.14+1008)L

= 4954.8L

= $4.96m^3$

Quantities of materials per $1m^3$

Brick aggregate = $\frac{4 \times 973.04 \times 1}{4.96}$

= 784.71 Kg

Sand = $\frac{2 \times 1660 \times 1}{4.96}$

= 669.35 Kg

Cement = $\frac{1 \times 1440 \times 1}{4.96}$

= 290.32 Kg

Water = $\frac{0.7 \times 1440 \times 1}{4.96}$

= 203.2 Kg

Mix's water correction:

% absorption capacity = 12.34%

% pore moisture = 4.60%

Water to be absorbed by aggregate in each m^3 of concrete is: = $784.71 \times \frac{(12.34 - 4.6)}{100}$

= 60.74 Kg

∴ total amount of water to be added per m^3 of concrete is = (203.2 + 60.74)Kg = 263.94Kg

3.4.2. Concrete mix B (W/C = 0.7)

Concrete mix C was designed based on a saturated surface dry aggregate. The aggregate was immersed in water for 24 hours and later surface dried. The bulk density and specific gravity used were therefore those for a saturated surface dry aggregate. A water/cement ration of 0.70 was used.

Mix proportion - 1:2:4

Water/cement ratio - 0.70

Absolute volumes of materials

Absolute volume of brick aggregate = $\frac{4 \times 1079.7}{1.95}$ = 2214.77L

Absolute volume of sand = $\frac{2 \times 1660}{2.65}$ = 1252.83L

Absolute volume of cement = $\frac{1 \times 1440}{3.15}$ = 738.46L

Absolute volume of water = $\frac{0.7 \times 1440}{1.0}$ = 516.92L

Total absolute volume in litres

= (2214.77+1252.83+738.46+516.92)L

= 4722.98L

= $4.72m^3$

Quantities of materials per m^3

Brick aggregate = $\frac{4 \times 1079.7 \times 1}{4.72}$

= 915.0 Kg

Sand = $\frac{2 \times 1660 \times 1}{}$

= 703.39 Kg

Cement = $\frac{1 \times 1440 \times 1}{4.72}$

= 305.08 Kg

Water $= \frac{0.70 \times 1440 \times 1}{4.72}$

$= 213.56$ Kg

Concrete mix C (W/C = 0.85)

This mix was based on the principle of adding as much amount of water as will make the concrete workable. A preliminary mix was made and it was found appropriate to use a water/cement ratio of 0.85

Mix proportion - 1:2:4

water/cement ratio - 0.85

Absolute volumes of materials

Absolute volume of brick aggregate $= \frac{4 \times 973.04}{} = 2236.87$L

Absolute volume of sand $= \frac{2 \times 1660}{2.65} = 1252.8$L

Absolute volume of cement $= \frac{1 \times 1440}{3.15} = 457.14$L

Absolute volume of water $= \frac{0.85 \times 1440}{1} = 124$L

Total absolute volume in litres

$= (2236.87+1252.8+457.14+1224)$L

$= 5170.81$ L

$= 5.17 m^3$

Quantities of materials per m^3

Brick aggregate $= \frac{4 \times 973.04 \times 1}{5.17}$

$= 752.84$Kg

Sand $= \frac{2 \times 1660 \times 1}{5.17}$

$= 642.17$Kg

Cement $= \frac{1 \times 1440 \times 1}{5.17}$

Water $= \frac{0.85 \times 1440 \times 1}{5.17}$

$= 236.75$Kg

Table 3.6 - Summaries of concrete mix proportioning ratios

Mix	Mix proportioning ratios by weight	W/C effective	Specimens	Volume of cocrete + 10% waste (m^3)	Total amount of materials required			
					Cement (Kg)	Sand (Kg)	Brick Agg. (Kg)	Water (Kg)
A	1:2.31:2.70	0.70	70 cubes and 10 cylinders	0.493	143.13	329.99	386.86	100.18
B	1:2.31:30	0.70	"	0.493	150.40	346.77	451.1	105.29
C	1:2.31:2.71	0.85	"	0.493	137.32	316.59	371.15	116.72

3.4.3 Workability test

The degree workabilities of the concrete mixes were determined by the slump test. The degrees of workabilities obtsined were low for mixes A and B while high workability was obtained for mix C.

3.4.3.1 The Slump test

The test was conducted as described in B.S. 1881. A well polished and oiled slump mould was placed on a level plastic plate. It was held firmly in place and filled symmetrically in three layers of approximately equal volume. Each of the layer was rammed with 25 strokes of 20mm round ended rod. The top of the mould was levelled after the last layer. The mould was then withdrawn vertically upward and the slump measured. The slumps obtained and the corresponding degree of workabilities are discussed in chapter four.

3.4.4 Moulding and compaction of concrete specimens

Two types of cast iron moulds were used. The moulds were 150mm x 150mm x 150mm cubes and 150mm dia x 300mm cylinders.

The concretes were compacted by vibration carried out with vibrating table. The cubes were filled in three equal layers and each of the layers was vibrated for about one minute. The cylinders were filled in four layers and each was vibrated for the same period of time as with cubes.

3.4.5 Curing of Specimens

The concrete specimens were cured by completely immersing them in water uptil the time they are required for testing. This was done by demoulding the specimens after about 24 hours from the time of casting and immediately immersing them in water. The average temperature during the period of curing was 24°C.

3.5 TESTS ON HARDENED CONCRETE

Destructive methods of testing were used in this investigation. The tests conducted were the ultimate crushing test for cubes, split tensile and static modules of elasticity tests for cylinders. The density of the concrete was also found.

3.5.1 Density of Concrete

The density of the "brick aggregate concrete" was determined based on three moisture condition of the concrete. These are:

(i) Saturated surface dry,

(ii) Air dry,

(iii) Open dry.

The densities were determined by weighing a 150mm x 150mm x 150mm concrete cube specimens under each of the above moisture conditions and the densities calculated using the relationship:

$$\text{Density} = \frac{\text{Mass}}{\text{volume}}$$

For each of the conditions, an average was calculated from 5 cubes. Table 3.7 illustrates the density calculations.

Table 3.7 Density Calculations

Specimen	Condition	Volume (m^3)	Average Mass (Kg)	Average Density (Kg/m^3)
A	S.S.D.	3.38×10^{-3}	7.28	2153.85
	Air-dry	"	7.05	2085.80
	Oven-dry	"	6.32	1869.82
B	S.S.D.	"	7.30	2159.76
	Air-dry	"	7.12	2106.51
	Oven-dry	"	6.35	1878.70
C	S.S.D.	"	7.38	2183.43
	Air-dry	"	7.15	2115.38
	Oven-dry	"	6.40	1893.49

3.5.2 Ultimate Crushing Strength

The specimens used for this test were cubes of size 150mm x 150mm x 150mm. A total of 200 cubes were crushed. The crushing was done at 7, 14, 21 and 28 days from the date of casting. The crushing was carried out while the cubes were at the saturated surface dry condition. This was in order to have a constant water content and thus constant water pressure in the specimens as specified in B.S. 1881. The type of crushing machine used was motorised hydraulic compression machine of 1520KN capacity. The following precaution were taken in order to avoid

variations in results due to testing errors;

(a) The cubes were placed centrally in-between the platens to avoid eccentricity in loading.

(b) Uniform rate of loading was applied.

(c) All projections from the faces in contact with the platens were scraped off.

(d) The loading was applied through two smooth surfaces.

3.5.3 Tensile Strength

This was determined by the cylinder splitting method and was carried out at the end of 28 days of moist curing.

The test was conducted as described in B.S. 1881 (1970). This involves loading a 150mm diameter by 300mm long cylinders along a generator until the cylinder splits. The loading was applied through two packings measuring 30mm x 300mm. The loading arrangement for this test is as shown in plate II.

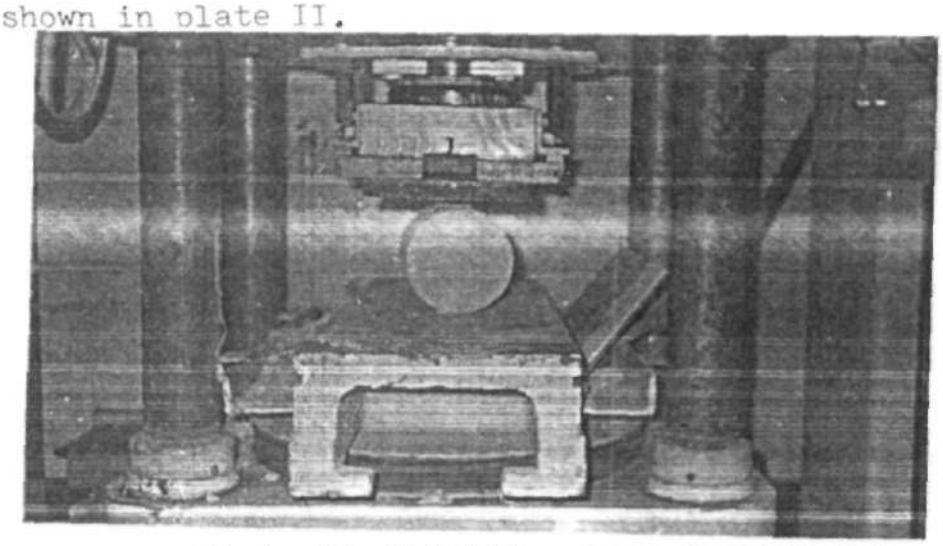


Plate II Splitting test arrangement.

The tensile strength of the concrete was computed using the relationship.

$$fct = \frac{2P}{\pi DL}$$

Where; P = maximum failure load in newtons

L = length of cylinder in mm

D = diameter of cylinder in mm

The results for this test are given in chapter four.

3.5.4 Static Modulus of Elasticity

The test of determining the static modulus of elasticity was conducted as specified in B.S. 1881 (1970). Concrete cylinders measuring 150mm diameter by 300mm were used after curing for 28 days.

The test started by finding the compressive strength of the concrete. This was done by crushing three 150mm x 150mm x 150mm cubes casted at the same time with the cylinder specimens and calculating the average. The specimens for determining the modulus of elasticity were ther loaded and unloaded once to a stress of one-third of the ultimate crushing strength of the concrete. Consequent decrease in length of specimens were then read from the mounted compressometer. Three readings were taken during loading as well as during unloading.

Plate III shows the positions of the extensometer and the dial guage in a universal testing machine.

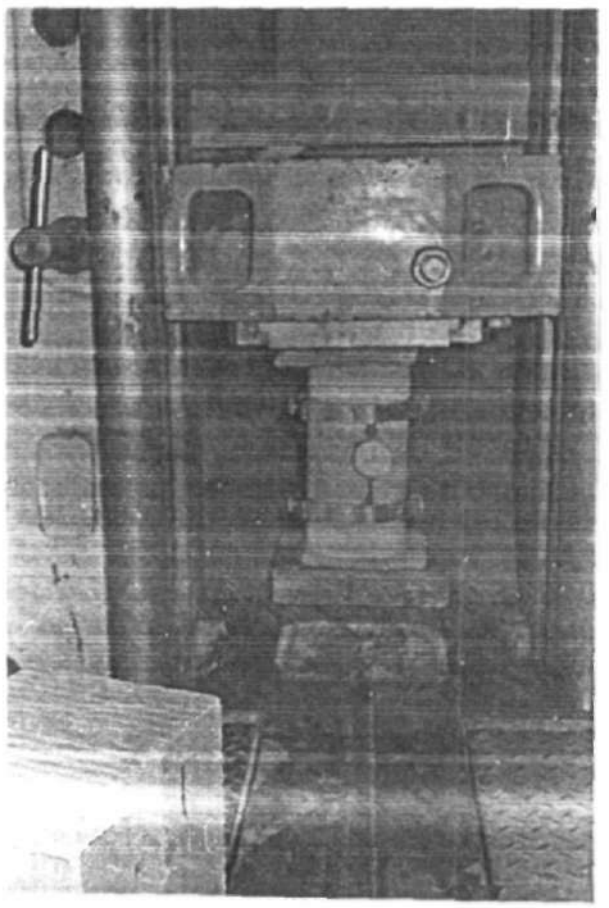


Plate III - Positions of extensometer and dial guage.

The strains at each loading stage were then calculated using the relationship.

$$\text{Mean strain} = \frac{\text{Mean dial reading (mm)}}{\text{Length of cylinder(mm)}}$$

The values of the strain were plotted against the corresponding compressive stress, and the secant modulus of elasticity determined at 50% of the concrete strength. The results for this experiment are given in chapter four.

CHAPTER FOUR

4.0 TEST RESULTS AND DISCUSSION

The results of the various tests conducted in chapter three are reported here. However only summaries of these results are presente. The detailed results are to be found in the appendices.

Discussion on the results obtained and comparisons with normal concrete were also carried out.

4.1 RESULTS

4.1.1 Brick aggregate

The properties of the brick aggregate determined in chapter three are presented in table 4.1. The properties of sand and river gravel are also included in the table for comparison purposes.

Table 4.1 - Physical properties of aggregate.

S/No.	Properties	Sand	brick aggregate	river gravel
1.	specific gravity (S.S.D.)	2.6	1.95	2.5-3.0
2.	Bulk density (Kg/m^3) (dry, uncompacted)	1660.0	973.04	1240.0
3.	Bulk density (Kg/m^3) (wet compacted)		1079.70	
4.	Voids ratio		4.40	
5.	Absorption capacity (%)	1.1-3.1	12.34	2.0-4.5
6.	Moisture content (%)	0.3-0.8	4.60	0.5-1.1
7.	Particle shape	sub-rounded		rounded
8.	Particle texture	smooth & rough	smooth & rough	smooth

Grading of the aggregates

The aggregates sieve analysis conducted in chapter three is plotted below. The combined grading curve for the fine and coarse aggregate falls within zone B of the British Standard grading curves.

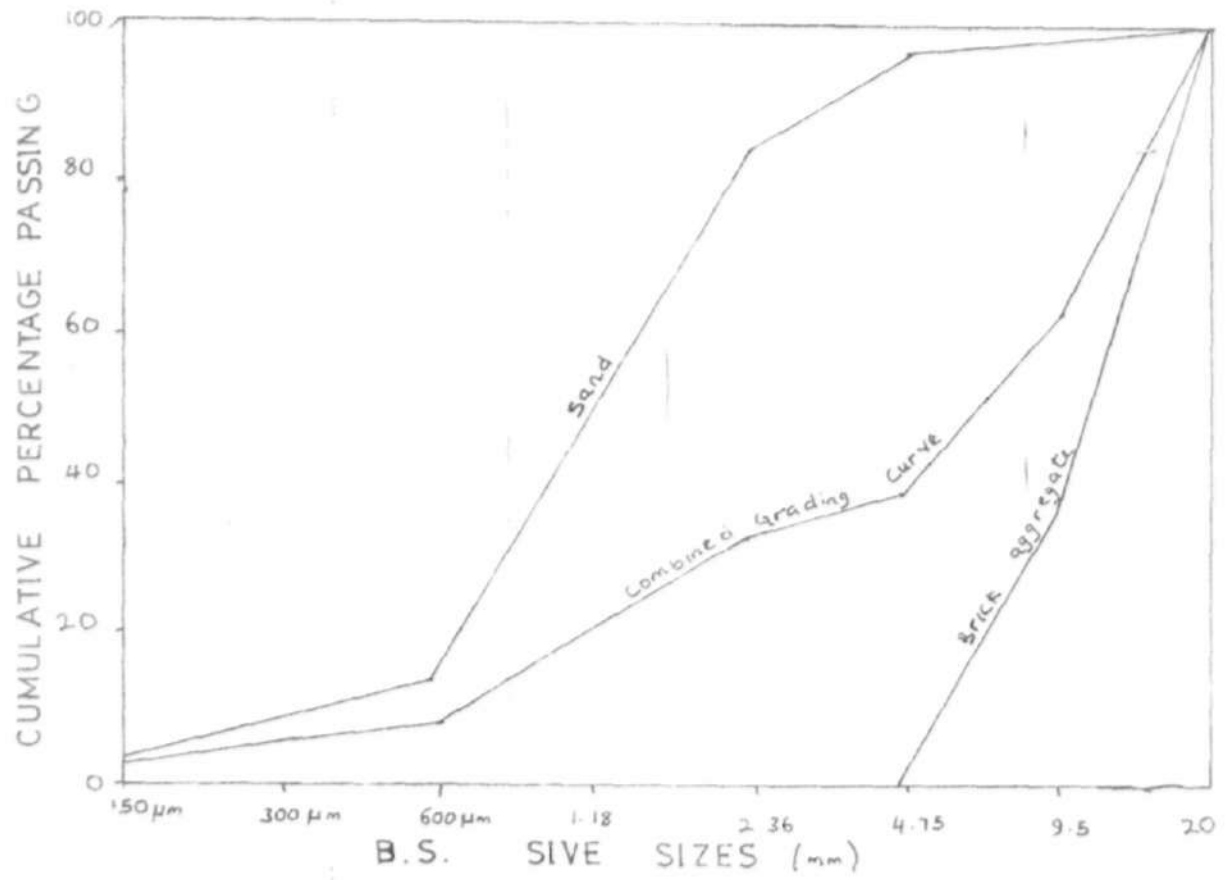


Fig. 4.1 - Grading Curves.

4.1.2 FRESH CONCRETE

Workability

The results of the workability tests for the concrete mixes are as shown in table 4.2 below.

Table 4.2 - Results of Workability tests

Mix	w/c ratios	slump (mm)	Degrees of workability
A	0.7	30.0	Low
B	0.7	45.0	Low
C	0.85	120.0	high

4.1.3 HARDENED CONCRETE

Density

The results of concrete densities determined at over-dry, air-dry and saturated surface dry conditions for the three concrete mixes are as shown in table 4.3 below:

Table 4.3 - Densities of concrete

Mix	Condition	Average density (Kg/m^3)
A	S.S.D.	2153.85
	Air-dry	2085.80
	Oven-dry	1869.82
B	S.S.D.	2159.76
	Air-dry	2106.51
	Oven-dry	1878.70
C	S.S.D.	2183.43
	Air-dry	2115.38
	Oven-dry	1893.49

Compressive Strength

The average compressive strength of the concrete mixes are given in table 4.4. The detailed results are to be found in appendix I while the statistical analysis is in appendix IV. The development of compressive strength with age for the concrete mixes are presented in figure 4.2. The results are available up to the age of 28 days.

Table 4.4 - Average compressive strength

Mix	Age (days)	w/c ratio	strength (N/mm^2)
A	7	0.7	11.91
	14	"	16.33
	21	"	16.51
	28	"	18.20
B	7	0.7	11.18
	14	"	13.40
	21	"	14.91
	28	"	17.74
C	7	0.85	8.22
	14	"	9.13
	21	"	11.72
	28	"	13.17

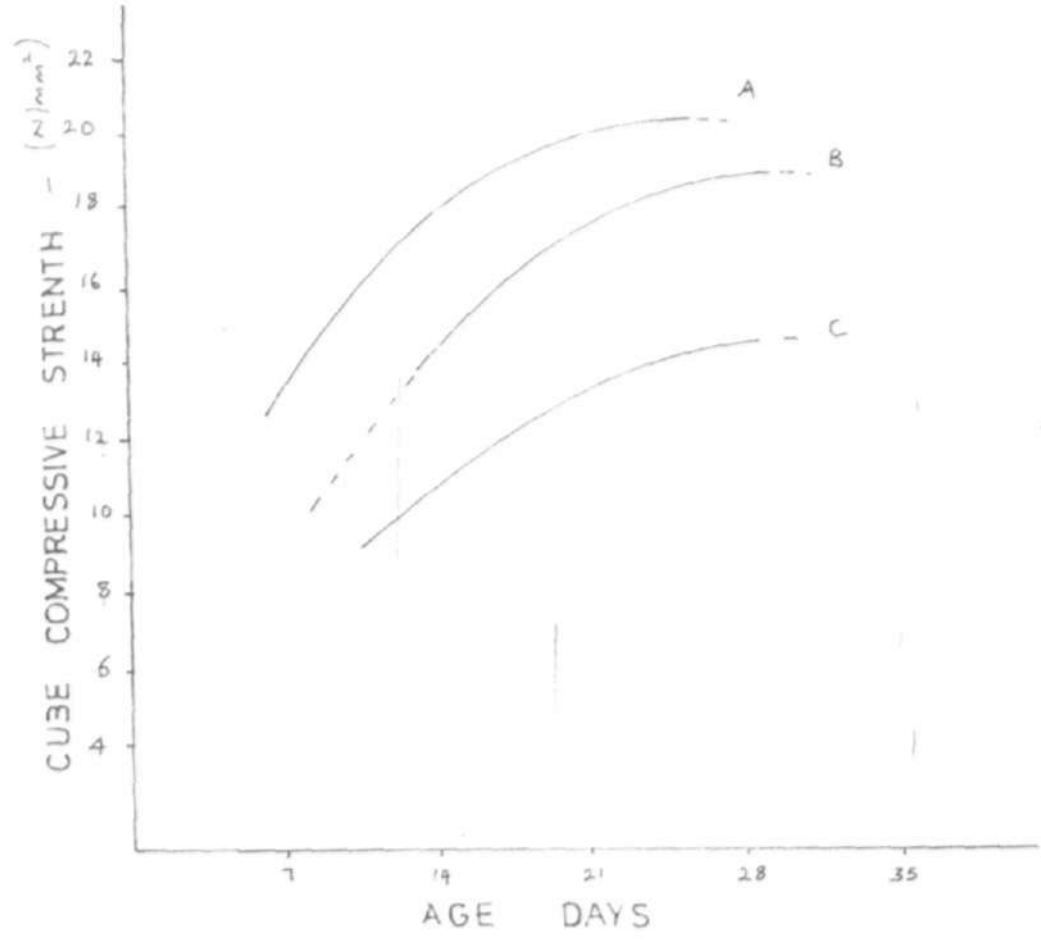


Fig. 4.2 - Compressive strength versus age.

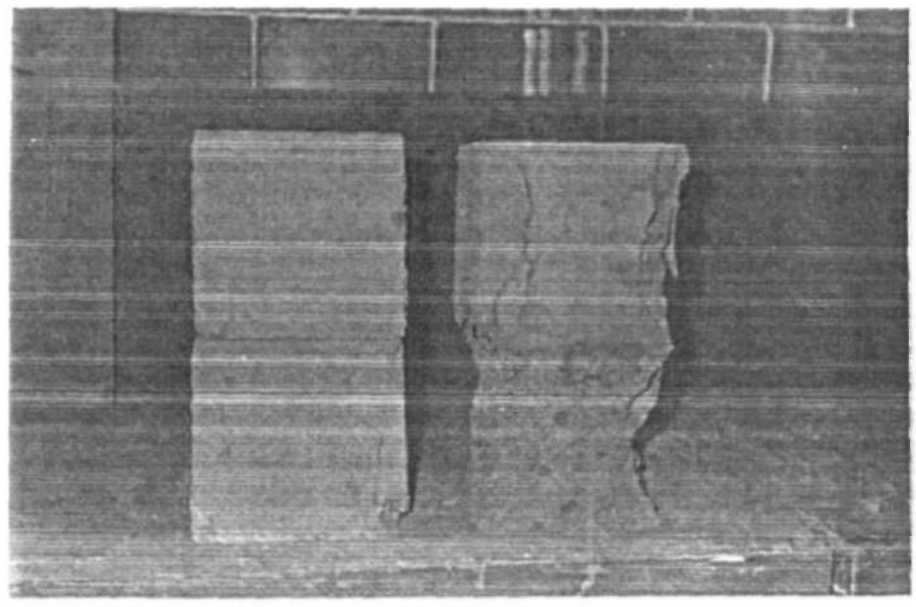


Plate IV. - Failure in brick concrete.

Split Tensile Strength

The split tensile strength of the concrete mixes were calculated using the following relationship as given by Akazawa of Japan (1942):

$$fct = \frac{2P}{L.d.}$$

where = fct = split tensile strength (N/mm^2)

P = failure load (N)

L = length of cylinder (mm) and

d = diamter of cylinder (mm).

The results of the splitting test are given in table 4.6 overleaf. The results are for 28 days of age.

Table 4.6 - Summaries of 28-day split tensile strength of the concrete mixes.

Mark	w/c ratio	Age (days)	Weight of cylinder (Kg)	Failure Load (KN)	split tensile strength (N/mm^2)
A	0.7	28	45.64	120.00	1.7
B	0.7	28	45.88	110.4	1.56
C	0.85	28	45.84	106.2	1.50

Static Modulus of Elasticity

The detailed results of this test are given in appendix III.

The mean strains were calculated the following relationship:

$$\text{Mean strain} = \frac{\text{Mean reading}}{\text{length of cylinder}}$$

The average strengths of three cubes (for each mix) that were used as a guide during the loading of the cylinders are given in apperdix III. The summaries of the stress with corresponding strain for the concrete mixes are as shown in table 4.6 overleaf.

Table 4.6 - Stress and strain summaries

S/No.	Mix	Stress	Mean strain $(1x10^{-4})$	
			Loading	Unloading
1	A	0.00	0.00	1.58
2	"	2.26	2.50	4.13
3	"	4.53	4.72	6.00
4	"	6.79	7.47	7.40
1	B	0.00	0.00	2.45
2	"	2.26	3.73	5.18
3	"	4.53	5.58	7.32
4	"	6.79	9.35	9.40
1	C	0.00	0.00	3.17
2	"	1.70	2.80	6.82
3	"	3.40	5.23	8.13
4	"	5.09	9.23	8.85

Figure 4.3 shows the stress-strain graphs for the three concrete mixes. The secant moduli of elasticity at a stress of 50% of the maximum applied stress were determined.

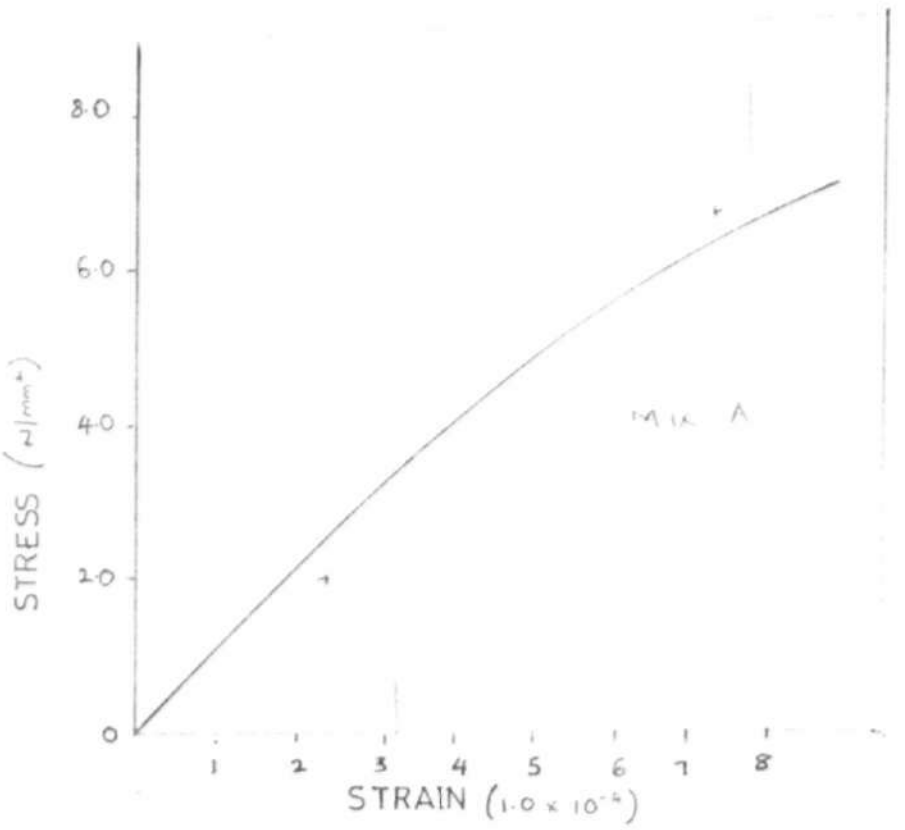


Figure 4.3(a) - Stress-strain graph for concrete A.

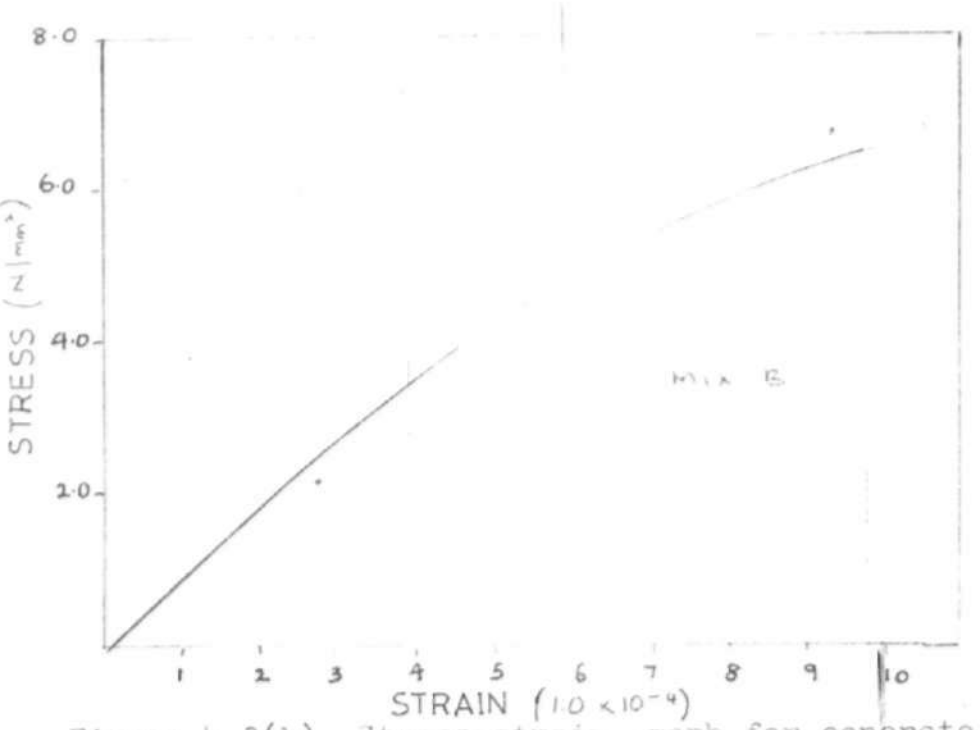


Figure 4.3(b) Stress-strain graph for concrete B.

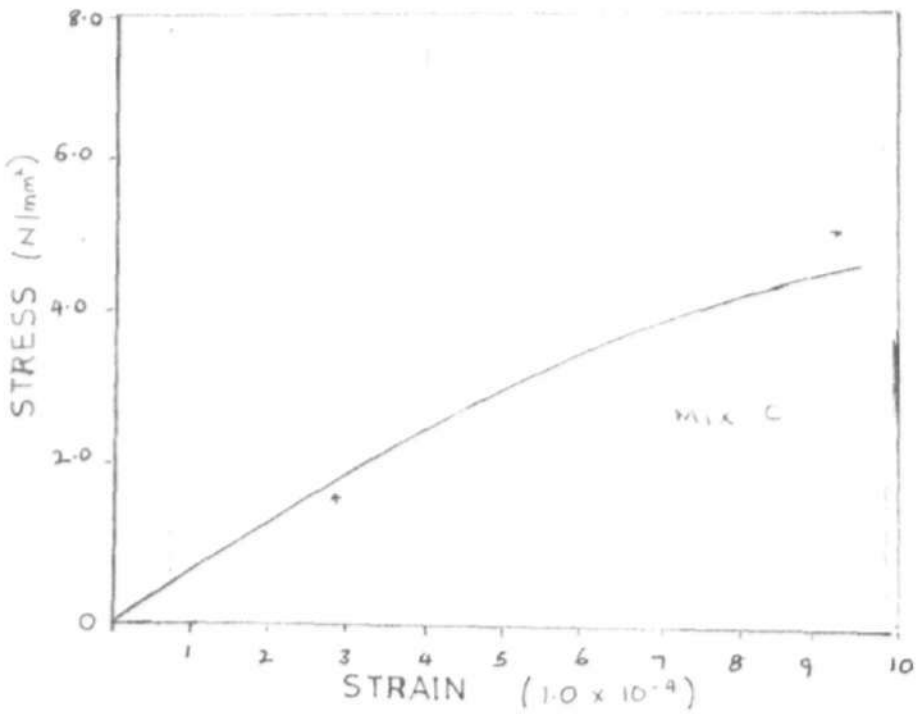


Figure 4.3(c) - Stress-strain graph for concrete C.

The static moduli of elasticity for the concrete mixes were calculated by determining the slopes of the stress-strain graphs at a stress of 30% of the maximum applied stress.

Table 4.7 - Moduli of elasticity (at 28 days of age)

S/No.	Mix	w/c ratio	28-day compressive strength (N/mm^2)	Moduli of elasticity (N/mm^2)
1.	A	0.7	18.30	10609.4
2	B	0.7	17.74	8487.5
3	C	0.85	13.17	6623.4

4.2 DISCUSSION

4.2.1 Brick Aggregate

As expected, brick aggregate is lighter than normal aggregate like river gravel. This can be seen from the values of specific gravities as shown in table 4.1. This being 1.95 and 2.5 to 3.0 for brick and gravel aggregates respectively. The absorption capacity of the brick aggregate is about 3 to 6 times that of river gravel. Thus for the brick aggregate used in concrete, there has to be some way of dealing with this high water asorption.

The aggregate production process produces angular aggregates. This coupled with high absorption capacity may hinder the production of a workable mix with low water-cement ratio. But with adequate attention given to grading of the aggregates (coarse and fine), a workable mix could be obtained.

With the combined grading curve of the aggregates shown on figure A.1, the grading is neither fine nor coarse. This enabled the good degrees of workabilities obtained for the three mixes.

4.2.2 Fresh Concrete

Workability

The results of the workability tests presented in table 4.2 show that the grading of the aggregates has been good. This statement is made considering the fact

that the brick aggregate's shape and texture are angular and rough.

Mix A has lower slump than B, this is probably due to absorption. (see mix design in chapter three).

4.2.3. HARDENED CONCRETE

Density

Table 4.3 shows the results of "brick concrete" densities. The density ranges from 1870 to 2183 Kg/m^3. This is quite low when compared to a range of 2355 to 2563 Kg/m^3 for normal concrete. The density of light - weight concrete is from 400.5 to 1762 Kg/m^3. This means that brick concrete's density is in between that of normal weight and light-weight concrete. Thus one may say that this concrete belongs to the medium weight group.

Compressive strength

The brick concrete at the age of 28 days has a strength of about 18 N/mm^2 for a w/c ratio of 0.7 and about 13 N/mm^2 for a w/c ratio of 0.85. This compares favourably with the strength of normal concrete of same w/c ratio and at the same age. These being 21 N/mm^2 and 14 N/mm^2 for 0.7 and 0.85 w/c ratios. The pattern of failure in cubes under compression shows that the failure is by the break-down of the aggregate and mortar as shown on plate IV. In normal concrete of adequate strength, failure is mainly through the cement paste.

Split tensile strength

As with compressive strength, the split tensile strength seems to be dependent to some extent upon the strength of the aggregate. A strength of 1.50 to 1.7 N/mm^2 was obtained for the three concrete mixes.

The relationship between compressive strength and split tensile strength may be expressed by the following equation:

$$fct = 5.5\sqrt{fc}$$

For nomal concrete (sand and gravel), Winter and Nelson suggested the equation:

$$fct = 6.7\sqrt{fc}$$

The above two equations further indicates that the tensile strength of normal concrete is higher than that of brick concrete. This justifies the findings by Boni (1980) that the tensile strength of concrete is dependent upon the strength of the aggregate used.

Static Modulus of Elasticity

The values of moduli of elasticity shown on table 4.7 are lower than those of normal concrete having the same compressive strength. The modulus elasticity for normal concrete of about 20 N/mm^2 compressive strength is about 1.5 to 4.0 x 10^7 N/mm^2. This value is by far greater than that of brick concrete. The very small value of modulus of elasticity is due to the low stiffness of the aggregate. The

modulus of elasticity for brick concrete is about 48% lower than that of normal concrete.

Statistical Analysis

Statistical analysis was carried out for cube compressive strengths at 7 and 28 days of age. The histograms and normal probability curves for some of the analysed strengths are shown in figure 4.4. The details of the statistical analysis are to be found in appendix IV.

The degree of control exercised during the experiments can be said to be adequate due to the fact that all the standard deviations and coefficients of variations for the various data were far below the minimum specified. The minimum coefficient of variation required for site condition as given by Waddle (1962) is 15%.

Table 4.8 shows the standard deviations and coefficient of variations for the concrete mixes.

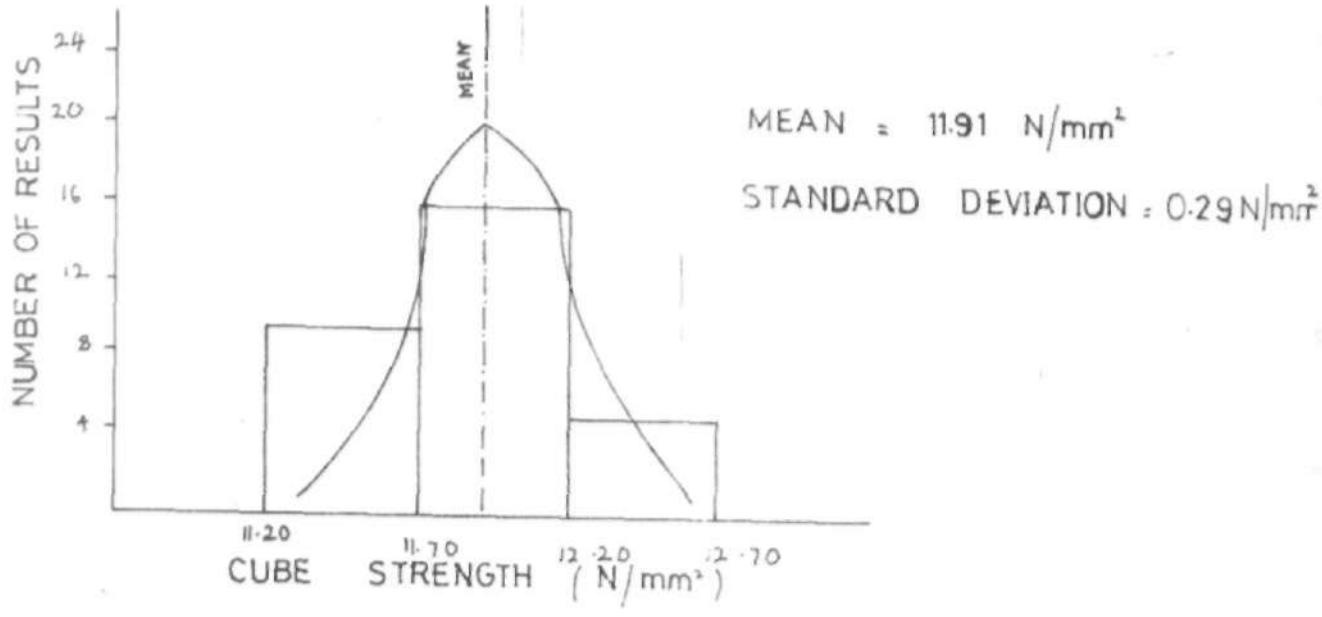


Figure 4.4(a) - Histogram and Normal probability curve for concrete A (7- days)

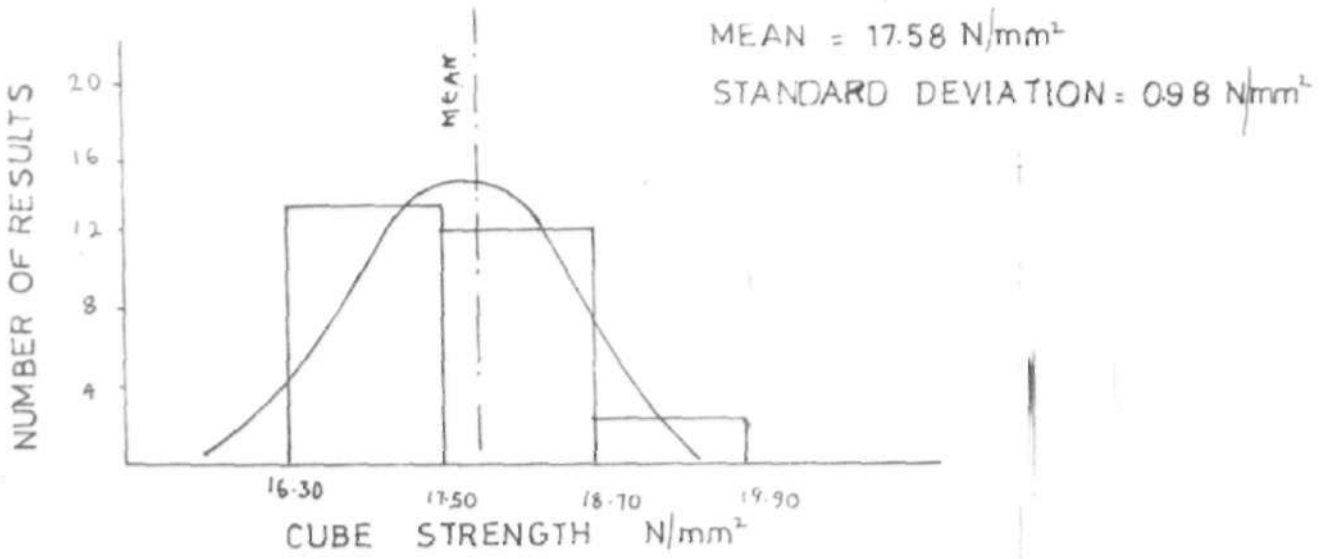


Figure 4.4(b) - Histogram and Normal probability curve for concrete B (28 days)

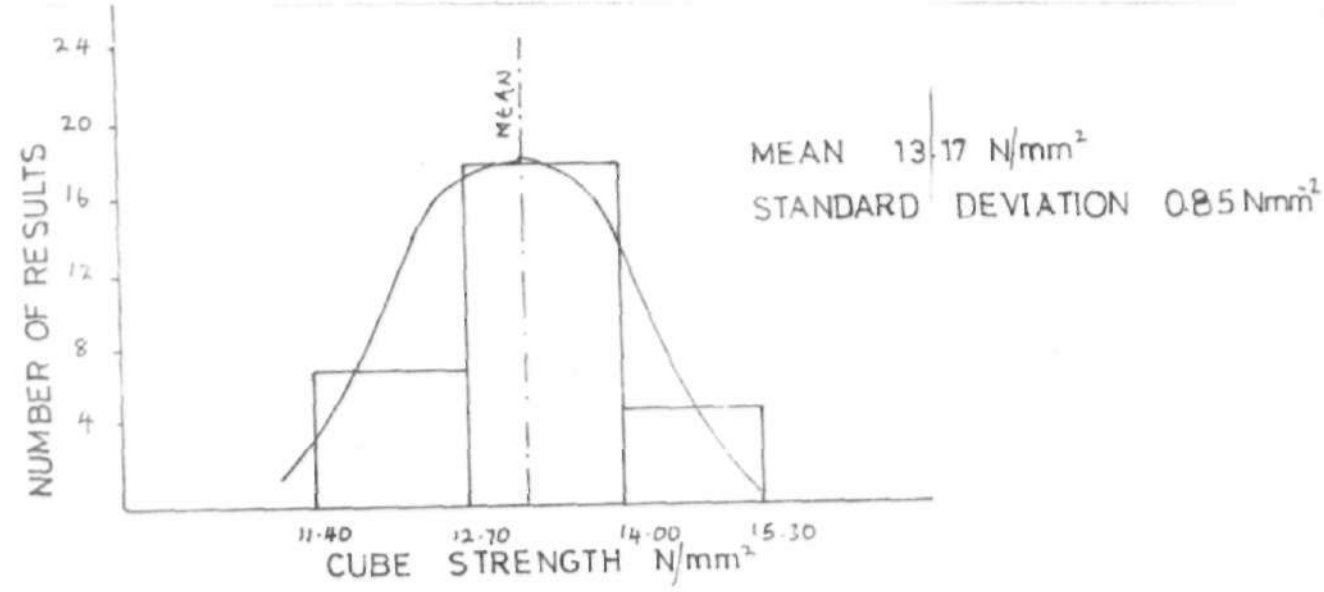


Figure 4.4(c) - Histogram and Normal probability curve for concrete C (28 days)

Table 4.8 - Standard deviations and coefficient of Variation for the concrete mixes.

S/No.	Age	A		B		C	
			V		V		V
1	7	0.29	2.43	6.54	4.83	0.67	8.13
2	28	0.66	3.63	0.98	5.54	0.85	6.45

4.3 CLASSIFICATION AND USE

From the results of the few number of tests conducted, "brick aggregate" concrete has adequate strengths and thus can be used for construction.

The density range of the "brick aggregate" concrete lies in between those of light-weight and normal weight concretes and thus may be said to be in the "medium weight" group. The lightness and strength of this concrete can be used to advantage when constructing structures in which lightness is required. The probable high thermal resistance of the brick aggregate concrete (due to the thermal resistance of bricks) could also be helpful when concrete for thermal structure is required.

Brick aggregate concrete (pending the outcome of investigations into permeability, creep and shrinkage properties) can be used where:

i. Lightness and strength are required;

ii. Thermal resistance.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the results of the research conducted, the following conclusions can be drawn:

(i) The brick aggregate which is angular in shape has very high percent absorption capacity. This being 3 to 6 times that of river gravel.

(ii) The specific gravity for the brick aggregate is 1.95 as compared to 2.5 to 3.5 for normal aggregate. Thus it is lighter than normal aggregate.

(iii) Concrete made with brick aggregate has a density range between those of normal and light-weight aggregates. The density of brick concrete is between 1870 to 2183 kg/m^3, while for light-weight is from 400.5 to 1762 kg/m^3 and that of normal weight ranges between 2355 to 2563 kg/m^3. Thus, brick concrete belongs to the medium density group.

(iv) The compressive strengths of the brick concrete compares favourably with that of normal concrete at the same age and with similar water-cement ratios. At the age of 28 days, the strengths are 18 N/mm^2 and 13 N/mm^2 for w/c ratios of 0.7 and 0.85 respectively. For normal concrete at the same age, strengths are 21 N/mm^2 and 14N/mm^2

for w/c ratios of 0.7 and 0.85 respectively.

(v) The tensile strength as determined by the cylinder splitting method at the age of 28 days is between 1.50 N/mm^2 to 1.7 N/mm.^{2} This is between $\frac{1}{8}$th to $\frac{1}{12}$th of the compressive strength as compared to a range of $\frac{1}{8}$th to $\frac{1}{12}$th for normal concrete (as given Elvery K.H. : 1963).

(vi) The modulus of elasticity of brick concrete is lower than that of normal concrete of the same compressive strength. It is about 48% lower than that of normal concrete.

(vii) From the limited number of tests carried out under laboratory conditions for period of up to 28 days, it would appear that the brick aggregate performs satisfactorily as a coarse aggregate in concrete.

5.2 RECOMMENDATIONS

(i) as the properties of bricks are quite variable, thorough investigation should be conducted before bricks from a particular source can be used for brick concrete.

(ii) Brick concrete should be used for minor concrete construction pending the outcome of further investigations on creep and shrinkage properties.

(iii) Test should also be carried out on the concrete's anchorage bond strength, shear and flexural strengths and certified adequate before used for reinforced concrete construction.

REFERENCES

1. Abrams, D.A. (1918) "Design of concrete mixtures." Chicago, Structural Materials Research Laboratory, Lewis Institute. Bulletin No.1

2. Boni, S.P.K. "The use of Sintered pelletised domestic refuse as an aggregate in concrete." Thesis submitted to University of Leeds for the degree of Ph.D. (1980) pp. 285.

3. B.S. 812 (1960): "Sampling and testing of mineral aggregates, sand and fillers."

4. B. S. 1881 (1952) "Methods of testing concrete."

5. Carneiro, F. (1947): "Une nouvelle methode d'essa pour determiner la resistance a latraction du beton Rilem Bulletin, June.

6. Elvery R. H. (1963) "Concrete practice": C.R. Books Ltd. Lennox House, Norfolk Street, W.C. 2.

7. Evans, E. P.: (1960): "The effect of curing condition on the physical properties of concretes," Ph.D. Thesis, University of London.

8. Evans, R. H. & Bennette, J.D. (1958): "Pre-stressed concrete - theory and design" Chapman & Hall, London.

9. Feret, R. "Sur la compacite des mortiers Hydrauliques" (On the compaction of hydraulic Mortars) Paris, Annales des ponts et Chaussees 1892, vol. 4, No. 21, Memoires serie fe.

10. George E. and Harmer E.D. (1955): "Composition and properties of concrete." Mcgraw - Hill Book Company Inc.

11. Glanvilla, W.H. et al : (1947) "The Grading of aggregates and workability of concrete," Road Research technical paper No. 5, H.M.S.O., London.

12. Illston, J.M. et al. (1979)" Concrete, Timber and Metals" Van Nostrand Reinhold Company.

13. Nelson, A. H. et al "Design of concrete structures" 9th edition, Mcgraw - hill Book Company, New York, 1979.

14. Neville, A. M. (1963) "Properties of concrete" Sir Isaac Pitman & Sons Ltd. London.

15. Orchard, D.F. (1973): "Concrete technology" volumes I & II : Applied Science publishers Ltd. London.

16. Portland Cement Association (1975): "Principles of Quality Concrete" : John Wiley & Sons, Inc. New York.

17. Price, W.H. , "Factors Insfluencing Concrete Strength", Journal American Concrete Institute, 47, pp 417-32 (february 1951).

18. Road Research Laboratory (D.S.I.R.) (1950) : "Design of concrete mixes", Road Note No. 4, Second edition H.M.S.O., London.

19. Wright, P.J.F. (1955): "Comments on an indirect tensile test on concrete cylinders", Magazine of Concrete Research No. 20, July.

APPENDIX 1

Detailed Result of the Ultimate Crushing Strength of Cubes

Table 6.1 - 7-day ultimate crushing strength of cubes

(Mix 1:2;4, w/c = 0.7)

S/NO.	Mark	Date of Cast	Weight of Cube (Kg)	Test Date	Age at Test (days)	Failure load (KN)	Cube strength (N/mm^2)
1	A3	10-9-87	7.2	17-9-87	7	273	12.13
2	"	"	7.2	"	"	270	12.00
3	"	"	7.4	"	"	275	12.22
4	"	"	7.2	"	"	273	12.13
5	"	"	7.2	"	"	273	12.13
6	"	"	7.4	"	"	254	11.29
7	"	"	7.3	"	"	273	12.13
8	"	"	7.3	"	"	260	11.56
9	"	"	7.4	"	"	275	12.22
10	"	"	7.2	"	"	275	12.22
11	"	"	7.2	"	"	260	11.56
12	"	"	7.2	"	"	265	11.78
13	"	"	7.3	"	"	260	11.56
14	"	"	7.3	"	"	273	12.13
15	"	"	7.3	"	"	273	12.13
16	"	"	7.3	"	"	273	12.13
17	"	"	7.4	"	"	273	12.13
18	"	"	7.4	"	"	256	11.38
19	"	"	7.4	"	"	260	11.56
20	"	"	7.2	"	"	273	12.13
21	"	"	7.2	"	"	262	11.64
22	"	"	7.2	"	"	273	12.13
23	"	"	7.2	"	"	262	11.64
24	"	"	7.3	"	"	268	11.91
25	"	"	7.3	"	"	264	11.73
26	"	"	7.2	"	"	264	11.73
27	"	"	7.2	"	"	273	12.13
28	"	"	7.2	"	"	275	12.22
29	"	"	7.2	"	"	275	12.22
30	"	"	7.2	"	"	260	11.56

Table 6.2 - 14-day Ultimate Crushing strength of cubes

(Mix 1:2:4, w/c 0.7)

S/No.	Mark	Date of Cast	Weight of Cube (Kg)	Test Date	Age at test (days)	Failure load (KN)	Cube Str. (N/mm^2)
1	A2	9/9/87	7.2	23-9-87	14	366	16.27
2	"	"	7.3	"	"	364	16.18
3	"	"	7.3	"	"	370	16.44
4	"	"	7.3	"	"	373	16.58
5	"	"	7.4	"	"	360	16.00
6	"	"	7.2	"	"	372	16.53
7	"	"	7.3	"	"	373	16.58
8	"	"	7.3	"	"	374	16.62
9	"	"	7.3	"	"	364	16.18
10	"	"	7.3	"	"	358	15.91

Table 6.3 - 21-day Ultimate Crushing Strength of Cubes

(Mix 1:2:4, w/c = 0.7)

1	A2	9-9-87	7.3	30-9-87	21	395	17.56
2	"	"	7.4	"	"	372	16.53
3	"	"	7.4	"	"	365	16.22
4	"	"	7.4	"	"	382	16.98
5	"	"	7.3	"	"	368	16.36
6	"	"	7.4	"	"	365	16.22
7	"	"	7.2	"	"	368	16.36
8	"	"	7.3	"	"	368	16.36
9	"	"	7.2	"	"	365	16.22
10	"	"	7.2	"	"	367	16.31

Table 6.4 - 28-day Ultimate Crushing strength of Cubes

(Mix 1:2:4, w/c = 0.7)

S/No.	Mark	Date of Cast	Weight of Cube (Kg)	Test Date	Age at test (days)	Failure Cube load (KN)	str.^{2} (N/mm^2)
1	A1	8/9/87	7.2	7/10/87	28	420	18.67
2	"	"	7.2	"	"	416	18.49
3	"	"	7.4	"	"	424	18.84
4	"	"	7.3	"	"	420	18.67
5	"	"	7.4	"	"	412	18.31
6	"	"	7.4	"	"	392	17.42
7	"	"	7.4	"	"	420	18.67
8	"	"	7.4	"	"	400	17.78
9	"	"	7.4	"	"	428	19.02
10	"	"	7.4	"	"	428	19.02
11	"	"	7.4	"	"	400	17.78
12	"	"	7.4	"	"	408	18.13
13	"	"	7.3	"	"	400	17.78
14	"	"	7.3	"	"	412	18.31
15	"	"	7.2	"	"	416	18.49
16	"	"	7.4	"	"	412	18.31
17	"	"	7.4	"	"	348	15.47
18	"	"	7.4	"	"	400	17.78
19	"	"	7.4	"	"	420	18.67
20	"	"	7.4	"	"	406	18.04
21	"	"	7.4	"	"	420	18.67
22	"	"	7.4	"	"	406	18.04
23	"	"	7.3	"	"	424	18.84
24	"	"	7.3	"	"	406	18.04
25	"	"	7.4	"	"	402	17.84
26	"	"	7.4	"	"	423	18.80
27	"	"	7.4	"	"	416	18.49
28	"	"	7.4	"	"	416	18.49
29	"	"	7.4	"	"	418	18.58
30	"	"	7.4	"	"	410	18.22

Table 6.5 - 7-day Ultimate Crushing Strength of Cubes
(Mix 1:2:4, w/c = 0.7)

S/NO.	Mark	Date of cast	Weight of Cube (Kg)	Test Date	Age at test (days)	Failure load (KN)	Cube strength (N/mm^2)
1	B3	11-9-87	7.2	18-9-87	7	266	11.82
2	"	"	7.2	"	"	240	10.67
3	"	"	7.2	"	"	252	11.20
4	"	"	7.3	"	"	238	10.58
5	"	"	7.2	"	"	240	10.67
6	"	"	7.2	"	"	265	11.78
7	"	"	7.2	"	"	248	11.02
8	"	"	7.2	"	"	272	12.09
9	"	"	7.2	"	"	250	11.11
10	"	"	7.3	"	"	250	11.11
11	"	"	7.2	"	"	248	11.02
12	"	"	7.2	"	"	245	10.89
13	"	"	7.4	"	"	245	10.89
14	"	"	7.4	"	"	248	11.02
15	"	"	7.3	"	"	284	12.62
16	"	"	7.3	"	"	260	11.56
17	"	"	7.3	"	"	250	11.11
18	"	"	7.2	"	"	245	10.89
19	"	"	7.2	"	"	260	11.56
20	"	"	7.2	"	"	250	11.11
21	"	"	7.2	"	"	248	11.02
22	"	"	7.2	"	"	220	9.78
23	"	"	7.2	"	"	244	10.84
24	"	"	7.2	"	"	245	10.89
25	"	"	7.2	"	"	245	10.89
26	"	"	7.2	"	"	248	11.02
27	"	"	7.2	"	"	245	10.89
28	"	"	7.2	"	"	262	11.64
29	"	"	7.2	"	"	264	11.73
30	"	"	7.3	"	"	268	11.91

Table 6.6 - 14-day Ultimate Crushing Strength of Cubes
(Mix 1:2:4, w/c = 0.7)

S/No.	Mark	Date of Cast	Weight of Cube (Kg)	Test Date	Age at test (days)	failure load (KN)	Cube strength (N/mm^2)
1	B2	12/9/87	7.2	26/9/87	14	310	13.78
2	"	"	7.2	"	"	304	13.51
3	"	"	7.3	"	"	280	12.44
4	"	"	7.2	"	"	254	11.29
5	"	"	7.3	"	"	318	14.13
6	"	"	7.3	"	"	304	13.51
7	"	"	7.2	"	"	320	14.22
8	"	"	7.2	"	"	305	13.56
9	"	"	7.2	"	"	318	14.13
10	"	"	7.2	"	"	302	13.42

Table 6.7 - 21-day Ultimate Crushing Strength of Cubes
(Mix 1:2:4, w/c = 0.7)

1	B2	12/9/87	7.4	30/10/87	21	340	15.11
2	"	"	7.4	"	"	324	14.40
3	"	"	7.2	"	"	328	14.58
4	"	"	7.4	"	"	328	14.58
5	"	"	7.3	"	"	328	14.58
6	"	"	7.2	"	"	340	15.11
7	"	"	7.2	"	"	358	15.91
8.	"	"	7.2	"	"	326	14.49
9	"	"	7.4	"	"	338	15.02
10	"	"	7.3	"	"	344	15.29

Table 6.8 - 28-day Ultimate Crushing Strength of Cubes
(Mix 1:2:4, w/c = 0.7)

S/NO.	Mark	Date of cast	Weight of cube (Kg)	Test Date	Age at test (days)	Failure load (KN)	Cube Strength (N/mm^2)
1	B1	10/9/87	7.2	8-10-87	28	440	19.56
2	"	"	7.3	"	"	380	16.89
3	"	"	7.3	"	"	404	17.96
4	"	"	7.3	"	"	368	16.36
5	"	"	7.4	"	"	380	16.89
6	"	"	7.5	"	"	408	18.13
7	"	"	7.4	"	"	408	18.13
8	"	"	7.3	"	"	400	17.78
9	"	"	7.3	"	"	380	16.89
10	"	"	7.3	"	"	420	18.67
11	"	"	7.3	"	"	384	17.07
12	"	"	7.3	"	"	384	17.07
13	"	"	7.4	"	"	380	16.89
14	"	"	7.4	"	"	368	16.36
15	"	"	7.3	"	"	420	18.67
16	"	"	7.4	"	"	420	18.67
17	"	"	7.3	"	"	380	16.89
18	"	"	7.3	"	"	436	19.38
19	"	"	7.3	"	"	400	17.78
20	"	"	7.5	"	"	400	17.78
21	"	"	7.4	"	"	420	18.67
22	"	"	7.3	"	"	400	17.78
23	"	"	7.3	"	"	420	18.67
24	"	"	7.4	"	"	388	17.24
25	"	"	7.5	"	"	440	19.56
26	"	"	7.4	"	"	420	18.67
27	"	"	7.3	"	"	384	17.07
28	"	"	7.3	"	"	384	17.07
29	"	"	7.3	"	"	380	16.89
30	"	"	7.3	"	"	380	16.89

Table 6.9 - 7-day Ultimate Crushing Strength of Cubes

(Mix 1:2:4, w/c = 0.65)

S/No.	Mark	Date of cast	Weight of Cube (Kg)	Test Date	Age at test (days)	Failure load (KN)	Cube Strength (N/mm^2)
1	C3	15/9/87	7.4	22/9/87	7	185	8.22
2	"	"	7.4	"	"	195	8.67
3	"	"	7.4	"	"	192	8.53
4	"	"	7.2	"	"	180	8.00
5	"	"	7.4	"	"	165	7.33
6	"	"	7.2	"	"	192	8.53
7	"	"	7.2	"	"	192	8.53
8	"	"	7.4	"	"	198	8.80
9	"	"	7.4	"	"	196	8.71
10	"	"	7.5	"	"	195	8.67
11	"	"	7.2	"	"	168	7.47
12	"	"	7.2	"	"	170	7.56
13	"	"	7.3	"	"	170	7.56
14	"	"	7.3	"	"	208	9.24
15	"	"	7.3	"	"	185	8.22
16	"	"	7.4	"	"	170	7.56
17	"	"	7.2	"	"	186	8.27
18	"	"	7.2	"	"	168	7.47
19	"	"	7.2	"	"	200	8.89
20	"	"	7.3	"	"	196	8.71
21	"	"	7.2	"	"	206	9.16
22	"	"	7.2	"	"	172	7.64
23	"	"	7.2	"	"	148	6.58
24	"	"	7.4	"	"	156	6.93
25	"	"	7.2	"	"	202	8.98
26	"	"	7.4	"	"	178	7.91
27	"	"	7.4	"	"	188	8.36
28	"	"	7.2	"	"	196	8.71
29	"	"	7.4	"	"	200	8.89
30	"	"	7.3	"	"	194	8.62

Table 6.10 - 14-day Ultimate Crushing Strength of Cubes

(Mix 1.2:4, w/c = 0.85)

S/No.	Mark	Date of Cast	Weight of Cube (Kg)	Test Date	Age at test (days)	Failure load (KN)	Cube Strength (N/mm^2)
1	C2	14/9/87	7.1	28/9/87	14	214	9.51
2	"	"	7.2	"	"	208	9.24
3	"	"	7.2	"	"	216	9.60
4	"	"	7.1	"	"	200	8.89
5	"	"	7.1	"	"	208	9.24
6	"	"	7.1	"	"	212	9.42
7	"	"	7.1	"	"	196	8.71
8	"	"	7.2	"	"	188	8.36
9	"	"	7.1	"	"	216	9.60
10	"	"	7.2	"	"	200	8.89

Table 6.11 - 21-day Ultimate Crushing Strength of Cubes

(Mix 1:2:4, w/c = 0.85)

1	C2	14/9/87	7.3	5/10/87	21	270	12.00
2	"	"	7.3	"	"	260	11.56
3	"	"	7.2	"	"	262	11.64
4	"	"	7.1	"	"	258	11.47
5	"	"	7.1	"	"	278	12.36
6	"	"	7.3	"	"	280	12.44
7	"	"	7.1	"	"	266	11.82
8	"	"	7.1	"	"	250	11.11
9	"	"	7.2	"	"	264	11.73
10	"	"	7.1	"	"	248	11.02

Table 6.12 - 28-day Ultimate Crushing strength of Cubes

(Mix 1:2:4, w/c = 0.85)

S/N6.	Mark	Date of Cast	Weight of Cube (Kg)	Test Date	Age at test (days)	Failure load (KN)	Cube strength (N/mm^2)
1	C1	13/9/87	7.2	11/10/87	28	300	13.33
2	"	"	7.4	"	"	300	13.33
3	"	"	7.4	"	"	296	13.16
4	"	"	7.2	"	"	284	12.62
5	"	"	7.4	"	"	296	13.16
6	"	"	7.4	"	"	296	13.16
7	"	"	7.3	"	"	302	13.42
8	"	"	7.4	"	"	302	13.42
9	"	"	7.4	"	"	284	12.62
10	"	"	7.4	"	"	302	13.62
11	"	"	7.3	"	"	300	13.13
12	"	"	7.3	"	"	300	13.13
13	"	"	7.4	"	"	286	12.71
14	"	"	7.2	"	"	300	13.13
15	"	"	7.2	"	"	260	11.56
16	"	"	7.2	"	"	264	11.73
17	"	"	7.2	"	"	320	14.22
18	"	"	7.4	"	"	284	12.62
19	"	"	7.2	"	"	260	11.56
20	"	"	7.2	"	"	288	12.80
21	"	"	7.3	"	"	258	11.47
22	"	"	7.2	"	"	308	13.69
23	"	"	7.2	"	"	300	13.13
24	"	"	7.1	"	"	316	14.04
25	"	"	7.4	"	"	328	14.58
26	"	"	7.2	"	"	324	14.40
27	"	"	7.2	"	"	342	15.20
28	"	"	7.3	"	"	300	13.13
29	"	"	7.3	"	"	302	13.42
30	"	"	7.4	"	"	306	13.60

Detailed results of the cylinder split test

Table 6.13 - 28-day split tensile strength

S/No.	Mark	Date of Cast	Weight of cylinder (Kg)	Test date	Age at test (days)	w/c ratio	Failure load (KN)	Tensile streng. (N/mm^2)
1	A	11/10/87	45.80	10/11/87	28	0.7	120	1.70
2	"	"	45.84	"	"	"	120	1.70
3	"	"	45.78	"	"	"	122	1.73
4	"	"	45.80	"	"	"	125	1.77
5	"	"	45.88	"	"	"	120	1.70
1	B	12/10/87	45.68	10/11/87	28	0.7	108	1.53
2	"	"	45.88	"	"	"	110	1.56
3	"	"	45.76	"	"	"	110	1.56
4	"	"	45.66	"	"	"	105	1.49
5	"	"	45.84	"	"	"	114	1.61
1	B	13/10/87	45.84	10/11/87	28	0.85	100	1.41
2	"	"	45.82	"	"	"	105	1.49
3	"	"	45.70	"	"	"	110	1.56
4	"	"	45.78	"	"	"	110	1.56
5.	"	"	45.51	"	"	"	106	1.50

APPENDIX III

Detailed results of the static modulus of elasticity determination

Table 6.14 - Average cube crushing strength of the concrete

S/No.	Mark	Weight (Kg)	Age (days)	Failure load (KN)	Compressive strength (N/mm^2)
1	A	7.4	28	360	16.00
2	B	7.4	28	360	16.00
3	C	7.3	28	300	13.33

Table 6.15 - Test Readings for Static Modulus of Elasticity determination.
(Specimens - cylinders, mix 1:2:4, w/c = 0.7
Age 28 days)

Mark			A	
S/No.	Load (KN)	Stress (N/mm^2)	Readings (2×10^{-3}mm)	
			Loading	Unloading
1	0.00	0.00	20.00	50.00
2	40.00	2.26	80	110.00
3	80.00	4.53	140	176.00
4	120.00	6.79	220	220
5	0.00	0.00	20.00	41.00
6	40.00	2.26	70.00	108.00
7	80.00	4.53	136	166.00
8	120.00	6.79	210	212.00
9	0.00	0.00	20	50.00
10	40.00	2.26	80	130.00
11	80.00	4.53	150	192.00
12	120.00	6.79	249	228.00
13	0.00	0.00	20	48
14	40.00	2.26	70	148
15	80.00	4.53	140	186
16	120.00	6.79	222	228

Table 6.16 Test readings for static modulus of Elasticity determination.
(Specimens - cylinders, mix 1:2:4, w/c = 0.7
Age 28 days)

MARK			B	
S/No.	Load (KN)	Stress (N/mm^2)	Readings (2×10^{-3} mm)	
			Loading	Unloading
1	0.00	o.00	20	50.00
2	40.00	2.26	76	128.00
3	80.00	4.53	148	184.00
4	120.00	6.79	228	230.00
5	0.00	0.00	20	68.00
6	40	2.26	84	154.00
7	80	4.53	170	220
8	120	6.79	270	272
9	0.00	0.00	20	100
10	40	2.26	92	210
11	80	4.53	192	280
12	120	6.79	340	360
13	0.00	0.00	20	76
14	40.00	2.26	78	130
15	80.00	4.53	160	194
16	120.00	6.79	284	266

Table 6.17 - Test readings for static modulus of Elasticity determination.

(Specimens-cylinders, mix 1:2:4, w/c =0.85 Age 28 days)

Mark			C	
S/No.	Load (KN)	Stress (N/mm^2)	Readings ($2x10^{-3}$mm)	
			Loading	Unloading
1	0.00	0.00	20	60
2	30.00	1.70	76	140
3	60.00	3.40	150	204
4	90.00	5.09	214	250
5	0.00	0.00	20	136
6	30.00	1.70	90	260
7	60.00	3.40	196	332
8	90	5.09	370	300
9	0.00	0.00	20	104
10	30.00	1.70	90	180
11	60.00	3.40	136	240
12	90.00	5.09	262	272
13	0.00	0.00	20	80
14	30.00	1.70	80	238
15	60.00	3.40	146	200
16	90.00	5.09	230	240

Table 6.18 - Stress with the corresponding strain.

S/No.	Mark	Stress	Mean readings (2×10^{-3} mm)		Mean Strain (1×10^{-4})	
			Loading	Unloading	Loading	Unloading
1	A	0.00	20.00	47.25	0.00	1.58
2	"	2.26	75.00	126.00	2.50	4.13
3	"	4.53	141.50	180.00	4.72	6.00
4	"	6.79	224.00	222.00	7.47	7.40
1	B	0.00	20.00	73.50	0.00	2.45
2	"	2.26	82.50	155.50	2.75	5.18
3	"	4.53	167.50	219.50	5.58	7.32
4	"	6.79	280.50	282.00	9.35	9.40
1	C	0.00	20.00	95.00	0.00	3.17
2	"	1.70	84.00	204.50	2.80	6.82
3	"	3.40	157.00	244.00	5.23	8.13
4	"	5.09.	276.50	255.50	9.23	8.85

APPENDIX IV

Statistical Analysis of Results

Statistical analysis of the results were carried out in order to assess the quality control exercised. The analysis was only conducted for the results of 7 and 28-day ultimate crushing strength of cubes. Other results were not considered due to the few number of specimens involved. The histogram and normal probability curves for the analysis are given in chapter four.

The statistical values calculated are:-

n = number of specimens

x = sum of individual strength

$\bar{x}$ = mean strength

= standard deviation and

v = coefficient of variation ($V = \frac{\sigma}{\bar{x}} \times 100\%$)

Table 6.19 - Statistical analysis for 7-day compressive strength (specimen A1)

$x(N/mm^2)$	11.29	11.38	11.56	11.64	11.73	11.78	11.91	11.98	12.13	12.23	12.36
f	1	1	5	2	2	1	1	1	11	4	1

n = 30

x = 357.43 N/mm^2

$\bar{x}$ = 11.91 N/mm^2