PROPERTIES OF CONCRETE USING "ATILE" SEEDS AS COARSE AGGREGATE

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JULY, 1996.

DECLARATION

I hereby declare that this thesis has been composed by me unaided, and that it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All quotations are distinguished by quotation marks and the sources of information are specifically acknowledged by means of references.

30/5/97

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DATE

CERTIFICATION

We hereby certify that this thesis entitled ***"PROPERTIES OF CONCRETE USING 'ATILE' SEED AS COARSE AGGREGATE"*** by ***YAKUYIYA, A. SHEYIN*** meets the conditions governing the award of the degree of Master of Science *(M. Sc.)* Construction Technology of the Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

To my Late dear Wife, **Susan**

&

Our Son, **Divine.**

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ABSTRACT

This thesis is an investigation into the properties of concrete using "Atile" seeds as coarse aggregate.

The work involves the prior determination of the physical properties of the "Atile" seeds in the laboratory, e.g. specific gravity, absorption rate, bulk density, moisture content, voids ratio, porosity, etc. using standard methods of determination of these properties as given by Orchard (1962), Neville (1981), **and** Murdock and Brook (1984), and mix design.

The properties of concrete investigated are compressive strength, resistance to abrasion as compared with normal concrete, cost comparison of units of "Atile" concrete and normal concrete, Modulus of Elasticity, bond, and split tensile.

The compressive strength was determined at ages of 7, 14, and 28 days of curing while all others (except for the cost comparison of units) were determined at 28 days of curing.

The compressive strength tests gave a range of 10.15N/mm to 18.27N/mm characteristic strength making it suitable for both structural and plain concrete construction.

For the resistance to abrasion, the concrete produced of "Atile" eroded almost 2.5 times the normal concrete. The relatively low cost of the "Atile" was offset by the high cement content needed.

The Modulus of Elasticity ranges from 4.10kN/mm^2 to 10.12kN/mm^2, i.e. about 17% to 28% of that of the normal concrete. This low value of the Modulus of Elasticity makes this type of

concrete suitable for resisting impact loads. The rich mix provided the greatest bond with both deformed and plain bars than the relatively weaker mix. The split tensile tests gave results ranging from 4% to 7% of the compressive? strength of the same mix at 28 days of age.

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B - Bulk density of "Atile" Aggregate.
n_p - Porosity of "Atile" Aggregate.
$\tilde{x}$ - Accepted Analysed Mean Strength.
x_i - Measurement.
S - Standard Deviation.
n - Number of Measurements.
$S_{\tilde{x}}$ - Mean-Square Error/Standard Error.
$\acute{\epsilon}$ - Accuracy of Measurement.
f - Reliability of Measurement.
X_0 - Characteristic Strength.
K - Probability Factor.
$\acute{\alpha}$ - Value of Reliability for n-1.
R.P.M. - Rounds per minute.
H.P. - Horse Power.
Hz - Hertz.
E - Modulus of Elasticity.
f - Applied Stress.
w - Load.
A - Cross-sectional Area.
X - Deformation under load, w.
L - Length of the Member.
e - Deformation per unit length or strain.
P - Splitting Load.
l - Length of Cylinder.
d - Diameter of Cylinder.

CHAPTER ONE - INTRODUCTION

1.0 Background

Agricultural by-products are increasingly finding greater application in the Construction Industry as efforts are geared towards exploring possible substitute materials for the production of concrete in terms of aggregate, i.e. both coarse and fine. Another factor as to the favourable disposition toward agricultural by-products is to explore possible ways of disposing of these by-products that tend to constitute a health hazard and an eye-sore.

Research works into the use of agricultural by-products for concrete production have been entered into such as sawdust, other woodwastes such as splinters and shavings, rice husk, cork granules, palm kernel shells, periwinkle shells, etc. and these researches have come up with ways of putting these by-products into useful application.

"Atile", scientifically called Canarium Schweinfurthii, is a small oval fruit with a hard stone-like seed. It has a yellowish green colour when unripe and bluish black when ripe. The seed has been used in traditional construction - particularly in flooring and wall construction where the trees are grown.

One of the major reasons for which the National Building and Road Research Institute (NBBRI) was established was to conduct *research on local building and construction materials to determine the most effective and economic methods of their utilisation.* Infact, the NBBRI recognised from inception that one of the most effective strategies in reducing the cost of housing was the development of effective building materials from locally abundant materials such as clay, agricultural and industrial wastes (NBRRI, 1991).

This research work therefore, at the onset, is out to compare the properties of concrete using "Atile" seeds with regards to compressive strength, resistance to abrasion, cost comparison of units, Modulus of Elasticity, bond and split tensile strength.

1.1 AIM

The aim was to assess the properties of concrete produced using "Atile" seeds as coarse aggregate based on acceptable parameters.

1.2 OBJECTIVES

The objectives among others include the following:

(a) To determine the characteristics of "Atile" as an aggregate, e.g. shape, surface texture, water absorption, etc. that will affect the strength;

(b) To determine trial mixes and arrive at a suitable mix design;

(c) To determine the resistance of concrete produced using "Atile" seeds as compared with ordinary (normal) concrete;

(d) To come out with a definite position of the potentials or otherwise of the "Atile" seed as an aggregate in concrete production.

1.3 NEED FOR THE STUDY

The need to investigate the performance/properties of concrete produced using "Atile" seeds as a coarse aggregate arises from the following:

(i) The traditional aggregates are becoming scarce, so the need to look for substitute materials;

(ii) The traditional materials are becoming very expensive due to production costs emanating from high import duties on the machinery and spares, maintenance and running costs of the equipment;

(iii) The depreciation of the local currency against other international currencies has also made the production very expensive thereby making it necessary to look for substitute materials that are relatively cheaper.

(iv) "Atile seeds are being used as a flooring material in traditional construction with mud in areas this material is found so that there is the need to further investigate its application using cement as the binder instead of mud.

1.4 METHODOLOGY

The material was acquired and any preparation required on the aggregate was done, i.e. sieving off unwanted particles like grass blades and removing dried uneaten flesh of the fruit sticking to the seeds.

Trial mixes were prepared dry first before adding water to the dry mix. In this case, the mix consisted of cement, sand, "Atile" seeds (as coarse aggregate) and water in specified ratios. This was cast in cube moulds of 150mm, (Novgorodsky, 1973) and cylinders of 300mm length and 150mm diameter (Neville, 1981).

The design of mixes was according to the standard method of mix design. The water-cement ratio "law" was applied instead of proportioning on the basis of the cement content preferable for lightweight aggregate mixes (Neville, 1981). The reason for this is that the aggregate is oval in shape with a sealed surface with little absorption.

Curing of cubes and cylinders began 24 hours after casting and the crushing was phased at 7, 14 and 28 days of curing for the test cubes and 28 days for all the test cylinders.

Results collated were analysed and the average and characteristic strengths for the mixes were calculated using the standard methods of analysis of specimens for less than 25 in number as given by Novgorodsky (1973). From the results, conclusions have been drawn and recommendations made.

1.5 SCOPE AND LIMITATIONS

The main properties tested in the research work were the compressive strength (crushing strength) as stipulated in the cube-crushing tests by Novgorodsky (1973), resistance to abrasion, cost comparison of units, Modulus of Elasticity, bond and split tensile strength.

Due to limitation of time, long-term properties of concrete like creep could not be tested but with the results of the Modulus of Elasticity, creep could be understood in terms of its magnitude

- either small or much.

Limited quantity of test cube moulds made casting of higher numbers of cubes without much variation impossible and financial constraints in terms of transporting the "Atile" aggregate from areas it is available - Plateau State and Southern Kaduna State to Zaria contributed in just having a limited quantity of the aggregate for the experiments.

CHAPTER TWO - *LITERATURE REVIEW*

2.0 Introduction

An attempt is made to present the information available on the "Atile", i.e. its family, where it is found, how it is cultivated and its present uses and information on concretes produced of similar materials - particularly lightweight concrete.

2.1.0 CANARIUM SCHWEINFURTHII - Group Background

Burseraceae, a large family of which Canarium Schweinfurthii is a member, is found in the tropics in rain forests and in dry areas (Voorhoeve, 1979).

In West Africa, this family is represented by five genero only. These include Boswellia (otherwise called Frankincense African Elemi - Elemier d'Afrique), Comiphora (African Myrrh), Santiria (which is Pachylobus - bush butter tree, Native Pear in Southern Nigeria (Dalziel, 1936) and Dacyodes. This family of Burseaceae is found in Nigeria (Keay et.al., 1964).

The name "Canarium" is from the original Malayan Vernacular name "Kenari" in the Molucca Isles of Malaya. Schweinfurthii refers to G.A. Schweinfurth, a German Explorer and Scientist (1836-1925) the collector of the type of specimen.

The genus Canarium Linne is widespread in South-East and Tropical Australia with about 70 species; but on the main land of Africa, only two species occur: Canarium Madagascariense in East Africa and Canarium Schweinfurthii in West and Central Africa (Voorhoeve, 1979).

It is variously called in West Africa: Burkina Fasso (Cien or

Paja); Sierra Leone (mbili by the Me); Liberia (goe-kwehn by Bassa); Côte d'Ivoire (aie'le or ahiele by Agni and Appollonian Nzima); Ghana (bedimunua by the Ashanti and kurutwe by Wass and others); Nigeria (atile or atilis by Hausa, eshia by Nupe, Fwat by Berom, Fhat by Kagoro, Dihwat by Bajju (Kaje), ako by Yoruba, etc.). In the Cameroons, it is called wotua by Bakwiri; hehe by Bakundu and say eyidi by Duala.

This tree is of the upper canopy of the forest, sometimes even emergent up to 50m high and 1.5m in diameter, rarely up to 1.8m. (It is abundant in hill forests with good rainfall; but it is being planted now. On the Bauchi Plateau that extends to Jos and Kagoro, it is believed to have been introduced by the local people). The base of the young tree is swollen or provided with low, thick spreading root swellings, which on growing old,develop into heavy root ridges up to 0.4m thick,reaching as high as 0.9m on the bole (main trunk of the tree) and often spreading in sinuous curves far from the tree, partially above the ground. Above the root swellings, the bole is straight and cylindrical up to 30m free of branches when fully mature. The crown, abruptly spreading from the end of the bole, is heavily branched and rounded, not very dense, and characterised by the tufts of leaves at the end of the branchlets. The bark is yellowish brown or light-grey brown, rough and fissured, sometimes longitudinally flaky or scaly, sometimes weathering on the tree, often yellowish on the spreading surface roots, about 1cm thick, rather hard and fibrous; old trees are known to flake off their bark in conspicuous rectangular scales, Voorhoeve (1979).

Medicinal Importance

An infusion of the boiled bark is considered efficatious for removal of intestinal parasites. For leprosy, the inner bark is ground in a mortar and mixed with water, rubbed on the skin and dropped in ulcers twice daily and the patient is forbidden to eat cadfish and sexual intercourse becomes a taboo. A cure is promised within a year. The bark may be used for the coagulation of funtumia rubber, Voorhoeve (1979). Again, medicinally, a decoction of the bark is an ingredient in prescription for dysentery. The oil is commonly used in Northern Nigeria, both internally and externally as well as in superstitious practices. In Camerouns, chancre is treated by a decoction of the barks of canarium, Chlorophora and Mammea Ebboro, in which the patient sits for two hours, after which a dressing of powdered leaves of Alchomea is applied (Dalziel, 1936).

The slash is red or light brown, emitting a strong turpentine-like odour and exuding a heavy, sticky oleoresin, very odorous, colourless at first but solidifying to a sulphur-yellow resin-could be whitish, (Keay et. al., 1964) which is not unpleasant to taste; it gives an incense odour in burning and is sometimes so used, as well as being a local illuminant. This wax-like resin melts easily and is used to repair pottery, and by hunters as flares ("bush-candle"). It is ground up with oil or shea butter, etc to impact fragrance for anointing the body, and used also to fumigate apartments to drive out mosquitoes. The soot is rubbed into incisions in tattooing similarly to prepared indigo and charcoal. The resin could be of some commercial value if collected and stored in a soft state without allowing it to harden and crack.

Dalziel (1936) notes that Chevalier stated that the gum copal of this species is known in Côte d'Ivoire by its Adiokrou name "aie're". According to Dalziel, Elemi proper was formerly used in medicinal ointments and plasters, and is used at present in industry in varnishes. The African elemi, sometimes imported into Europe is an oleo resin with pleasant aromatic odour resembling true elemi (of canarium luzonicum from the Philippine Islands) in chemical properties and composition, but with a smaller proportion of volatile oil. The resin is sometimes eaten in small amounts as an antidote for gonorrhoea.

Physical Characteristics

Dalziel and Voorhoeve note that the sapwood is whitish and often very thick (up to 10cm wide) with pinkish reflections; the heart is also pink, darkening to light brown mahogany colour. It is comparatively soft, elastic, lighter in weight and colour than a mahogany, but had been sold before as Gabon Mahogany, light Benin or Pink mahogany and white mahogany, the last name being given also to timber of pachylobus klaineanus, a Gabon tree, (Dalziel, 1936). Native uses of the wood include mortars, canoes, planks, general building purposes and fuel.

As the wood is fairly light and not very strong, it has a specific gravity of about 0.5 (Voorhoeve, 1979). The texture is rather coarse, the grain straight or interlocked. Its quarter-sawn timber gives a decorative striped figure and the wood has a satiny lustre. Where it is used as furniture, it has severe dulling effect on tools and so not very suitable for interior work, joinery and construction. The wood is perishable, likely to be *stained and attacked by ambrosia beetles or termites. It* is extremely resistant to impregnation thereby making seasoning quite difficult. In Europe, Voorhoeve notes that it is sometimes used as core veneer which might create a possible market, as canarium is fairly common in Liberia.

Canarium Schweinfurthii is found in the evergreen forests, the *semi-deciduous-and* the gallery forest. Keay et. al. (1964) state that its habitat is secondary forest and sometimes planted. It prefers well-drained slopes. Values of 20 - 30 trees of 60cm diameter or more per square mile (about 2.56sq.km) have been recorded in Liberia (Voorhoeve, 1979).

The tree is deciduous in the first half of the dry season, October to January. The flowering season is from February to May. In Nigeria, the fruits are from February to March and June to August (Keay et.al., 1964).

Although canarium has not been exploited commercially on a large scale, most of it is planted for the fruit to be sold. Infact, in areas it is found and grown, people use it as a source of income. It is sold in markets in areas where the tree is found. The fruit is like an olive or date, 25-38mm long, blue black with a triangular calyx persisting at the base. The slight greenish outer pulp is of oily consistence and edible which is why the fruit is sold and eaten and the hard nut discarded.

The nuts are made into necklace; and are sometimes carved and used for making musical instruments. The nuts are cut and stringed round a calabash gourd (called "shaka" or "chaka") which produces a "Chack" sound. There are 160 - 270 seeds per pound and this is about 360 - 600 per kilogramme. The seed remains viable for over two years (Voorhoeve, 1979).

2.2.0 LIGHTWEIGHT CONCRETE - Its Historical Development

The discovery or advent of cement has brought about a "permanent" solution to efforts in achieving durable forms of building construction; it has virtually replaced almost every form of binder in solid and rigid construction. That cement has great advantages is indisputable; it can be mixed with diverse materials to produce different forms of concrete - dense (heavyweight/conventional) concrete, lightweight concrete, insulating concrete, etc, depending on the intended use to which the concrete will be put or the materials used to obtain the finished product.

Lightweight concrete is used today in practically every application of normal weight concrete where reduction in dead weight leads to significant savings in the cost of the structure.

Lightweight concrete is not just one product but a spectrum of concretes that yield a variety of results and a number of needs. It can be a gaseous or foamed concrete that uses specially prepared chemicals; it can be of no-fines concrete that uses ordinary gravel or crushed stone, a normal weight aggregate concrete with an excessive amount of entrained air, or a concrete that is made from lightweight aggregates. Lightweight concrete is taken to mean " a concrete with a dry density of between 300 and 1850kg/cu.m" (Neville, 1981).

Notwithstanding the fact that it is only in recent years that lightweight concrete has become familiar, it is definitely not a new class of building materials. The Romans employed a lot of lightweight concrete and it is known that the 43.59m diameter dome of the Pantheon in Rome, built in the 2nd century A.D. is largely composed of in-situ concrete employing pumice aggregate.

In Nigeria, the work into the suitability of certain materials for the production of lightweight concrete is relatively new; Nuhu-Koko (1988) on "the use of palm kernel shells as aggregate for concrete" and Bukata (1989) on the "the use of periwinkle shells as lightweight aggregate for concrete construction" are M.Sc. theses in the Department of Building, Ahmadu Bello University, Zaria, Nigeria that came out with favourable results. However, not much attention may be given to the use of lightweight concrete in Nigeria for many years to come for the simple fact that rocks abound to supply coarse aggregate "forever", and also if the present trend of lack of governmental interest persists. While most countries have industrial wastes to be used for lightweight aggregate, the situation is not the same in Nigeria.

The development of new types of lightweight concretes and the increasing use made of such materials is reflected in and was itself encouraged and helped by the work of research workers in many research institutions throughout the world. Initial research works on the possible use of lightweight aggregate to produce lightweight concrete were extended to the study of structural use of lightweight concrete.

2.2.1 Need for Lightweight Concrete

The most obvious characteristic of lightweight concrete is the weight which is often only a fraction of that of ordinary concrete. Reduction in density leads to reduction of deadloads which may lead to reduced sizes in many sections and therefore, may require less concrete and reinforcing steel. Lightweight concrete may cost more per cubic metre, but the structure may cost less as a result of reduced dead weight. Overall reduction in building weight generally reduces foundation costs. The lower density (reduced density) enhances faster building rates, lower haulage and handling cost, complex designs being made possible and also taller buildings.

A less obvious but nonetheless important characteristic of lightweight concrete is the relatively low thermal conductivity which it possesses - a property that is known to improve with decreasing density. Infact, it is known that thermal insulation varies inversely with the unit weight (density) of concrete (Neville, 1981). In view of the foregoing therefore, the use of lightweight concrete would be most appropriate for our climatic conditions. The point would have been made if it is realised that a 150mm solid wall of aerated concrete will give an insulation about 4 times that of a 225mm blockwall.

In framed structures, the frame has to carry the load of floors and walls and considerable savings in cost can be brought about by using lightweight concrete for floors, partitions and external cladding.

Experimental and practical experience in the industry has shown that faster building rates can be achieved with lightweight concrete than with the more traditional materials, and for this reason many builders today are prepared to pay considerably more for lightweight concrete unit than for bricks for the same wall area. With most building materials such as clay bricks, the haulage load is limited not by volume but by weight. With suitably designed containers, much larger volume of lightweight concrete can be hauled economically.

Quite apart from their technical advantage in building, some lightweight concrete have the additional merit of providing an outlet for industrial and/or agricultural wastes, e.g. clinker, pulverised fuel ash, blast furnace slag, rice husk, palm kernel shells, periwinkle, etc. Apart from agriculture, building is the largest single industry and the only one able to absorb industrial wastes which are produced in millions of tonnes annually. While it is true that the conventional materials can last "forever", it is equally true that in many areas, the traditional concrete materials, sand and gravel, are becoming very scarce. Lightweight concretes, even if it had no other merit, would eke out the supplies of concreting materials in these areas. In Nigeria here, where the traditional materials are not scarce, the machineries for their production are imported which are very expensive-moreso with the low exchange rate of the Naira.

Apart from the initial cost, sales tax, transporting to unloading point and handling charges, life (operating hours) span, depreciation, repairs and renovation, fuel and power, lubrication, taxes, storage, installation charges will all be shouldered by the consumer of the product - there is need to explore other avenues that need little or no treatment or where inexpensive treatment of materials will be involved to reduce the cost.

For many purposes the advantages of lightweight concretes outweigh its disadvantages and there is a continuing worldwide trend toward using more lightweight concretes and also toward using it in new applications including prestressed concrete, high-rise buildings and even shell roofs.

2.3.0 CLASSIFICATION OF LIGHTWEIGHT CONCRETES

Neville (1981) gives three broad methods of producing lightweight concrete as follows: In the first, porous lightweight aggregate of low apparent specific gravity is used instead of ordinary aggregate whose specific gravity is approximately 2.6. The resultant concrete is generally known by the name of lightweight aggregate used.

In the second method, introduction of large voids within the concrete or mortar mass is adopted to produce the lightweight concrete. These voids should be clearly distinguished from the extremely fine voids produced by air entraining. This type of concrete is variously known as aerated, cellular, foamed, gas concrete or porous concrete.

The third means of obtaining lightweight concrete is by the "no-fines" method, which is based on eliminating the fine aggregate in the mix and introducing large interstitial voids and mostly coarse aggregate of ordinary concrete is used generally. This concrete is described by the term "no-fines" concrete.

The afore-mentioned methods are but one means of making concrete light - this involves including air into its composition. Although there are three distinct types - no fines, lightweight aggregate and aerated - concretes are made which are combinations of these e.g. no-fines concrete employing the use of lightweight aggregates, and aerated concrete containing cellular aggregate.

A further classification of lightweight concrete is based upon the purpose for which it is to be used: distinguishing between structural lightweight concrete and concrete used in non-load bearing walls, for insulation purposes, and the like. In the past, structural lightweight concrete tended to be a close-textured concrete made with lightweight aggregate but, since this is not always the case now, it is preferable to base the classification of structural lightweight concrete on a minimum compressive strength.

According to ASTM standard 0.330-77, structural lightweight concrete should have a compressive strength, measured on a standard cylinder at 28 days of not less than 17 N/sq.mm . The density of such concrete, determined in the dry state should not exceed 1850 kN/cu.m and is usually between 1400 and 1800 kg/cu.m. Insulating concrete generally has a density lower than

800 kg/cu.m and a strength between 0.7 and 7N/sq.mm. The essential feature of insulating concrete is its co effecient of thermal conductivity which should be below about $0.3J/m^2 S\,^0C/M$. (Neville, 1981).

Because of the generally lower modulus of elasticity of lightweight concrete allowance must be made for creep in lightweight concrete even though the creep, taken on the basis of the stress/strength ratio is of the same order as for ordinary concrete speculations have it that long term creep for lightweight concrete is somewhat higher than for ordinary concrete- this has not been proved though. Poisson's ratio appears to be similar to that for ordinary concrete. "In general, the modulus of elasticity is about 1/2 to 3/4 of that of ordinary concrete of the same strength. The modulus varies with density according to to the expression: $Ec = 1.7e^{2}$ feu 0.33×10^{-6} for concrete of density (e) between 1400 and 2300 kg/cu.m (Neville, 1981).

The rate of strength gain of lightweight concrete is similar to that of ordinary concrete under the same curing conditions but is generally less sensitive to absence of moist curing.

It is important to note that the strength of lightweight concrete used for non-structural purposes is not of primary importance: the main requirements are thermal insulation, a good surface for rendering, and not too high a shrinkage, nail-holding properties, and in the case of precast blocks, ease of cutting.

2.4.0 MIX DESIGN

The required properties of hardened concrete are specified by the designer of the structure and the properties of fresh concrete are governed by the type of construction and by the techniques of placing and transportation. These two sets of requirement enable the engineer to determine the composition of the mix, bearing in mind the degree of control exercised on the site. Mix design according to Neville (1981), can be defined as 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 notably consistence, strength and durability.

2.4.1 BASIC CONSIDERATION

Essentially, in the introduction, two main points were stressed: the concrete is to have certain specified minimum properties, and that it is to be produced as economically as possible.

In concreting, cost is incurred from materials, plant and labour; the variation in the cost of materials arises from the *fact* that *cement is more expensive* than aggregate, so that it becomes quite the natural thing to do by aiming at as lean a mix as possible. Neville (1981) states that the use of comparatively lean mixes confers also considerable technical advantages not only in the case of mass concrete where the evolution of excessive heat of hydration may cause cracking, but also in *structural concrete where a rich mix may* lead to *high* shrinkage and cracking. It is therefore clear that making a mistake on the side of rich mixes is not desirable, even when cost is not the issue at stake.

In the past, the prescription of the proportions of the materials was the normal thing in specification. Despite the use of certain traditional mixes, variability of the mix ingredients, concrete having fixed cement - aggregate proportions and a given workability, no exact strength was achieved. while good materials made the specification unduly restrictive, adequate strength could not be achieved using the prescribed mix proportions elsewhere. A solution was sought by introducing clauses in the grading of aggregate and the shape of particles but this proved hopeless as the distribution of natural aggregates in many countries made these restrictions often uneconomic. Adherence to the above requirements of strength, mix proportions, and aggregate grading and shape does not leave room for economics in the mix design and makes progress in the production of cheap and satisfactory mixes on the basis of a study of the properties of concrete impossible.

Nowadays, the tendency is to be less restrictive in making specifications. Specifications lay down limiting values but often give as a guide the traditional mix proportions for the benefit of the contractor who does not wish to use a high degree of control. The limiting values may cover a range of properties; according to Neville (1981), the more usual ones are:

a) "Minimum" compressive strength necessary from structural considerations;

b) Maximum water - cement ratio and/or maximum cement content, and in certain conditions of exposure, a minimum content of entrained air to give adequate workability;

c) Maximum cement content to avoid cracking due to temperature cycle in mass concrete;

d) Maximum cement content to avoid shrinkage under conditions of exposure to a very low humidity; and

e) Minimum density for gravity dams and similar structures.

These various requirements must then be satisfied in the mix design calculations. Infact the CP 110: 1972 has moved further than its predecessors toward this approach of using design mixes where various minimum strengths of concrete are specified for various uses, i.e. 7N/sq.mm for plain concrete; 15N/sq.mm for reinforced concrete with normal aggregate; 30N/sq.mm for post-tensioned concrete; and 40N/sq.mm for pre-tensioned concretes.

In the strict sense of it, a design is impossible since the materials used are essentially variable and many of their properties cannot be assessed quantitatively, so that what is done is no more than an intelligent guess at the optimum combinations of the ingredients on the basis of the relationships of the various properties. To obtain a satisfactory mix, trial mixes are necessary to go along with the estimation of the properties of the available materials. Adjustments in the mix proportions are made as more trial mixes are made to arrive at a fully satisfactory mix.

It is worthy of note here that the laboratory exercise does not provide the final answer even when the moisture condition of aggregate is taken into account. Only a mix made and used on the site can guarantee that all properties of the concrete are satisfactory in every detail for the particular job at hand. Two points necessitate the statement above: Firstly, the mixer used in the laboratory is generally different in type and performance from that used on the site.

Secondly, the wall effect (arising from the surface to volume ratio) in laboratory test specifications is larger than in the full size structure, so that the sand content of the mix as determined in the laboratory may be unnecessarily high.

Other factors such as the effects of handling and transporting, delay in placing, and weather conditions may also influence the properties of concrete on the site; but these are secondary and necessitate minor adjustments in the mix proportions during the progress of work.

2.4.2 FACTORS IN THE CHOICE OF MIX PROPORTIONS

The objective in designing a concrete mix is to determine the proportions of cement, fine and coarse aggregates and water which will satisfy the following requirements:

Compressive Strength

a. Mean Strength: This is one of the most important properties of concrete both per se and in so far as it influences many other desirable properties of the hardened concrete. Basically, the mean compressive strength required at a specified age, usually 28 days, determines the nominal water-cement ratio.

b. Minimum Strength: Structural design is based on the assumption of a certain minimum strength of concrete, but the actual strength of concrete produced, whether on the site or in the laboratory is a variable quantity. The design aims at a mean strength higher than the minimum strength.

Quality Control

Neville (1981) notes that the lower the difference between the minimum strength and the mean strength of the mix the lower the cement content that need be used. The factor controlling this difference for concrete of a given level of strength is the quality control. By this, it it meant the control of variation in the properties of the mix ingredients and also control of accuracy of all those operations which will affect the strength or consistence of concrete batching, mixing, placing, curing and testing.

Cements from different sources bring about variations just as grading of aggregates. Variations in strength of concrete arise also from inadequate mixing, insufficient compaction, irregular curing, and variations in testing procedures. These factors need to be controlled.

Quality Control is sometimes taken to be synonymous with production of high-strength concrete. This is certainly not so as low strength concrete can be manufactured under good control and this is indeed practised in the case of mass concrete construction where obtaining large quantities of lean concrete of low variability results in large economics. The degree of control is evaluated by the variation in the test results by various statistical techniques.

Finally, it must be remembered that control includes supervision, and its absence, coupled with inferior workmanship, can nullify all the efforts of mix design and specification- quotes Glanville thus, "the difference between good and bad workmanship and supervision may well be represented by the difference between almost indefinite life (of concrete) and a life of only a few years."

Durability

Concrete of reasonable strength, if properly placed, is durable under ordinary conditions but when high strength is not necessary and the conditions of exposure are such that high durability is vital, it is the durability requirement that will determine the water-cement ratio to be used. It is worthwhile noting that strength, type of cement, and durability determine between them the water-cement ratio required-one of the essential quantities in calculation of mix proportions.

Workability

Strength of concrete depends on the quality and quantity of water used. The water content of a mix should never be higher than required to make the concrete sufficiently workable in place. A low water-cement ratio in a concrete mix makes the concrete stiff and might be very difficult to consolidate.

The term 'workability' is difficult to define precisely: it is used to describe the ease with which concrete mixes can be compacted and the highest workability must be aimed at getting the concrete as completely compacted as possible while using the lowest possible water-cement ratio.

From the foregoing, it is possible to say that workability means testing of the quantity of water. Workability of concrete is affected by the water-cement ratio, the aggregate-cement ratio; the size and type of aggregate and the grading of the aggregate.

The workability that is considered desirable is dependent on two factors: The first of these is the size of the section to be concreted and the amount and spacing of reinforcement; the second is the method of compaction to be used.

Finish

A property closely related to workability is cohesiveness, and this depends largely on the proportion of fine particles in the mix.

2.5.0 PROPERTIES OF LIGHTWEIGHT CONCRETE

In general, it can be said that the behaviour of hardened lightweight concrete can be viewed in a similar way to that of normal concrete, i.e. the same properties and behavioural aspects are considered for both, although quantitatively, there are very significant differences. The properties of concrete are a function of time and ambient humidity, and this is why, in order to be of value, tests on concrete have to be performed under specified or known conditions. The most common of all tests on hardened concrete is the compressive strength test, partly because it is easy to carry out, and partly because most of the desirable characteristics of concrete are qualitatively related to its strength; but mainly because of the intrinsic importance *of the comprehensive strength of concrete in construction.*

2.5.1 Compressive Strength

The compressive strength of lightweight concrete is very much affected by the same factors as it is in normal concrete, although the role of the aggregate is not quite the same because there is greater compatibility, with respect to deformation behaviour, between the aggregate and mortar. This means that despite the rather weak aggregate particles, it is still readily possible to obtain quite high strengths from lightweight aggregate concrete. Paste strength (and hence water-cement ratio) is still an over-riding influence; because of the larger water contents absorbed by the aggregates, there can be major differences between total and free water-cement ratios and complications that arise through use of the former make it desirable, if at all possible, to use the latter, even though it may be rather approximate.

The strength of concrete is affected by many factors but chief among these are: density, water-cement ratio, type, fineness and chemical composition of cement, admixtures, curing conditions, compaction, type of aggregate, testing procedure.

According to Deshpande (1983), the following table gives the extent to which some of these factors can affect strength in concrete:

Table 2.1 : Factors Affecting Strength in Concrete

S/No	Factors Causing Variation	Approximate total variation in Concrete Strength.
1.	Quality of Cement	Up to 50% or more
2.	Grading of aggregate	Up to 20%
3.	Bulking of fine aggregate due to moisture present.	10% allowing for average bulking up to 25% when no allowance is made for bulking.
4.	Batching by weight	8%
	By volume:	
	i) Good	16%
	ii) Normal	Up to 70%
	iii) Bad	100%
5.	Poor Compaction	Up to 50%
6.	Factors connected with making and testing of cubes.	Up to 30%

SOURCE: Indian Concrete Journal, November 1983.

2.5.2 Density

The range of densities which can be obtained with the different forms of lightweight concrete according to the Cement and Concrete Association and as obtained from other sources is from as low as 300 to as high as 1850kg/cu.m. The purpose for which it may be used can be classified very approximately according to its density as from 243 kg/cu.m for heat insulation of pipes to 2430kg/cu.m for prestressed concrete. A breakdown is as follows:

Table 2.2 : Density Range for Different Uses of Concrete.

USE	DENSITY RANGE
Heat insulation of pipes	243 - 405kg/cu.m
Protected insulative screeds	292 - 405 "
Screed carrying traffic	486 - 972 "
Casing of structural steel	648 - 972 "
Partition and Panel walls and non-loadbearing walls	648 - 972 "
For loadbearing walls and rendered exterior walls	810 - 1620 "
For prestressed concrete	1782 - 2430 "

SOURCE: Orchard, 1963.

2.5.3 Tensile Strength

The strength of concrete is difficult to determine because standard tests are necessarily subject to the influence of a large number of variables either unknown or not capable of control. Standard cube and cylinder tests were adopted to determine an index, rather than an absolute measure, of the crushing strength of concrete. Various methods have been tried to obtain at least an index of the tensile strength of concrete but none proved entirely suitable. However, the cylinder splitting test method has become prominent in recent years.

A knowledge of the value of tensile strength is required for the satisfactory design of prestressed concrete structures, liquid retaining structures, roadway and runway slabs. It is of considerable importance in resisting cracks due to changes in moisture content or temperature.

The tensile strength is determined by the formula $f = 2P/ dl$ when the cylinder split test is used where

f = tensile strength in N/sq.mm
P = failing load in N
d = diameter of cylinder in mm
l = length of cylinder in mm

Advantages attributed to this test are that it can be carried out in the normal cube testing machine and the tensile stresses are, theoretically, induced uniformly over about three-quarters the diameter of the specimen. The strength thus obtained is about one-fifteenth of the compressive strength and is affected largely by the same factors as in the bending strength (Lydon, 1972).

The tensile strength of concrete varies from one-eight of the compressive strength at early ages to about one-twentieth later. The tensile and shear strengths of lightweight aggregate concrete are less than that for natural aggregate concrete of the same compressive strength. The reduction in the case of tensile strength may be as *much* as 30 *per* cent, Lydon (1972).

2.5.4 Modulus of Elasticity

For the same compressive strength, the modulus of elasticity of lightweight concrete is in general considerably lower than that of dense, gravel concrete (normal concrete). For concrete of high strength the percentage difference is a bit greater than for weaker mixes, but in general, the E-value (Modulus of Elasticity) of lightweight concrete ranges between one-third and two-third of the E-value of the corresponding gravel concrete mix (*Kinniburgh and Short*, 1963).

A range of 0.5 to 0.75 of the value of the natural aggregate concrete of the same compressive strength is taken. This varies from 7 to 21 kN/sq.mm.

The modulus of elasticity increases with the cube strength and with the density of the concrete. The modulus of elasticity is of special importance for structural lightweight concrete construction because of its effect on the deflections of flexural members, on the distribution of internal forces in the cross-section of compression members and on the critical load in the case of members liable to failure due to elastic instability, where the lower E-value of lightweight concrete has an unfavourable influence. On the other hand, the resistance of lightweight concrete members to impact loads may be enhanced by their lower modulus of elasticity.

2.5.5 Thermal Insulation

One of the striking features of lightweight concretes is the relatively high thermal insulating values which they exhibit: the insulation being more or less inversely proportional to the density of the material.

2.5.6 Fire Protection

Another application of thermal insulation is in the protection of structures against fire damage. Lightweight concretes have in general a good resistance to high temperatures. The effect of fire on a structural element of a building depends on the temperature reached, the duration of the fire and of course on the nature of the unit and its intrinsic resistance to thermal change.

2.5.7 Durability

This is the ability of the material to withstand the effects of its environment. In a building material, this may be interpreted as chemical attack, physical stress and mechanical assault.

Experience has shown that properly proportioned, fully compacted lightweight aggregate concrete exhibits adequate durability and compares quite reasonably with very good quality normal concrete (Lydon, 1972).

2.5.8 Resistance to Abrasion

This falls under durability but is considered separately for the fact that it is a property to be determined in comparison to that of the normal concrete.

In BS Code of Practice, CP/3, Chapter ix: 1950, Durability, Abrasion is defined as "the wear or removal of the surface of a solid material as a result of relative movement of other solid bodies in contact with it". In other words, it is a scraping away process whereby the surfaces of materials are rubbed against one another. The extent to which surfaces are worn away is more important than the fact that rubbing will theoretically cause wearing way. Addleson (1972) gives the following factors as influencing the extent to which surfaces will be worn away as:

1. the period of time during which rubbing takes places;
2. the surface characteristics of the two surfaces in contact;
3. the resistance to rubbing, i.e. friction, provided by

the two surfaces.

The latter is directly related to the surface characteristics of the two materials and the pressure exerted during rubbing.

The significance of abrasion is appreciated more when it is seen that abrasion can be positively put into use and can cause unwanted damage.

In order to determine the severity of conditions likely to lead to damage by abrasion, it is necessary to consider the agencies which cause the abrasion to take place.

Dust, dirt and grit generally account for the most common abrasives encountered in buildings. These are readily available on horizontal surfaces such as floors where as an example, the abrasion may be interspersed between the soles of shoes and the floor finish. The action of walking does in some degree constitute a rubbing action and so, under conditions such as these, abrasion results. Wheeled traffic may be regarded in a similar way. The severity of conditions, in so far as the floor is concerned will depend on:

i. The amount and efficiency of abrasive material available;
ii. The relative properties of the two surfaces rubbing against one another; and
iii. The amount of traffic, whether foot or wheeled.

In terms of the damage which may be occasioned by abrasion in buildings, difficulties have been encountered in making any positive quantitative assessments of the susceptibility of materials to abrasion (Addleson, 1972). The whole question of abrasion is treated primarily on the basis of experience.

2.5.9 Creep

Concrete is not a dimensionally stable material, even where its changes in temperature do not occur. Due to loss of moisture, it is subject to shrinkage; it expands if wetted and it deforms permanently or creeps when subjected to sustained compressive or tensile stresses.

Short and Kinniburgh (1963) bring to light the fact that even though movement of moisture and creep are fundamentally different in nature, they affect each other and are both affected by a variety of circumstances such as the type of exposure to which the concrete is subjected, the mix used, the type of aggregate used, the dimensions of the member and other factors.

2.5.10 Bond Strength

Composite methods of construction, such as reinforced concrete, are dependent for their safety and stiffness on the transmission of the internal forces between the constituent materials in a cross-section. The transfer of the internal forces and the composite character of the construction are maintained either by bond resistance or through anchorage forces.

Short and Kinniburgh (1963) suggest that at least three distinct elements may affect the bond performance of reinforced concrete namely: colloidal adhesion, i.e. glueyness, shrinkage of the concrete around the reinforcement and frictional forces at the interfaces of the steel and concrete. Internal vibration is effective in securing adequate bond between concrete and reinforcing steel over the same radius of action, appropriate to a given period of vibration as for unreinforced concrete (Orchard, 1972).

The maintenance of bond in reinforced concrete structures is possible because steel and concrete expand and contract at very similar rate under changing thermal conditions. Were it not so, recurring thermal stresses would occur which might lead to failure in bond.

Tests for bond include: Pull-out tests, Push-out tests and Beam and Bean-type tests (ASTM No. 169, 1956). Values for permissible bond stress and methods of calculating the stress are given in CP 8110: 1985.

Bending dimensions for reinforcement are given in BS 4466: 1969. In general, hooks and bends are used at the end of bars to reduce the length of straight bar that would otherwise be required for anchorage (Murdock and Brook, 1984).

Other properties that are of importance in lightweight concrete are: water absorption, rain penetration, acoustic properties, cutting, nailing and rendering, shrinkage and moisture movement, the effect of water-cement ratio, the effect of sand admixture.

2.6.0 THE USE OF LIGHTWEIGHT CONCRETE

The principal uses of lightweight concrete either when cast in situ or precast are:

1. For screeds and thickening for general purposes,

especially when such screeds or thickening add weight to floors, or other structural members.

2. For screeds and walls where timber has to be attached by nailing.
3. For casing structural steel to protect it against fire and corrosion and as a covering for architectural purposes.
4. For heat insulation on roofs.
5. For insulating water pipes.
6. For the construction of partitions, walls and panel walls in framed structures.
7. For fixing bricks to receive nails from joinery, principally in domestic or domestic-type construction.
8. For general insulative walls.
9. If surface rendered for external walls of small-houses.
10. For reinforced concrete with greater advantage of higher rises with lower deadload.

2.7 PROCESSING OF TEST DATA - Reality Observed

When it comes to dealing with "situations", i.e. where opinion is required, most people accept a range of view points. In handling numbers or manipulating numerate data, there is generally felt to be one answer, the "true", exact answer. Inspite of the fact that the mere operations carried out on the numbers must always result in only one correct answer, life is much more subtle than that and the really important aspect is the manner in which the numbers are obtained and the precision with which they are endowed. If there is any trace of doubt at all about the numerical values being operated upon, then naturally there must be some doubt about the final resulting number, even though the number is correct in terms of the arithmetic being performed. The magical exactitude of numbers is not matched by reality (Lydon, 1972). This is seen clearly when dealing with data based on measurement, because the act of measuring inevitably introduces a source of error, a degree of uncertainty, into the observed parameter.

2.7.1 Principal Methods of Statistical Control

Methods of control currently employed can be classified in accordance with the object, means and time of control, their influence on production process and its results, etc. They may be visual, physical, mechanical, chemical, geometric and technological with respect to the objects of control (Novgorodsky, 1973).

Methods of control may be manual, mechanical, and automatic. Depending on time of control, a distinction is made between constant and periodic inspection, with respect to the production process operational (step by step) and acceptance inspection. Operational and acceptance inspection, in turn, may be total (when all the products are checked) and random (when only part of the products are chosen).

The above methods allow detection of variations, defects and rejects but can neither foresee nor prevent the occurrence of defective products without the proper statistical data processing.

2.8.0 BASIC STATISTICAL CHARACTERISTICS

Novgorodsky (1973) defines statistical values as "experimental data obtained in testing structures or by statistical observation of the technological process which may have specific probability values, that is, values that change as a result of chance magnitudes".

If the statistical data apply to the entire phenomenon or process under study, they represent a universe. A sampling study of a process of experimental data selected by chance according to a definite method for the study of specific properties if an original population is known as a sampling population. In order to be able to objectively estimate the universe from the results of a sampling population, the latter should reproduce a proportion of the universe or approach it.

The probability of a process, or even a phenomenon under study is the relation of the number of cases in which these events are repeated to the number of all possible cases. Probability is estimated by a positive number not exceeding unity.

The arithmetic mean and standard deviation are used in processing the results of observations and analysing the accuracy of processes to be investigated and the quality of products.

The arithmetic mean is the equation obtained by dividing the sum of measured values by the number of observations as in the formula:

$$X = \frac{x + x + \ldots\ldots + x}{n}$$

$$= \frac{\overset{n}{x}_{i}}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

where x , x ....x = values of separate measurements.
n = number of observations.

The sum of deviations of the measured quantities from the arithmetic mean in a symmetrical distribution is always equal to zero because the quality characteristics deviate from the mean on both sides, hence one part will be positive and the other negative and in algebraic addition their sum will be zero.

The arithmetic mean as a statistical characteristic is chiefly employed for uniform populations and the greater the number of observations, the closer will it be to the actual value. However, a mass phenomenon can not be evaluated by the arithmetic mean value.

In order to evaluate the uniformity of a mass phenomenon and the degree of dispersion of numerical values of measured quantities from the arithmetic mean, use is made of the root-mean-square deviation. The standard deviation is the most widely used characteristic of dispersion or uniformity of a measured parameter with a large number of observations. This deviation is equal to 10 the square root of the arithmetic mean of the squares of the deviations or the square root of the variance magnitude.

Variance, on the other hand, is the relation of the sum of the square of deviations of all measurements from their mean value to the total number of measurements.

The standard deviation according to Novgorodsky (1973) in a large sampling (n>25) is given in the formula:

$$S = \sqrt{(x - \tilde{x})^2 + (x - \tilde{x})^2 + \ldots + (x - \tilde{x})^2} \quad \ldots\ldots\ldots.2.2$$

$$= \sqrt{(x - \tilde{x})^2 / n}$$

while that in a small sampling (n<25) is

$$S = \sqrt{(x - \tilde{x})^2 / n-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.2.3$$

The formula shows that the measure of dispersion in estimating the uniformity of a mass phenomenon will not be the mean deviation; the positive and negative deviations when squared will yield positive values which are in direct proportion to the degree of dispersion of quality characteristics.

In effect, both variance and the standard deviation are measures of dispersion and characterise the degree of spread of particular values of quality characteristic relative to the mean value.

2.9.0 GRAPHIC METHOD OF PROCESSING EXPERIMENTAL DATA

Test data can be presented in tables, charts and also with the help of mathematical equations. The tabular method is the simplest and most widely used method of presenting the test data, and it fully reproduces the results obtained. However, the tabular method is not as descriptive as the graphic.

In the graphic method, it is possible to obtain a clear picture of any change of variables and determine the character of the change and by means of this method to find intermediate value of variables without too many computations. Graphic methods of processing experimental data also help to derive an empirical formula when the processes under study are not subordinate to the known theoretical laws. In this case, formulae and constants are established by test data.

CHAPTER THREE

3.0 Laboratory Procedure and Mix Design

This chapter sets down the work done in the laboratory to ensure that test results so obtained are reliable. Where there was the need for a control, that was ensured. The physical properties of the "Atile" aggregate were determined before the mix design was carried out because the mix design is dependent on the physical properties of the "Atile" aggregate. Standard methods of determining these properties were used as given by Orchard (1962), Neville (1981), and Murdock and Brook (1984).

3.1.0 Physical Properties of the "Atile" Aggregate

The main physical properties that were determined are: Specific Gravity, Absorption Rate, Bulk Density, Moisture Content, Voids Ratio, Porosity, Sieve Analysis and Fineness Modulus.

3.1.1. Specific Gravity

The following values were obtained:

Weight of bottle = 607.7g

Weight of bottle filled with water B = 1610.0g

Weight of aggregate D = 250.0g

Weight of bottle plus aggregate C = 857.5g

Weight of bottle plus aggregate plus water A = 1656.0g

Apparent Specific Gravity = D/[D-(A-B)]

= 250/[250-(1656-1610)]

= 1.23

In the Gross Apparent Specific Gravity, the weight of sample of saturated and surface dry aggregate, C was used.

Weight of sample of saturated and surface dry aggregate, C = 271.0g

= 271/[271 - (1656 - 1610)]

= 1.2

3.1.2. Absorption Rate

The dry specimen was left in the pycnometer for twenty-four hours after which it was surface-dried under the fan but still left saturated. The weight of the sample of the saturated and surface dry aggregate = 271.0g.

.'. Absorption Rate = 8.4%.

3.1.3 Bulk Density

(a) Loose Bulk Density:

Weight of container of known volume = 17.2kg.

Weight of container of known volume filled with aggregate = 19.55kg.

Weight of aggregate in container = (17.55-17.2)kg

= 2.35kg.

Weight of aggregate in second test = 2.35kg.

Average weight of aggregate in container = 2.35kg.

Volume of container = $(0.15 \times 0.15 \times 0.15)m^3 = 3.375 \times 10^{-3}m^3$.

.'. Loose Bulk Density = $2.35kg/3.375 \times 10^{-3}m^3 = 696.00kg/m^3$.

(b) Compacted Bulk Density:

Three tests were carried out with the following results:

Weight of container of known volume filled with compacted aggregate:

i) = 19.70kg; ii) = 19.70kg; iii) 19.70kg.

Average = 19.70kg.

.'. Compacted Bulk Density = (19.70 - 17.2)kg/3.375 x $10^{-3}m^3$.

= 741kg/m^3.

The bulk Density ranges from 696 to 741kg/m^3, and a value of 736kg/m^3 will be used in the calculations.

3.1.4 Moisture Content

A sample was dried and the final dry weight was noted.

Weight of sample before drying = 250g.

Weight of sample after drying = 181g.

Weight of moisture = 69g.

.'. Moisture Content = (250 - 181) x 100/250 = 27.6%

3.1.5 Voids Ratio

This is the total porosity expressed as the ratio of void volume to the solid volume.

.'. Weight of aggregate replaced by voids in lb/ft^3

= 62.4 x 5.6 - B, where B = Bulk Density of aggregate.

But 35.32ft^3 = 1m^3 .'. Weight of aggregate replaced by voids in m^3 = 1.22 x 62.4 x 35.32 - B

.'. Percentage of voids

= [(1.23 x 62.4 x 35.32) - B] x 100/ 1.22 x 62.4 x 35.32 = 72.6%.

3.1.6 Porosity

This is the total porosity expressed as the ratio of void volume to bulk volume.

Porosity, n_p = Void ratio x 100/(1 + voids ratio)

= 0.726 x 100/(1 + 0.726) = 0.726 x 100/1.726 = 42%.

3.1.7 **Sieve Analysis of the "Atile" Aggregate**

Weight of test sample = 10.0kg.

Sieve No. (mm)	Weight Retained (kg)	Weight Passing (kg)	Percentage Passing
20.00	-	10.00	100.00
13.20	8.75	1.25	12.50
9.20	1.15	0.10	5.00
4.75	0.10	0.00	-

This shows that the aggregate is not well-graded, thus confirming further that the high value of percentage voids obtained earlier was an indication that the aggregate is not well-graded.

3.1.8 **Fineness Modulus of "Atile" Aggregate**

This is calculated by adding the percentage by weight retained on a series of sieves and dividing by 100.

Sieve No (mm)	Weight Retained (kg)	Percentage Retained by Weight.
20.00	-	-
13.20	8.75	87.50
9.50	1.15	99.00
4.75	0.10	100.00
2.36	-	100.00
1.18	-	100.00
600um	-	100.00
300um	-	100.00
150um	-	100.00
Total		786.50

.'. Fineness Modulus of "Atile" Aggregate = 7.87

3.2.0 MIX DESIGN

The various materials used in the production of the "Atile" concrete and their quantities and ratios and precautionary measures taken or controls are discussed here.

3.2.1 Materials

Cement

The cement used was the Ordinary Portland Cement (OPC) manufactured by the Ashaka Cement Company in Bauchi. It happens to be the cement used in the Department of Building, Ahmadu Bello University, Zaria and incidentally the most available locally in Zaria - but by no means the cheapest!

Sand

Dredged sand as supplied to the Department of Building, A.B.U., Zaria was used. It had to be sieved and graded because of the high content of 600 and 150µm sizes.

"Atile" Aggregate

This was transported to Zaria, as it is not available in Zaria, from the Southern part of Kaduna State and also Plateau State. These are the areas the material aggregate is found.

3.2.2 Mixes

Three mixes were designed and for each mix, thirty cubes and twelve cylinders were moulded. Ten cubes were used for each age of crushing and the cylinders for the split, bond and Modulus of Elasticity tests.

For the mix 1:1:2, a water-cement ratio of 0.4 was adopted; the mix 1:1.5:3 had a water-cement ratio of 0.45 and 0.55 for the mix 1:2:4. These water-cement ratios were adopted from the trial mixes undertaken.

For the test of resistance to abrasion, a mix of 1:2:4 for normal aggregate was used and 1:1:2 for the "Atile" aggregate.

A typical calculation of quantities of materials for the mix 1:1:2 is given below:

Cement has a bulk density = 1440kg/m^3 and specific gravity of 3.15.
For sand, density = 1600kg/m^3 and specific gravity = 2.65.
For "Atile", density = 736kg/m^3 and specific gravity of 1.22.
Absolute volume for cement = 1440 x 1000/3.15 = 457.14 litres.
Absolute volume for sand = 1600 x 1000/2.65 = 603.77 litres.
Absolute volume for "Atile" = 736 x 1000/1.22 = 1206.56 litres.
Absolute volume for water = 1440 x 1000 x 0.4 = 576.00 litres.
Total = 2,843.47 litres.
= 2.84m^3.

Quantities of materials to 1m^3 of concrete:
Cement = (1440kg/m^3)/2.84^{8} = 506kg.
Sand = (1600kg/m^3 x 1)/2.84m^3 = 562.69kg.

"Atile" = (736kg/m^3 x 2)/2.84m^3 = 517.68kg.

Actual quantities of materials: This had to be calculated since the moulds available were twelve and do not make up to 1m^3.
12 moulds = 12 x 3.375 x $10^{-3}m^3$ = 4.05 x $10^{-2}m^3$
Add 10% waste = 4.46 x $10^{-2}m^3$.

∴ Materials for the twelve cubes are calculated as below:

Cement = $506kg/m^3 \times 4.46 \times 10^{-2}m^3$ = 22.54kg.

Sand = $526.69kg/m^3 \times 4.46 \times 10^{-2}m^3$ = 25.07kg.

"Atile"= $517.68kg/m^3 \times 4.46 \times 10^{-2}m^3$ = 23.06kg.

Water = $202.57kg/m^3 \times 4.46 \times 10^{-2}m^3$ = 9.03kg.

For the cylinders, there were twelve available and the calculation for materials was based on the twelve cylinders with 10% waste provision made.

3.3.0 PROPERTIES OF "ATILE" CONCRETE

In producing the "Atile" concrete, certain properties of it were investigated. These properties are those that are common to all concretes especially in their fresh state. These properties tested are: Workability, slump, compacting factor, and compacting range.

The workability of concrete is affected by the water-cement ratio; the aggregate-cement ratio; the size and type of aggregate and the grading of the aggregate. The best practical test on the field for determining the workability of concrete is the slump test.

The following procedure was adopted in the Slump Tests:

(i) For each mix, a representative sample of concrete was taken and within the shortest possible time (2 minutes or thereabout), the mould was filled in 4 equal layers.

(ii) Each layer was tamped 25 times with a steel rod of 610mm length and 16mm diameter.

(iii) The next thing was to strike off top level and clean off any leakage around the base of the mould.

(iv) The mould was raised carefully in a vertical direction.

(v) The mould was placed next to the slump and the slump was measured. For all the slumps, no shear or collapse slump occurred.

(vi) The results were recorded while the moulds were cleaned and dried.

In effect, work is done to compact concrete into a given mould and this is what the expression of workability represents.

For the mix 1:1:2 the slump was a true slump of 4mm.

For the mix 1:1.5:3 the slump was a true slump of 6mm.

For the mix 1:2:4 the slump was a true slump of 26mm.

As it is well-known, the slump test has limitations despite its being useful as a means of controlling concrete on the site and for detecting differences in the water content of successive intended identical mixes. The apparatus is cheap, portable and robust and therefore suitable for site use. It is difficult to see how the value of the slump is connected with the workability as just defined and the value of the slump obtained can be irregular and often does not agree with observed workability. A large variation in slump can be obtained with the same concrete and with many forms of slump or subsidence, making it difficult to decide which point should be measured.

3.3.2 Compacting Factor

This was developed by the Road Research Laboratory and is quite widely used especially for laboratory purposes. The test is designed to apply a given amount of work to a given amount of concrete and to reduce to a minimum the work lost in overcoming the friction between the concrete and the containing surfaces. A large proportion of the work is therefore expended usefully in overcoming the internal friction of the concrete and the test is therefore a good measure of the workability as previously defined. It gives a more sensitive and consistent result than the slump test and its chief sphere of use is with very dry mixes which give no slump and cannot therefore be compared by that method.

The compacting factor is a ratio. It is the ration of partially compacted concrete to fully compacted concrete. For mix 1:1:2, the compacting factor was derived thus:

Weight of empty container, A = 6.0kg.

Weight of container with uncompacted concrete, B = 12.3kg.

Weight of container plus fully compacted concrete, C = 14.8kg.

∴ Compacting Factor = (12.3 - 6.0)kg/(14.6 - 6.0)kg = 0.72.

For the mix 1:1.5:3:

A = 6.0kg; B = 13.0kg; C = 14.9kg

∴ Compacting Factor = (13.0 - 6.0)kg/(14.9 - 6.0)kg = 0.79.

For mix 1:2:4:

A = 6.0kg; B = 13.4kg; C = 14.8kg.

∴ Compacting Factor = (13.4 - 6.0)kg/(14.8 - 6.0)kg = 0.84.

CHAPTER FOUR

4.0 Tests, Results and Analysis of Results

This chapter presents the test results, analysis and interpretation of results as set out to be determined. The analysis is based on that given by Novgorodsky (1973) for samples less than 25 in number. The work covers the six major properties set out to be determined - these are compressive strength; resistance to abrasion of concrete produced using "Atile" seeds as compared with concrete of normal aggregate; cost comparison of units of "Atile" and normal concrete, Modulus of Elasticity; bond and split tensile.

4.1.0 Compressive Strength

Three mixes were adopted vis: 1:1:2; 1:1.5:3 and 1:2:4. The 150mm cubes were demoulded after twenty-four hours of casting and cured in a tank pending the crushing age. The crushing ages adopted were 7, 14, and 28 days for all the mixes.

Table 4.1: Results for 1:1:2 at Seven Days

S/No.	Weight (kg)	Density (kg/m^3)	Strength (N/mm^2)
1.	6.3	1867	8.5
2.	6.3	1867	9.8
3.	6.2	1837	8.5
4.	6.3	1867	9.8
5.	6.2	1837	8.5
6.	6.3	1867	8.4
7.	6.3	1867	9.7
8.	6.2	1837	8.4
9.	6.3	1867	9.8
10.	6.2	1837	9.7

$\tilde{x} = 9.11 N/mm^2$

Table 4.2: <u>Analysis of Results for 1:1:2 at 7 Days of Age</u>

Measurement No.	x_i	$(x_i - \tilde{x})$	$(x_i - \tilde{x})^2$
1.	8.5	-0.61	0.3721
2.	9.8	+0.69	0.4761
3.	8.5	-0.61	0.3721
4.	9.8	+0.69	0.4761
5.	8.5	-0.61	0.3721
6.	8.4	-0.71	0.5041
7.	9.7	+0.59	0.3481
8.	8.4	-0.71	0.5041
9.	9.8	+0.69	0.4761
10.	9.7	+0.59	0.3481

$$\Sigma(x_i - \tilde{x}) = 0; \quad \Sigma(x_i - \tilde{x})^2 = 4.249$$

The Standard error is determined by the formula:

$$S_{\tilde{x}} = \pm \sqrt{\Sigma_1^n (x_i - \tilde{x})^2 / n(n-1)}$$

$$= \pm \sqrt{4.249/90} = \pm\ 0.22$$

The accuracy of the measurements, ϵ with reliability, $\alpha = 0.99$ (Table 4.3) is

$$= t_\alpha\ S_{\tilde{x}} = 3.25 \times 0.22$$

$= \pm\ 0.72 N/mm^2$ which is 7.85% of the arithmetic mean of the compressive strength. It can be inferred on the basis of the data obtained that with a probability of 0.99, the unknown value of the compressive strength is within the limits

$$\tilde{x} - \epsilon = 9.11 - 0.72 = 8.39 N/mm^2.$$

$$\tilde{x} + \epsilon = 9.11 + 0.72 = 9.83 N/mm^2.$$

Table 4.3 <u>Different Reliability Values</u>

n - 1	VALUE WITH RELIABILITY, ƒ			
	0.95	0.98	0.99	0.999
1.	12.706	31.821	63.657	636.619
2.	4.303	6.965	9.925	31.598
3.	3.182	4.541	5.841	12.941
4.	2.776	3.747	4.604	8.610
5.	2.571	3.365	4.032	6.859
6.	2.447	3.143	3.707	5.959
7.	2.365	2.998	3.499	5.405
8.	2.306	2.896	3.355	5.041
9.	2.262	2.821	3.250	4.781
10.	2.228	2.764	3.169	4.587
11.	2.201	2.718	3.106	4.487
12.	2.179	2.681	3.055	4.318
13.	2.160	2.650	3.012	4.221

Source: Novgorodsky (1973).

The unknown value of the compressive strength at age 7 days for the mix 1:1:2 is accepted as $\tilde{x} = 9.11\text{N/mm}^2$. This also shows that the number of tests conducted is sufficient to obtain the arithmetic mean and the results lie within the limits of permissible deviations.

The characteristic strength is calculated using the formula:

$X_0 = \tilde{x} - KS$ where X_0 is the characteristic strength;

$\tilde{x}$ is the accepted analysed mean strength;

K is the probability factor = 1.64; and

S is the Standard Deviation.

$\therefore$ the characteristic strength, $X_0 = (9.11 - 1.64 \times 0.69)\text{N/mm}^2$

$= 7.98\text{N/mm}^2$.

4.1.2 **Results for 1:1:2 at 14 days (see Appendix A for other results).**

$\tilde{x} = 14.5N/mm^2$; $(x_i - \tilde{x})^2 = 3.5213$.

Standard Deviation, $S = \pm \sqrt{3.5213 \div 9} = \pm 0.62$.

Standard Error, $S_{\tilde{x}} = \pm \sqrt{3.5213 \div 10 \times 9} = \pm 0.126$.

The accuracy of the measurements, $\acute{\epsilon}$ with reliability ʃ = 0.99 is = $t\acute{\alpha}S_{\tilde{x}} = 3.25 \times 0.196 = \pm 0.64N/mm^2$ which is 4.42% of the arithmetic mean of the compressive strength. It can be inferred on the basis of the data obtained that with a probability of 0.99, the unknown value of the compressive strength is within the limits

$\tilde{x} - \epsilon = 14.54 - 0.64 = 13.85N/mm^2$

$\tilde{x} + \epsilon = 14.54 + 0.64 = 15.24N/mm^2$.

The unknown value of the compressive strength at age 14 days for the mix 1:1:2 is accepted as $\tilde{x} = 14.54N/mm^2$. This also shows that the number of tests conducted is sufficient to obtain the arithmetic mean and the results lie within the limits of permissible deviations.

$\therefore$ the characteristic strength, $X_0 = (14.54 - 1.64 \times 0.62)N/mm^2$
$= 13.48N/mm^2$.

4.1.3 Results for 1:1:2 at 28 Days

$\tilde{x} = 20.08N/mm^2$; $(x_i - \tilde{x})^2 = 10.8994$.

Standard Deviation, $S = \pm \sqrt{10.8994 \div 9} = \pm 1.101$.

Standard Error, $S_{\tilde{x}} = \pm \sqrt{10.8994 \div 10 \times 9} = \pm 0.35$.

The accuracy of the measurements, $\acute{\epsilon}$ with reliability ʃ = 0.99 is = $t\acute{\alpha}S_{\tilde{x}} = 3.25 \times 0.35 = \pm 1.14N/mm^2$ which is 5.68% of the arithmetic mean of the compressive strength. It can be inferred on the basis of the data obtained that with a probability of 0.99, the unknown value of the compressive strength is within the limits

$\tilde{x} - \epsilon = 20.08 - 1.14 = 18.94\text{N/mm}^2$

$\tilde{x} + \epsilon = 20.08 + 1.14 = 21.22\text{N/mm}^2$.

The unknown value of the compressive strength at age 28 days for the mix 1:1:2 is accepted as $\tilde{x} = 20.08\text{N/mm}^2$. This also shows that the number of tests conducted is sufficient to obtain the arithmetic mean and the results lie within the limits of permissible deviations.

∴ the characteristic strength, $X_0 = (20.08 - 1.64 \times 1.101)\text{N/mm}^2$

$= 18.27\text{N/mm}^2$.

4.1.4 <u>Results for 1:1.5:3 at 7 Days</u>

$\tilde{x} = 9.19\text{N/mm}^2$; $(x_i - \tilde{x})^2 = 4.9106$.

Standard Deviation, $S = \pm \sqrt{(4.9106 \div 9)} = \pm 0.739$.

Standard Error, $S_{\bar{x}} = \pm \sqrt{(4.9106 \div 10 \times 9)} = \pm 0.234$.

The accuracy of the measurements, ϵ with reliability $f = 0.99$ is = $t_\alpha S_{\bar{x}} = 3.25 \times 0.234 = \pm 0.76\text{N/mm}^2$ which is 8.28% of the arithmetic mean of the compressive strength. It can be inferred on the basis of the data obtained that with a probability of 0.99, the unknown value of the compressive strength is within the limits

$\tilde{x} - \epsilon = 9.19 - 0.76 = 8.43\text{N/mm}^2$

$\tilde{x} + \epsilon = 9.19 + 0.76 = 9.95\text{N/mm}^2$.

The unknown value of the compressive strength at age 7 days for the mix 1:1.5:3 is accepted as $\tilde{x} = 9.19\text{N/mm}^2$. This also shows that the number of tests conducted is sufficient to obtain the arithmetic mean and the results lie within the limits of permissible deviations.

$\therefore$ the characteristic strength, $X_0 = (9.19 - 1.64 \times 0.739)\text{N/mm}^2$

$= 7.98\text{N/mm}^2$.

4.1.5 **Results for 1:1.5:3 at 14 days**

$\tilde{x} = 11.69\text{N/mm}^2$; $(x_i - \tilde{x})^2 = 4.7135$.

Standard Deviation, $S = \pm \sqrt{(4.7135 \div 9)} = \pm 0.724$.

Standard Error, $S_{\tilde{x}} = \pm \sqrt{(4.7135 \div 10 \times 9)} = \pm 0.23$.

The accuracy of the measurements, ϵ with reliability $\int = 0.99$ is = $t_{\alpha}S_{\tilde{x}} = 3.25 \times 0.23 = \pm 0.75\text{N/mm}^2$ which is 6.39% of the arithmetic mean of the compressive strength. It can be inferred on the basis of the data obtained that with a probability of 0.99, the unknown value of the compressive strength is within the limits

$\tilde{x} - \epsilon = 11.69 - 0.75 = 10.94\text{N/mm}^2$

$\tilde{x} + \epsilon = 11.69 + 0.75 = 12.44\text{N/mm}^2$.

The unknown value of the compressive strength at age 14 days for the mix 1:1.5:3 is accepted as $\tilde{x} = 11.69\text{N/mm}^2$. This also shows that the number of tests conducted is sufficient to obtain the arithmetic mean and the results lie within the limits of permissible deviations.

$\therefore$ the characteristic strength, $X_0 = (11.69 - 1.64 \times 0.724)\text{N/mm}^2$

$= 10.50\text{N/mm}^2$.

4.1.6 Results for 1:1.5:3 at 28 days

$\tilde{x} = 14.63 N/mm^2$; $(x_i - \tilde{x})^2 = 6.5261$.

Standard Deviation, $S = \pm \sqrt{(6.5261 \div 9)} = \pm 0.852$.

Standard Error, $S_{\bar{x}} = \pm \sqrt{(6.5261 \div 10 \times 9)} = \pm 0.269$.

The accuracy of the measurements, $\hat{\epsilon}$ with reliability $f = 0.99$ is = $t_{\alpha} S_{\bar{x}} = 3.25 \times 0.269 = \pm 0.88 N/mm^2$ which is 6.02% of the arithmetic mean of the compressive strength. It can be inferred on the basis of the data obtained that with a probability of 0.99, the unknown value of the compressive strength is within the limits

$\tilde{x} - \epsilon = 14.63 - 0.88 = 13.75 N/mm^2$

$\tilde{x} + \epsilon = 14.64 + 0.88 = 15.51 N/mm^2$.

The unknown value of the compressive strength at age 14 days for the mix 1:1.5:3 is accepted as $\tilde{x} = 14.63 N/mm^2$. This also shows that the number of tests conducted is sufficient to obtain the arithmetic mean and the results lie within the limits of permissible deviations.

$\therefore$ the characteristic strength, $X_0 = (14.63 - 1.64 \times 0.852) N/mm^2$
$= 13.23 N/mm^2$.

4.1.7 Results for 1:2:4 at 7 Days

$\tilde{x} = 9.13 N/mm^2$; $(x_i - \tilde{x})^2 = 4.3596$.

Standard Deviation, $S = \pm \sqrt{(4.3596 \div 9)} = \pm 0.696$.

Standard Error, $S_{\bar{x}} = \pm \sqrt{(4.3596 \div 10 \times 9)} = \pm 0.22$.

The accuracy of the measurements, $\hat{\epsilon}$ with reliability $f = 0.99$ is = $t_{\alpha} S_{\bar{x}} = 3.25 \times 0.22 = \pm 0.72 N/mm^2$ which is 7.84% of the arithmetic mean of the compressive strength. It can be inferred on the basis of the data obtained that with a probability of 0.99, the unknown value of the compressive strength is within the limits

$\tilde{x} - \epsilon = 9.13 - 0.72 = 8.14\text{N/mm}^2$

$\tilde{x} + \epsilon = 9.13 + 0.72 = 9.85\text{N/mm}^2$.

The unknown value of the compressive strength at age 7 days for the mix 1:2:4 is accepted as $\tilde{x} = 9.13\text{N/mm}^2$. This also shows that the number of tests conducted is sufficient to obtain the arithmetic mean and the results lie within the limits of permissible deviations.

$\therefore$ the characteristic strength, $X_0 = (9.13 - 1.64 \times 0.696)\text{N/mm}^2$

$= 7.99\text{N/mm}^2$.

4.1.8 <u>Results for 1:2:4 at 14 days</u>

$\tilde{x} = 10.74\text{N/mm}^2$; $(x_i - \tilde{x})^2 = 7.6739$.

Standard Deviation, $S = \pm \sqrt{(7.6739 \div 9)} = \pm 0.923$.

Standard Error, $S_{\tilde{x}} = \pm \sqrt{(7.6739 \div 10 \times 9)} = \pm 0.292$.

The accuracy of the measurements, ϵ with reliability $f = 0.99$ is = $t_{\alpha}S_{\tilde{x}} = 3.25 \times 0.292 = \pm 0.95\text{N/mm}^2$ which is 8.85% of the arithmetic mean of the compressive strength. It can be inferred on the basis of the data obtained that with a probability of 0.99, the unknown value of the compressive strength is within the limits

$\tilde{x} - \epsilon = 10.74 - 0.95 = 9.79\text{N/mm}^2$

$\tilde{x} + \epsilon = 10.74 + 0.95 = 11.69\text{N/mm}^2$.

The unknown value of the compressive strength at age 14 days for the mix 1:2:4 is accepted as $\tilde{x} = 10.74\text{N/mm}^2$. This also shows that the number of tests conducted is sufficient to obtain the arithmetic mean and the results lie within the limits of permissible deviations.

$\therefore$ the characteristic strength, $X_0 = (10.74 - 1.64 \times 0.923)\text{N/mm}^2$
$= 9.23\text{N/mm}^2$.

4.1.9 <u>Results for 1:2:4 at 28 days</u>

$\tilde{x} = 11.64\text{N/mm}^2$; $(x_i - \tilde{x})^2 = 7.4355$.

Standard Deviation, $S = \pm \sqrt{(7.4355 \div 9)} = \pm 0.909$.

Standard Error, $S_{\tilde{x}} = \pm \sqrt{(7.4355 \div 10 \times 9)} = \pm 0.288$.

The accuracy of the measurements, ϵ with reliability $f = 0.99$ is $= t_d S_{\tilde{x}} = 3.25 \times 0.288 = \pm 0.94\text{N/mm}^2$ which is 8.08% of the arithmetic mean of the compressive strength. It can be inferred on the basis of the data obtained that with a probability of 0.99, the unknown value of the compressive strength is within the limits

$\tilde{x} - \epsilon = 11.64 - 0.94 = 10.70\text{N/mm}^2$

$\tilde{x} + \epsilon = 11.64 + 0.94 = 12.58\text{N/mm}^2$.

The unknown value of the compressive strength at age 28 days for the mix 1:2:4 is accepted as $\tilde{x} = 11.64\text{N/mm}^2$. This also shows that the number of tests conducted is sufficient to obtain the arithmetic mean and the results lie within the limits of permissible deviations.

$\therefore$ the characteristic strength, $X_0 = (11.64 - 1.64 \times 0.909)\text{N/mm}^2$
$= 10.15\text{N/mm}^2$.

Figures 4.1, 4.2 and 4.3 give the strength development of the mixes with age. The initial strength development for the first seven days of age showed a very close range (region of 9.11 to 9.19N/mm^2) for all the mixes. The marked difference showed at the ages of 14 and 28 days (when the mixes would have developed up to 80% of their strength).

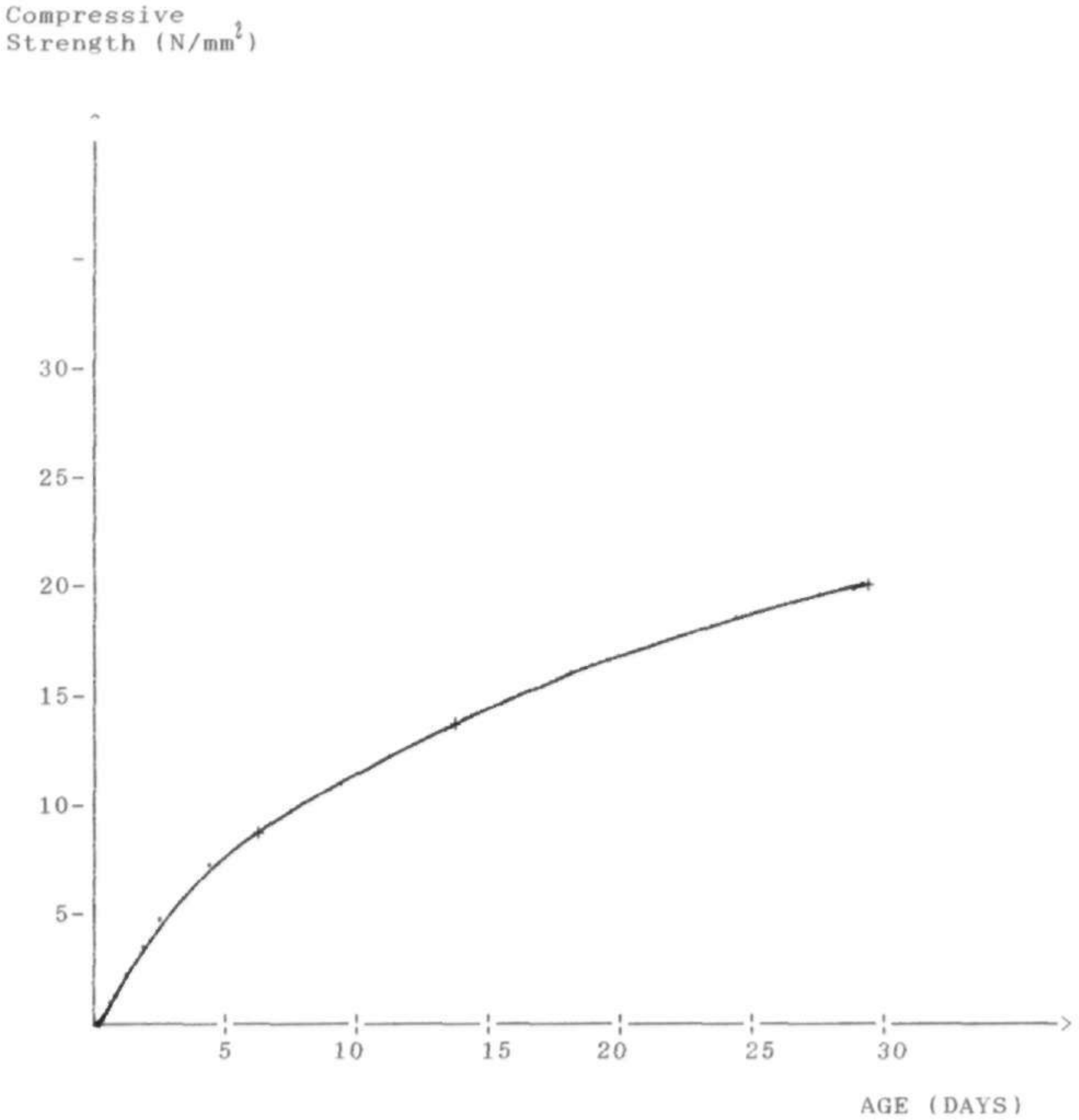


Figure 4.1:- STRENGTH DEVELOPMENT OF MIX 1:1:2 WITH AGE.

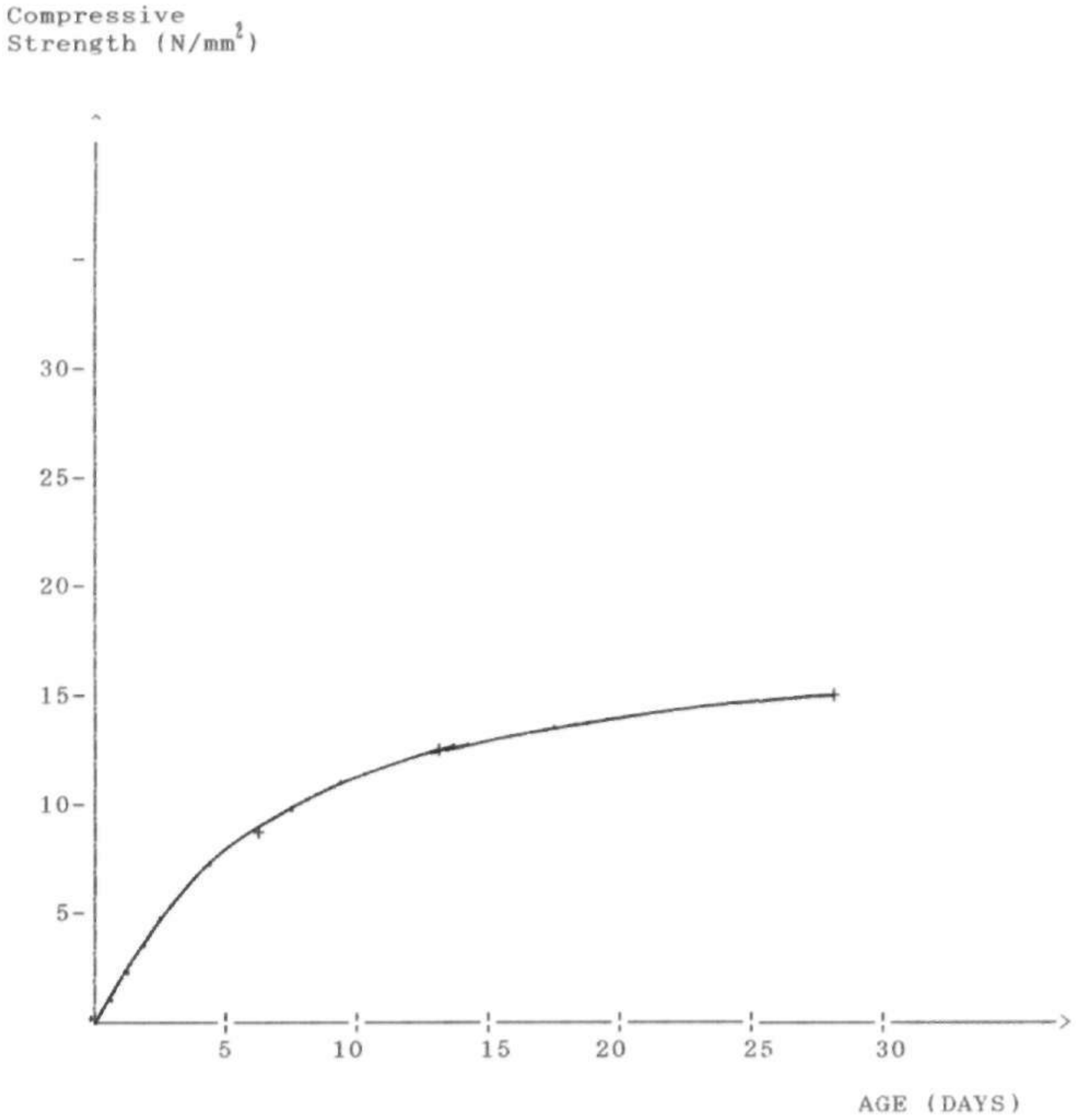


Figure 4.2:- STRENGTH DEVELOPMENT OF MIX 1:1.5:3 WITH AGE.

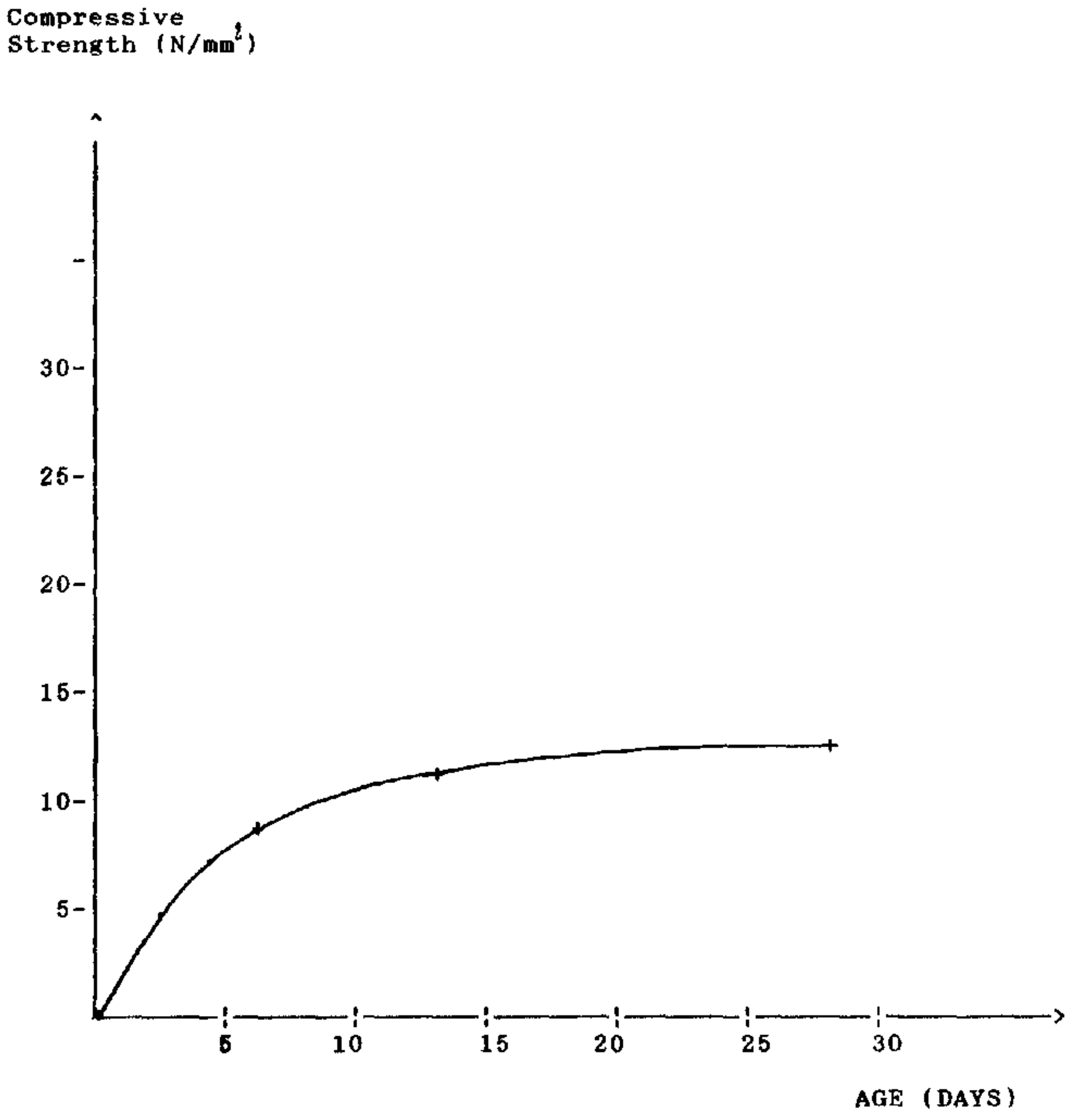


Figure 4.3:- STRENGTH DEVELOPMENT OF MIX 1:2:4 WITH AGE.

4.2.0 RESISTANCE TO ABRASION OF "ATILE" CONCRETE AS COMPARED WITH NORMAL CONCRETE.

The procedure adopted was to expose both specimens to the same conditions of abrasion. An abrasive machine was used with the following data:

Round per minute (R.P.M.) = 2,800.
Horse Power (H.P.) = 5.
Voltage = 230/250 Volts.
Frequency = 50 Hertz.

The normal concrete weighed 5.35kg while the "Atile" concrete weighed 3.75kg. The mixes were 1:2:4 and 1:1:2 respectively. This was informed on the basis that 1:1:2 strength of "Atile" concrete was closest to that of 1:2:4 of the normal concrete, i.e. 18.94 - 21.22N/mm^2.

A time of five (5) minutes was used in causing the abrasion and it was discovered that the "Atile" concrete eroded almost 2.5 times the normal concrete. The indentation into the "Atile" concrete by the abrasive machine was 30mm while that into the normal concrete was 13mm.

4.3.0 COST COMPARISON OF UNITS OF "ATILE" CONCRETE AND NORMAL CONCRETE.

The only area in which the units differed was in the coarse aggregate - the normal concrete had gravel for coarse aggregate while the "Atile" concrete had "Atile" seeds.

The relatively low cost of the "Atile" concrete was offset by the high cement content used. While the normal concrete required about 6 bags of cement in 1m^3 of concrete, the "Atile" concrete required more than 9 bags for the 1:1:2 mix.

The labour involved in acquiring the "Atile" seed was very cheap such that 1m^3 of "Atile" seeds cost as little as ₦150.00 as compared with about ₦400.00 for stone. Overall and reasonable costs can only be achieved in using "Atile" over stone when the whole structure is considered.

4.4.0 MODULUS OF ELASTICITY

The specimens were subjected to constant stress to a maximum stress (not up to destruction) of about a third or less than the crushing strength. The deformations were noted. The specimens were for the mix 1:1:2.

Figures 4.4 and 4.5 show the representations of the loading and unloading responses. The value of the Modulus of Elasticity for the mix 1:1:2 was calculated thus:

$$E = f/e = WL/AX \quad \ldots\ldots 4.1$$

where E is the Modulus of Elasticity;

$f = w/A$ is the applied stress, W being the load and

A is the cross-sectional area;

$e = X/L$ is the deformation per unit length or strain, and

X being the deformation under load, W, and

L the length of the member.

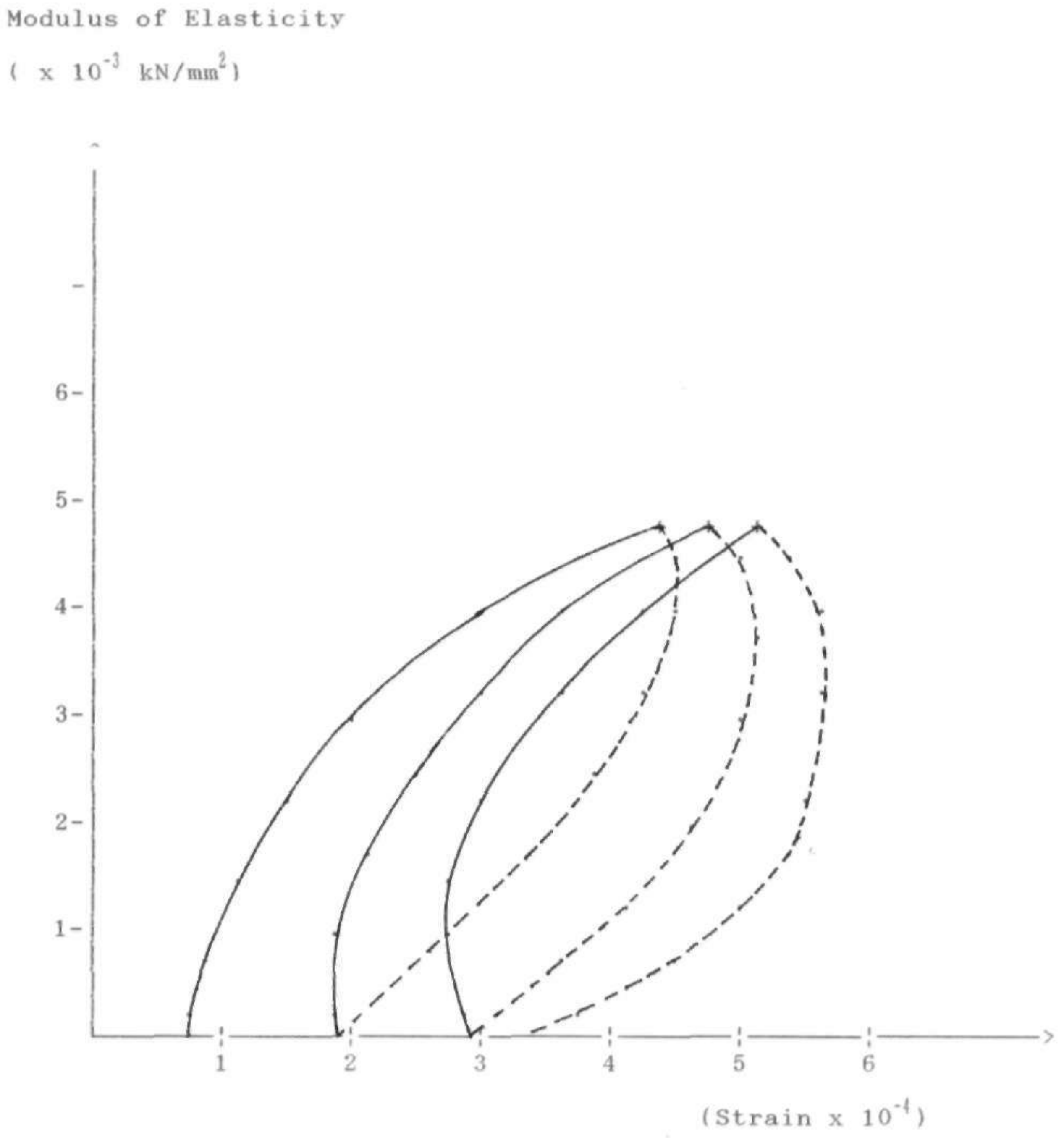


Figure 4.4 MODULUS OF ELASTICITY OF MIX 1:1:2

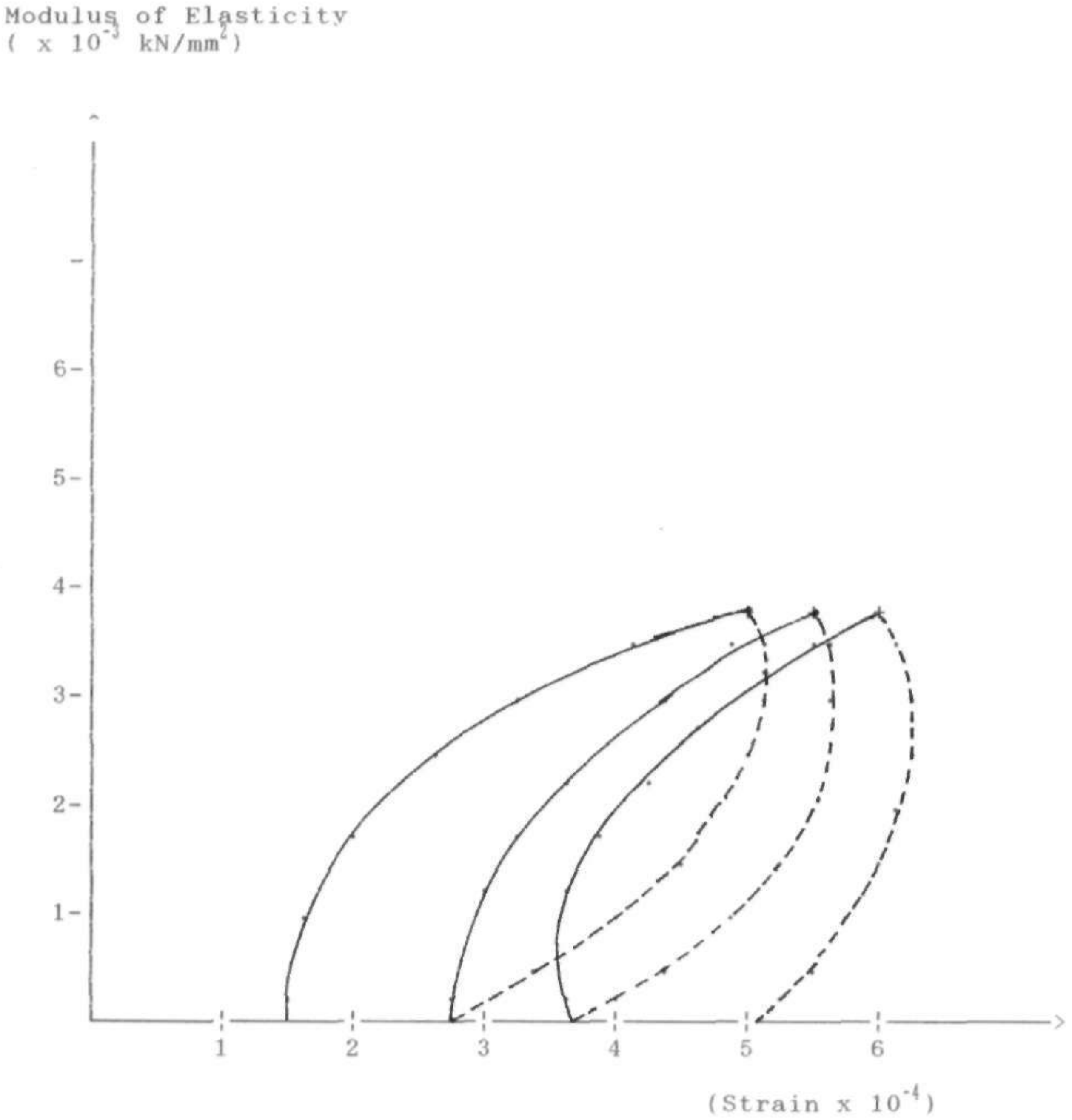


Figure 4.5 MODULUS OF ELASTICITY OF MIX 1:2:4

The Modulus of Elasticity test was for the richest mix 1:1:2 and the 1:2:4 mix. This was to get the range since 1:1.5:3 will be an intermediate value.

For the 1:1:2 at 28 days, the following result was obtained: $E = f/e = WL/AX = 4.25 \times 10^{-3} kN/mm^2 \div 4.2 \times 10^{-4} = 10.12 kN/mm^2$.

For the 1:2:4 at 28 days, the following result was obtained: $E = 3.38 \times 10^{-3} kN/mm^2 \div 8.2 \times 10^{-4} = 4.1 kN/mm^2$

The richer the mix, the higher the Modulus of Elasticity. The Modulus of Elasticity for "Atile" concrete ranges from 4.1kN/mm^2 to 10.12kN/mm^2 which is about 17% to 41% that of the normal concrete (See figures 4.4 and 4.5).

4.5.0 BOND

The "Push-out" Method of test was adopted for various sizes and types of bars and two different mixes, i.e. diameters 8, 10, and 12 of plain and deformed bars; and mixes 1:1:2 and 1:2:4.

The following re [illegible] obtained:

Table 4.4 : Test Result for Bond

MIX	MARK	WEIGHT (kg)	BAR-SIZE(mm)	BAR-TYPE	FORCE (kN)	REMARKS
1:1:2	S-1	10.20	8	DEFORMED	40.00	ROD BENT
"	"	9.85	"	"	36.50	" "
"	S-2	10.30	"	PLAIN	28.50	" "
"	"	9.90	"	"	23.00	" "
"	"	10.00	"	"	35.00	ROD BENT/ CONCRETE CRACKED
"	R	10.40	10	"	44.00	"
"	"	10.42	"	"	32.00	"
"	"	10.20	"	"	34.50	ROD BENT
1:2:4	L	9.55	"	"	18.50	PUSHED THROUGH
"	"	9.55	"	"	25.00	"
"	"	10.00	"	"	21.0	"
"	A-S	9.85	8	DEFORMED	23.50	CONCRETE CRACKED
"	"	9.25	"	"	25.00	PUSHED THROUGH
"	"	9.85	"	"	18.00	"
"	A-B	9.80	12	"	6.00	"
"	"	9.75	"	"	30.00	"
"	"	9.45	"	"	29.00	"

The rich mix of 1:1:2 provided a greater bond both with the deformed and plain bars than the relatively weaker mix of 1:2:4.

4.6.0 SPLIT TENSILE TESTS

The splitting test was for all mixes and the following are the results after 28 days of curing:

Table 4.5: <u>Test Results for Split Tensile of Mix 1:1:2</u>

Mix	Max. Load (kN)	Average Load (kN)	$(x_i - \tilde{x})$	$(x_i - \tilde{x})^2$
1:1:2	100		+5	25
	95	95	0	00
	90		-5	25

$\Sigma(x_i - \tilde{x}) = 0 \quad \Sigma(x_i - \tilde{x})^2 = 50$

Standard Deviation, $S = \pm \sqrt{(50 \div 2)} = \pm 5.0$

Mean-Square Error, $S_{\bar{x}} = \pm \sqrt{(50 \div 3x2)} = \pm 2.89$

The accuracy of the measurements, ϵ with reliability $f = 0.99$ is = $t_{\alpha}S_{\bar{x}} = 4.303 \times 2.89 = \pm 12.42$kN which is 13.08% of the arithmetic mean of the split value. It can be inferred on the basis of the data obtained that with a probability of 0.99, the unknown value of the split value is within the limits

$\tilde{x} - \epsilon = 95.00 - 12.42 = 82.58$kN

$\tilde{x} + \epsilon = 95.00 + 12.42 = 107.42$kN.

The unknown value of the split value at age 28 days for the mix 1:1:2 is accepted as $\tilde{x} = 95.00$kN. This also shows that the number of tests conducted is sufficient to obtain the arithmetic mean and the results lie within the limits of permissible deviations.

$\therefore f_t = 2P/\pi \times l \times d = 2 \times 95 \times 10^3 / \pi \times 300 \times 150 = 1.35\text{N/mm}^2$ which is 6.71% of the compressive strength of the same mix at age of 28 days.

Table 4.6: Test Results for Split Tensile of Mix 1:1.5:3

Mix	Max. Load (kN)	Average Load (kN)	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$
1:1.5:3	55		-5	25
	66	60	+6	36
	59		-1	1

$\Sigma(x_i - \bar{x}) = 0 \quad \Sigma(x_i - \bar{x})^2 = 62$

Standard Deviation, $S = \pm \sqrt{(62 \div 2)} = \pm 5.57$

Mean-Square Error, $S_{\bar{x}} = \pm \sqrt{(62 \div 3x2)} = \pm 3.22$

The accuracy of the measurements, ϵ with reliability $f = 0.99$ is = $t_{\alpha}S_{\bar{x}} = 4.303 \times 3.22 = \pm 13.86$kN which is 13.08% of the arithmetic mean of the split value. It can be inferred on the basis of the data obtained that with a probability of 0.99, the unknown value of the split value is within the limits

$\bar{x} - \epsilon = 60.00 - 13.86 = 46.14$kN

$\bar{x} + \epsilon = 60.00 + 13.86 = 73.86$kN.

The unknown value of the split value at age 28 days for the mix 1:1:2 is accepted as $\bar{x} = 60.00$kN. This also shows that the number of tests conducted is sufficient to obtain the arithmetic mean and the results lie within the limits of permissible deviations.

$\therefore f_t = 2P/\pi \times l \times d = 2 \times 60 \times 10^3 / \pi \times 300 \times 150 = 0.85 N/mm^2$ which is 5.80% of the compressive strength of the same mix at age of 28 days.

Table 4.7: **Test Results for Split Tensile of Mix 1:2:4**

Mix	Max. Load (kN)	Average Load (kN)	$(x_i - \tilde{x})$	$(x_i - \tilde{x})^2$
1:2:4	33		-0.67	0.4489
	34	33.67	+0.33	0.1089
	34		+0.33	0.1089

$\Sigma(x_i - \tilde{x}) = 0$ $\quad \Sigma(x_i - \tilde{x})^2 = 0.6667$

Standard Deviation, $S = \pm \sqrt{(0.6667 \div 2)} = \pm 0.58$

Mean-Square Error, $S_{\bar{x}} = \pm \sqrt{(0.6667 \div 3x2)} = \pm 0.33$

The accuracy of the measurements, ϵ with reliability $f = 0.99$ is = $t_{\alpha}S_{\bar{x}} = 4.303 \times 0.33 = \pm 1.43$kN which is 4.25% of the arithmetic mean of the split value. It can be inferred on the basis of the data obtained that with a probability of 0.99, the unknown value of the split value is within the limits

$\tilde{x} - \epsilon = 33.67 - 1.43 = 32.24$kN

$\tilde{x} + \epsilon = 33.67 + 1.43 = 35.10$kN.

The unknown value of the split value at age 28 days for the mix 1:2:4 is accepted as $\tilde{x} = 33.67$kN. This also shows that the number of tests conducted is sufficient to obtain the arithmetic mean and the results lie within the limits of permissible deviations.

$\therefore$ $f_t = 2P/\pi \times l \times d = 2 \times 33.67 \times 10^3 / \pi \times 300 \times 150 = 0.48\text{N/mm}^2$ which is 5.80% of the compressive strength of the same mix at age of 28 days.

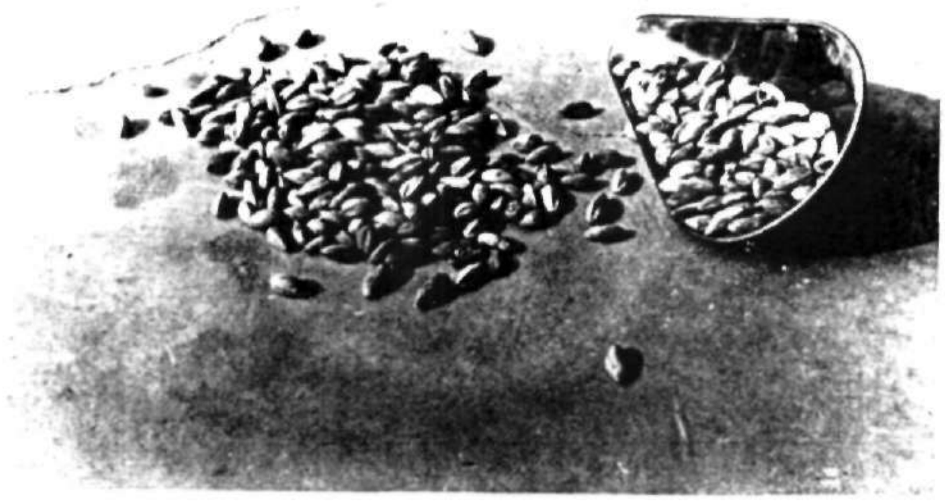


PLATE I - **Sample of "Atile" Aggregate.**
Source: Fieldwork.

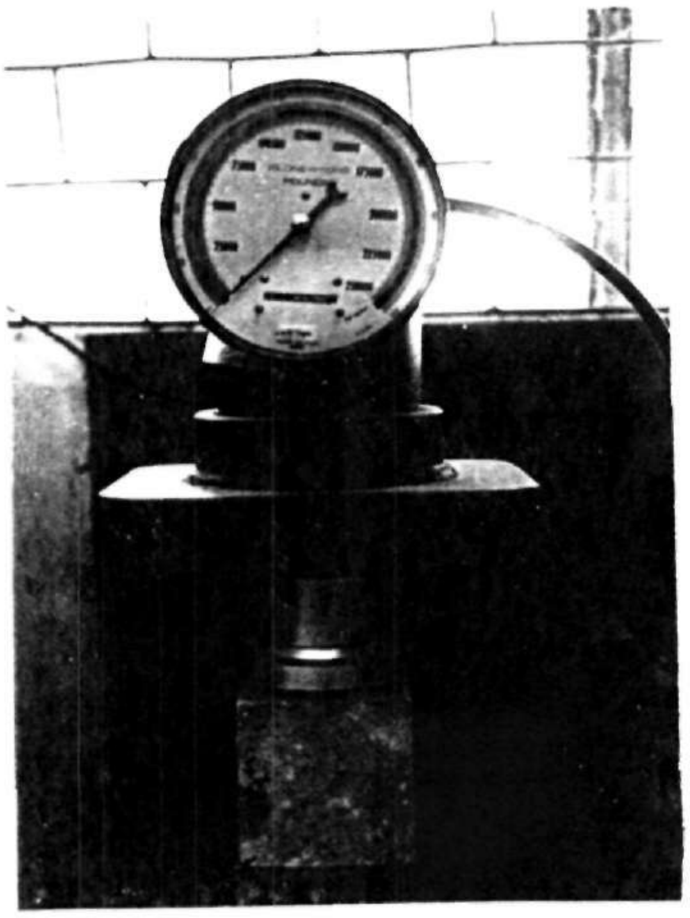
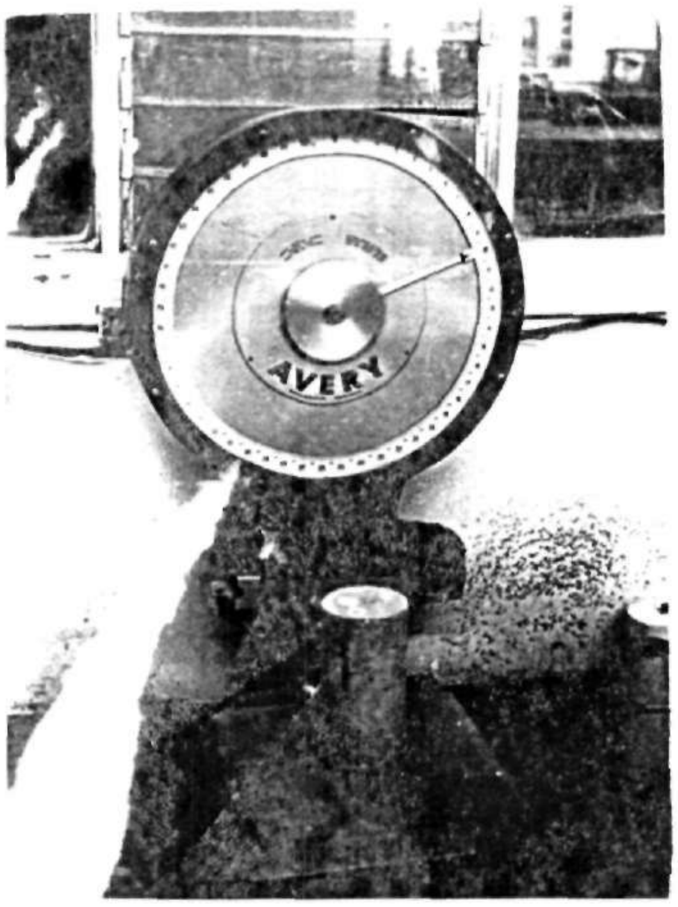


PLATE II - **Cube crushing of "Atile" Concrete.**
Source: Laboratory Work.

PLATE III - Sample of Test Cylinders.
Source: Laboratory work.



. IV - Weighing of Test Cylinders.
ce: Laboratory Work.

CHAPTER FIVE

5.0 Sumary

A recapitulation of the main physical properties of "Atile" aggregate and the properties of concrete produced using "Atile" is presented based on the findings. The recommendations are made as each property of the concrete produced using "Atile" seeds as coarse aggregate is considered. A general remark is made about the suitability of this concrete and its areas of application, while areas for further researchwork are recommended.

5.1.0 Physical Properties of "Atile" Aggregate

a). The specific gravity of the "Atile" aggregate is 1.22 which is about one-half that of the normal aggregate, making it a lightweight aggregate.

b). The absorption rate is 8.4%.

c). The bulk density of the "Atile" aggregate ranges from 696 to 741kg/m^3.

d). Moisture Content of the aggregate is 27.60%.

e). Void Ratio (percentage of Voids) is 72.60%

f). The grading characteristics do not satisfy the British and American requirements for lightweight aggregate.

g). Fineness Modulus of "Atile" aggregate is 7.87.

5.2 Properties of "Atile" Concrete

i). a). Compacting factor of "Atile" concrete ranges from 0.72 - 0.84.

b). The density of "Atile" concrete is from about 1700kg/m^3 to 1900kg/m^3 making it a near medium density concrete.

c). It has good workability, consistency and easy to place properties.

ii). The compressive strength tests ranged from 10.15N/mm^2 to 18.27N/mm^2 characteristic strength. This makes it suitable for both plain and structural concrete construction.

iii). "Atile concrete eroded almost 2.5 times the normal concrete when exposed to the same conditions of abrasion for the same periods. In effect, it should not be used as a finishing material but should be rendered off with cement-sand mortar.

iv). The relatively low cost of the "Atile" was offset by the high cement content used to produce strength comparable to that of normal concrete of mix 1:2:4. While the normal concrete required about 6 bags of cement in 1m^3 of concrete, the "Atile" concrete required higher - more than 9 bags which will lead to shrinkage and many large cracks.

v). The Modulus of Elasticity ranged from 4.1kN/mm^2 to 10.12kN/mm^2, increasing with increase in compressive strength. With such a low value of Modulus of Elasticity, higher deflections are to be expected with time, i.e. high values of creep. Therefore, it is not recommended for long span flexural members; such low E-values are good in resisting impact loads, especially in areas where pounding is common.

vi). The rich mix 1:1:2 provided the greatest bond with deformed bars and then with plain bars than the relatively weaker mix of 1:2:4. This agrees with the general tendency of concrete improving in with richer mixes.

vii). Split tensile test gave results of 4 - 7% of the compressive strength of the same mixes at 28 days of age.

5.3 Conclusion

From the foregoing, it can be seen that the behaviour of the hardened "Atile" concrete is similar to that of normal concrete albeit with slight differences. It can be used for mass concrete construction in solid ground floors that are prone to impact loads and short spanned structural elements.

5.4 Areas for Further Research

a). Flexural performance of "Atile" concrete.

b). Thermal insulation properties of "Atile" concrete.

c). Tensile strength of "Atile" concrete using partial replacement of cement by pozzolans.

d). A structure of "Atile" concrete.

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APPENDIX - A

COMPRESSIVE STRENGTH TEST RESULTS FOR ALL MIXES (N/mm^2)

NUMBER OF SAMPLES : 10

1:1:2 at 14 Days of age

13.88	14.99
13.90	15.10
13.98	13.90
15.10	13.87
15.68	15.10

1:1:2 at 28 Days of age

18.99	21.20
19.00	20.99
19.20	21.20
19.00	21.00
21.20	19.00

1:1.5:3 at 7 Days of age

8.44	8.47
8.45	9.86
9.93	9.77
9.94	8.60
8.50	9.94

APPENDIX - A (Continued)

1:1.5:3 at 14 Days of age

10.95	12.40
11.00	12.38
10.99	12.37
11.10	10.96
12.30	12.40

1:1.5:3 at 28 Days of age

13.83	15.50
13.85	13.84
15.49	13.85
15.45	15.48
14.00	15.50

1:2:4 at 7 Days of age

8.44	8.48
8.45	9.79
9.80	9.78
9.80	8.50
8.50	9.80

APPENDIX - A (Continued)

1:2:4 at 14 Days of age

9.88	9.90
11.58	10.05
9.85	9.84
11.58	11.58
11.57	11.56

1:2:4 at 28 Days of age

10.70	10.79
10.70	10.75
12.49	12.55
12.55	12.55
12.54	10.75