CHAPTER ONE

1.0 INTRODUCTION

1.1 General Background

The market for construction materials is characterized by import dependent materials which are produced to specific international standards to ascertain their quality. However, such materials are prohibitive in cost to the extent that the majority of our people have no access to basic building and road materials. Consequently, the construction situation is grossly inadequate in terms of quality and even quantity. The need then arises for locally procured construction materials that will not compromise cost for quality and safety of concretes produced from them.

Unfortunately, the adoption of local building/road materials is still facing the problem of social acceptability owing to the lack of standards and specifications and quality assurance for such materials. Standards and specifications are basic regulatory instruments for the promotion of acceptable products in the market, and in the context of construction materials, they ensure economy, quality, durability, safety and reliability in construction. The adoption of standards and quality control measures in the production of local construction materials can be an effective means of ensuring quality (Dirisu and Olabiran, 1991).

There is the need to conduct research into concretes produced from local construction materials in Nigeria which will not only make the nation self-dependent in terms of new materials but also help to conserve the scarce foreign exchange. One of such materials that could be adequately developed quality wise, for use in road and building construction sector of the economy is gravel, a coarse aggregate which is believed to be abundantly available in southwestern Nigeria.

Studies have shown that aggregates generally occupy 70 – 80% of the volume of Portland Cement Concrete (PCC) and 80 – 90% of the volume of Hot Mix Asphalt (HMA) concretes (Mehta and Monteiro, 1993) and can therefore be expected to have an important influence on their properties. Aggregates are not just inert fillers, aggregate properties influence workability, strength, stiffness, durability, creep and shrinkage properties of concrete (Kimberly, 2000). They are granular materials derived from natural rocks, crushed stones or natural gravels and sand (Salau, 2008). Although, synthetic materials such as slag and expanded shale or clay, for example, are used to some extent, they are mostly used in lightweight concretes. In addition to their use as economical fillers, aggregates generally provide concrete with better dimensional stability and wear resistance. A good aggregate should produce the desired properties in both fresh and hardened concrete (Jackson, 1977).

ACI (1999) also expresses similar view that Hydraulic cement concrete is a cement and water paste in which aggregate particles are embedded. Aggregate is granular material such as sand, gravel, crushed stone, and blast furnace slag that usually occupies largest proportion of the volume of concrete. Besides reducing volume changes due to drying shrinkage of the cement-water paste, aggregate is an inexpensive filler that reduces the cost of the concrete. Aggregate properties significantly affect the workability of plastic concrete and the durability, strength, thermal properties, and density of hardened concrete.

Aggregates occur naturally and different types could be found in different parts of the country, depending on their occurrence and other formation factors. Knowledge of aggregate locations and their characteristics is of paramount importance most especially at the planning stage of a project, because it will have a significant effect on the overall cost and quality of the project.

Hewitt and Cowan (1969) state that the principal uses for gravel are; for fill, granular base course and surface course in roads, aggregates in asphalt construction, coarse and fine aggregates in concrete, etc. Specifications for aggregate (gravel) to be used in concrete and asphalt construction are becoming stricter, and the presence of deleterious materials, such as chert and shale, restrict the markets for gravel from some areas of the country.

Round and crushed gravel competes with crushed stone as a coarse aggregate for concrete; preference mainly depending upon cost and availability. Concrete made with round stone aggregate is easier to work especially where concrete is placed in confined spaces. However, the irregular surfaces of the crushed aggregate give slightly better binding qualities and increased strength to the concrete. This work is expected to cover general study on coarse aggregate's (gravel) quality, formation, location and factors such as physical, chemical and mechanical characteristics that determine its qualities and that of the resulting concrete.

1.2 Research Problem

Gravels are naturally occurring construction materials which are widely used for production of concrete in Nigeria in general and in Southwestern Nigeria in particular. Besides occupying very large proportion of the volume of concrete, their geotechnical characteristics also influence the properties of concrete. Despite these, the gravels are dug and used blindly without any form of pretreatment or determination of their properties and that of concretes produced from them.

Investigation of physical and geotechnical parameters of concretes and those of gravels used for the production would enable generation of data not only for the formulation of indigenous standards, but would also help to avoid use of sub-standard gravels that might contribute to failures of concrete structures.

1.3 Aim and Objectives

1.3.1 Aim

The aim of this work is to identify, examine and assess the characteristics of concretes produced from gravel from selected locations in southwestern Nigeria.

1.3.2 Objectives

The aim of this study will be achieved through the following specific objectives;

1. Carrying out an inventory of major gravel pits in Southwestern part of Nigeria through purposive questionnaires and site visits.
2. Determining the physical and mechanical properties of the gravel
3. Conducting chemical content analyses of the gravel aggregates
4. Designing concrete mix 1:2:4 using the aggregates and construct and test concrete mix produced with the aggregates.
5. Drawing inferences in line with standards and specifications, statistically analyse the data and make recommendations on the use of concretes produced from gravel from selected locations in southwestern Nigeria.

1.4 Justification

NBRRI (2014a) estimates that Nigeria requires about 850,000 housing units annually for the next 20 years to solve her housing needs, a deficit estimated at 17 million units. It is estimated that about =N=60 trillion is required to fund the Nigerian housing deficit. Building and roads are structures, which serve as shelters and infrastructures for man, his properties and activities. They must be properly planned, designed and constructed to obtain desired satisfaction from environment. The factors to be observed in construction include durability, adequate stability to prevent its failure or discomfort to the users, resistance to weather, fire outbreak and other forms of accidents. The styles of construction are constantly changing with introduction of new materials and techniques of construction. Consequently, the work involved in the design and construction stages of projects are largely that of selection of materials, components and structures that will meet the expected construction standards and aesthetics on economy basis.

The changing problems in concrete technology like the inherent variability of construction materials and the construction process itself, the various criteria to define the serviceability, usefulness or life span for structures, all require a different and radical philosophy of design; limit state method of design (Oladapo, 1981). The design process must ensure the achievement of an acceptable probability that the structure being designed does not become unfit for the use for which it is required during its specified life. Ideally, the probability chosen should be related to the probability of structural failure (CEB-FIP, 1978). The designer is required to design his structure on the basis of the 'ultimate strength design method' and then to check that the structure satisfies some defined serviceability criteria

Several factors including use of sub-standard or low quality materials have been associated with the recurring cases of deadly collapse of buildings and failure of our roads. Uroko, (2009) stresses that in recent times, the incidence of building collapse in the country's major cities of Abuja the Federal Capital Territory, Lagos, the nation's commercial capital and Porthacourt, the Rivers state capital and home to nation's oil wealth, has been so high that to attempt a chronicle of the incidents will amount to reinventing the biblical Tower of Babel. To drive home this point, the list of reported cases of collapsed buildings in Nigeria between 2013 to 2014 (NBRRI, 2014b) shown in Table A1.0 (Appendix A) will testify to this assertion. The degree of deterioration on our roads has also reached an alarming proportion.

Concrete, as it is known today, is just a little more than one hundred years old, but within that period, it has become one of the best structural materials so far devised by mankind (Duntarn, 1980). Reinforced concrete has made possible the construction of structures which not only express the force distribution within them, but which also obey the law of statics; it has allowed considerable freedom in design of shapes and forms. More recently, it has found applications in the construction of pressure vessels for nuclear reactors. Aggregate as a chief constituent material in PCC & HMA concrete constitute between 70 – 90% in volume. It is therefore expected that aggregate will have overwhelming influence on the properties of concrete (Dahunsi, 2003). Stone, which is obtained from natural rock, is most durable and least expensive of all materials of construction. Aggregates significantly affect many fresh and hardened concrete properties and the long-term performance of the concrete structures. Despite their obvious importance, little consideration is often given to the testing of aggregates. Many aggregates and aggregate-related tests currently in use are empirical, without any direct relation to concrete performance. Furthermore, some of the most commonly used tests are not easy to perform and do not yield reproducible results. User-friendly, reproducible, precise tests that relate key aggregate properties to concrete performance are needed for use in conjunction with performance-related specifications (Amir, 2003). This research was therefore meant to address this need so that quality of the stones locally available in respect of their characteristics will be examined and related to performance. The Standard Organization of Nigeria (SON) published "Nigerian Industrial Standard NIS 13, Specification for Aggregate from natural sources for Concrete", but a thorough review of this document reveals that it mostly adopts foreign standards. In other words, there have not been any serious laboratory tests to determine the qualities of these locally available aggregates to arrive at indigenous standards. Salau, (2008) stresses that it is hard to believe that aggregates that are used in plain and reinforced concrete structures throughout Nigeria have no technical characteristics and are used blindly.

In Nigeria, and especially in southwestern part of the country, the aggregates are being used as dug. No tests or pre-treatment are carried out and those who claim to be washing the gravels before use, do not wash them thoroughly. Coarse and fine aggregates are obtained from various quarries in Nigeria. The quarries should be identified with the physical, mechanical and chemical characteristics of the aggregates.

Therefore, considering these housing deficit and incessant collapse of buildings and failures on our road networks which always lead to loss of precious lives and valuable properties, a thorough investigation of our local structural materials such as gravel is of utmost importance to the construction industry. Any effort put into investigation to know quality construction materials such as coarse aggregates (gravel) and the resulting concretes is in the right direction. This will increase the confidence of public, all levels of government and private developers in the usage of concretes produced from local construction materials, hence the need for this research work.

1.5 Study Area

Southwestern Nigeria which is the study area lies between latitudes 6^0N and 9^0N and longitudes 2.5^0E and 6^0E. It is one of the six geopolitical zones of the country and comprises six states. The states in this zone include;

Lagos as a city is the largest city in Nigeria and one of the most populous cities in the world. Being the industrial as well as commercial centre of the country, the city has a high population density and abundant economic opportunities, which in turn has led to over utilization of available utilities and resources. Lagos is located on lat.6.22^0N and long. 3.38^0E with land area of 3,345 sq km.

Oyo state is situated on the western part of Nigeria and is bounded in the south by Ogun state, and in the north by Kwara state. To the west it is bounded partly by Ogun state and partly by Republic of Benin, while in the east, it is bounded by Osun state. It is on latitude 7.4^0N and longitude 4.0^0E. Just like Lagos, Oyo state has a land area of 35,742.84 sq Km and very large population of about 6,617,720 (2006 census), with Ibadan, one of the largest cities in West Africa as its capital which ranks next to Lagos in terms of industrialization (Ayininuola and Olalusi, 2004).
Other states in the zone include Ogun state with Abeokuta as its capital. Ogun state is located between lat. 6.2^0N and 7.8^0N and between long. 3^0E and 5^0E. It has land area of 16,409.26 sq Km and population of 2,759,109 (1997 est.). It is bounded in the west by the Benin Republic, in the south by Lagos state and the Atlantic Ocean, in the west by Ondo state and in the north by Oyo state.

Ekiti state is situated entirely within the tropics. It is located between longitudes 4^0 5^1 and 5^0 45^1 East of Greenwich meridian and latitudes 7^0 15^1 and 8^0 5^1 north of the

Equator. It has land area of 6,353 sq km. It lies south of Kwara and Kogi states, east of Osun state and bounded by Ondo state in the east and in the south. The estimated population upon its creation on October 1st 1996 was put at 1,750,000 with the capital located at Ado-Ekiti.

Osun state has its capital at Osogbo. It is bounded in the west by Oyo state, Ondo and Ekiti states in the east, Kwara state in the north and Ogun state in the south. Osun state is located on lat. 7^0 45^1N and long. 4^0E. Its land area is 10,456 sq Km and 1997 estimated population of 2,551,522.

Ondo state is also located in southwestern Nigeria. The state is bounded in the east by Edo and Delta states, in the north by Ekiti and Kogi states, in the west by Osun and Ogun states and in the south by Atlantic Ocean. Ondo state is located on lat. 7^0 10^1N and long. 5.05^0E with land area of 15,500 sq km.

In this study area, there are many infrastructures such as high rise buildings, examples of which include NET building, 1004 buildings and Cocoa House. Also available are residential, commercial and industrial buildings which spread out of the towns and cities in the zone. There are also wide and expansive networks of highways and rural roads that interconnect villages, towns and cities in and out of the zone. These diverse infrastructures are made from different materials, mostly concrete, the constituents of which include coarse aggregates. Plate 1.1 shows geology and soil map of Nigeria. The figure also shows widespread of reddish gravelly soils on shale which spread all over the zone. Figure 1.1 is the map of southwestern part of the country which is the study area for this project.

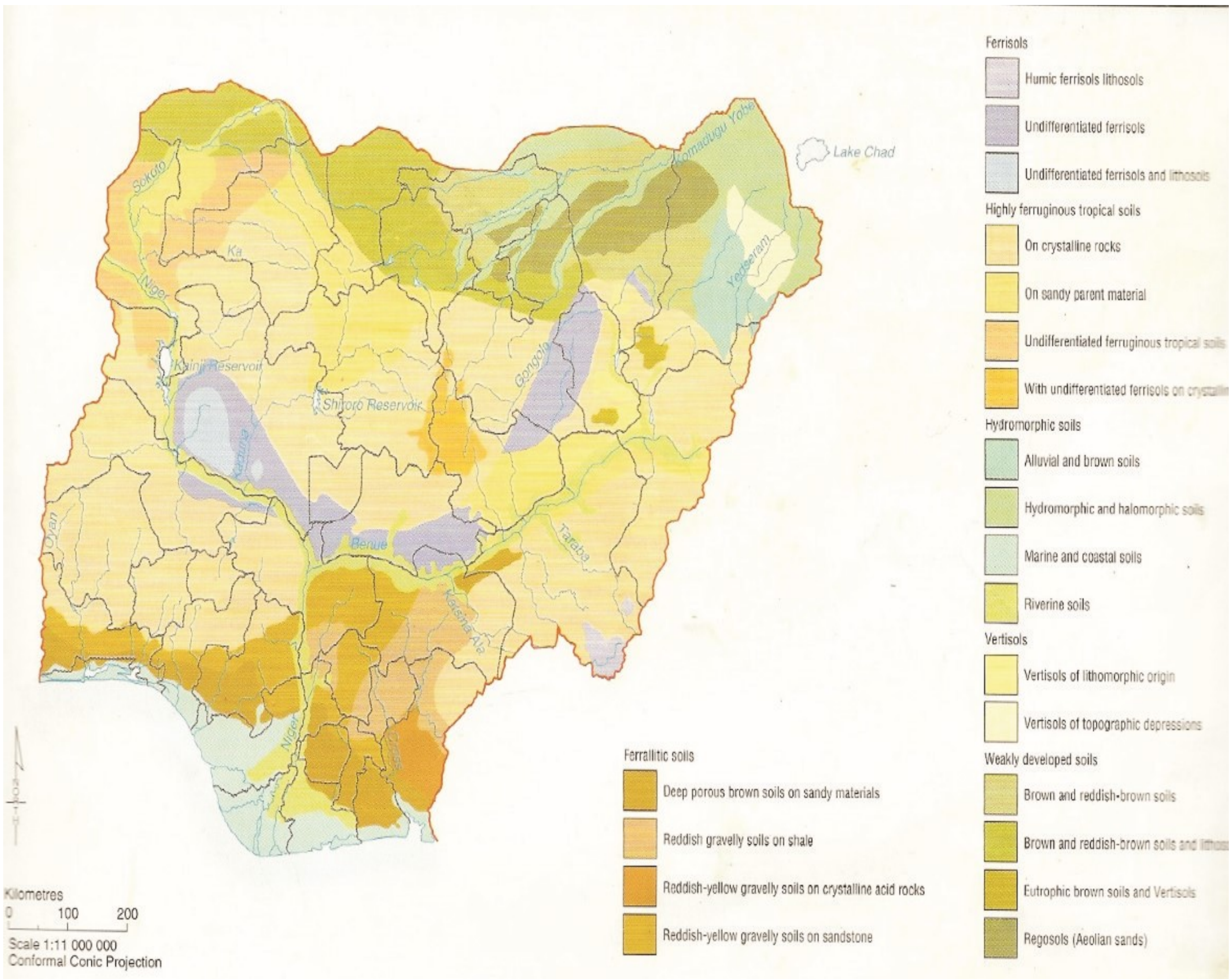

Plate 1.1. Nigeria Geology and Soils

Source: Frederick *et al,* (2006)

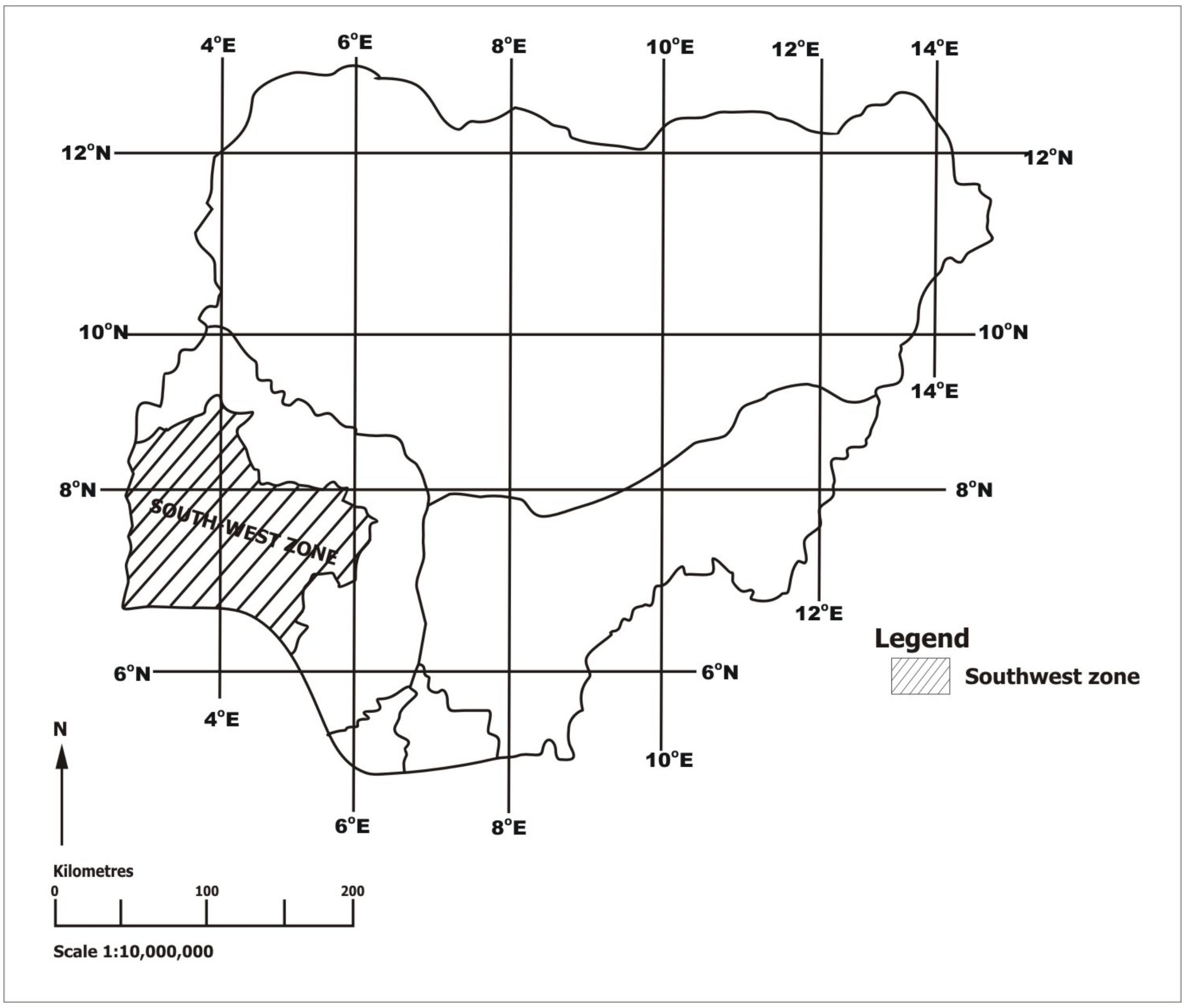

Figure 1.1. Map of Nigeria Showing the Study Area – Southwestern Zone.

Source: Frederick *et al,* (2006)

CHAPTER TWO

2.0 LITERATURE REVIEW

Literature review is an account of what has been published on this topic by accredited scholars and researchers. It is a text of scholarly papers, which includes the current knowledge, substantive findings, as well as theoretical and methodological contributions. The purpose is to convey to the readers what knowledge and ideas have been established on this research work, and what their strengths and weaknesses are.

Beshr *et al* (2003) studied the effect of coarse aggregate quality on the mechanical properties of high strength concrete. They considered the effects of four types of aggregates namely calcareous, dolomitic, quartzitic limestone and steel slag on the compressive and tensile strength, and elastic modulus of strength of concrete. The researchers concluded that the highest and lowest compressive strength was obtained in the concrete specimens prepared with steel slag and calcareous limestone aggregates respectively. Similarly, the split tensile strength of steel slag aggregate concrete was the highest, followed by that of dolomitic and quartzitic limestone aggregate concretes. The type of coarse aggregate also influences the modulus of elasticity of concrete.

Ke-Ru *et al* (2001) carried out tests to study the effect of the coarse aggregate type on the compressive strength, splitting tensile strength, fracture energy characteristic length and elastic modulus of concrete produced at different strength levels with 28 day target compressive strength of 30, 60 and 90 N/mm^2 respectively. Concretes considered in their paper were produced using crushed quartzite, crushed granite, limestone and marble coarse aggregates. The results show that the strength, stiffness, and fracture energy of concrete of a given water – cement ratio (w/c) depend on the type of aggregate, especially for high strength concrete. It is suggested that high – strength concrete with lower brittleness can be made by selecting high – strength aggregate with low brittleness.

Glaccio and Zerbino (1998) state that concrete is a composite and its properties depends on the properties of the component phases and the interaction between them. It is known that the interfaces are the weakest link in concrete, playing a very important role in the process of failure. This process is strongly related with the characteristics of the aggregates (especially, coarse aggregates) and with the relative differences in strength between matrix and inclusions. Their paper analyses the mechanical behaviour of high strength and conventional concrete prepared with coarse aggregates having significant differences in strength, shape and surface texture, porosity and absorption, and interface bond strength. Two different gravels and two different crushed stones were used. Concrete mixtures with w/c ratios of 0.30 and 0.50 were designed. The effects of aggregate type and strength level on concrete failure mechanism, including tensile and compressive strength, stiffness, energy of fracture and crack pattern, were analysed by the authors.

Zahida and Nagaraj (1996) in their work state that concrete is basically a heterogeneous material made up of ingredients with distinct physical and mechanical properties. As a result, the presence of inter-phases is inevitable. In the processing of concrete, fresh and hardened states are the two distinct stages. In the fresh state, the presence of inert constituents in the cement mortar matrix only dilutes the overall potential of concrete to flow. In the hardened state the synergetics play a dominant role in strength development. When the strength of coarse aggregate is far higher than the strength levels for which the matrix or concrete is processed, inter-phase bonding plays a dominant role on the strength. When the matrix strength is comparable to that of the aggregate strength, in contrast, the concrete strength is affected by the aggregate strength. Besides these aspects, the effect of the size and the surface texture of coarse aggregate have also been analyzed.

Al-Oraimi *et al* (2006) worked on the effect of the mineralogy of coarse aggregate on the compressive, flexural and splitting strength. Two aggregate sizes (10 and 20mm) were supplied locally from five different areas in Oman. Petrography analysis was carried out on all those samples. The water/cement ratio (w/c) was kept constant at 0.32 and silica fume and super-plasticizers were used in all mixes. The 28 – day compressive strength varied between 81.3 and 85.6 N/mm^2 for the 10mm maximum aggregate size, and ranged between 72.5 and 77.5 N/mm^2 for the 20mm maximum aggregate size. Therefore, use of smaller maximum aggregate size would give a higher strength and the mineralogy of the coarse aggregate would affect the strength of the concrete.

Other areas where similar works have been carried out include casting delay on workability and strength of concrete (Ravindrarajah, 1985). Sea dredged gravel versus crushed granite as coarse aggregate and this could be accessed through www.vbn.aau.dk/research/sea; and effect of weak rocks in coarse aggregate on the frost resistance – problem of using local gravel as coarse aggregate cited on www.springerlink.com; there is also work on pea gravel mix (problem clinic), article from concrete accessed through www.highbeam.com.

The past research works mentioned above further highlight that aggregate properties have influence on the properties of both fresh and hardened concrete. However no emphasis is laid on gravel as coarse aggregate to determine the properties of concretes.

2.1 Sources of Natural Aggregates

The age of the earth is thought to be about 4600 million years and the oldest known rocks are about 3800 million years. Geologists have divided the life-span of the earth into a time-scale. The largest time units are era; each era may be subdivided into periods, each period into epochs. The names of the periods are taken from a geographical locality in which the formations (large rock units) of that period were either first studied or are well displayed (Selby, 1985). For geological purposes the time-scale must necessarily cover all the time in which rocks have formed, but landforms of today have developed during only a small part of that time.

All materials used in construction of highway embarkments, fills, subgrades, and sub-bases originate from the earth. Most of these materials are natural in origin, i.e. they are the result of geological processes that occur naturally as opposed to synthetic materials which are the result of industrial processes i.e. slag, flyash (www.in.gov.//indot/file/earthworks.

Naturally occurring concrete aggregates are a mixture of rocks and minerals. A mineral is a naturally occurring solid substance with an orderly internal structure and a chemical composition that ranges within narrow limits. Rocks classified as igneous, sedimentary or metamorphic, depending on origin, are generally composed of several minerals (Barksdale, 1991). Table 2.1 illustrates the rocks and mineral constituent of aggregates.

The term rock is used for those materials of many kinds which form the greater part of the relatively thin outer shell, or crust, of the earth; some are comparatively soft and

Table 2.1. Rock and Mineral Constituents in Aggregates

Minerals	**Igneous Rocks**	**Metamorphic Rocks**	**Sedimentary Rocks**
Silica	Granite	Marble	
Quartz	Syenite	Metaquartzite	
Opal	Diorite	Slate	
Chalcedony	Gabbro	Phyllite	
Tridymite	Peridolite	Schist	
Cristobalite	Pegmatite	Amphibolite	
Silicates	Volcanic glass	Hornfels	
Feldspar	Obsidian	Gneiss	
Ferromagnesian	Pumice	Serpentinite	
Hornblende	Tuff		
Angite	Scoria		
Clay	Perlite		
Illites	Pitchstone		
Kaolinites	Felsite		
Chlorites	Basalt		
Montmorillonites			
Mica			
Zeolite			
Carbonate			
Calcite			Conglomerate
Dolomite			Sandstone
Sulphate			Quartzite
Gypsum			Graywacke
Anhydrite			Arkose
Iron Sulfide			Claystone
Pyrite			Siltstone
Marcasite			Argillite and Shale
Pyrrhotite			Carbonate
Iron Oxide			Limestone
Magnetite			Dolomite
Hematite			Marl
Geothite			Chalk
Ilmenite			Chert
Limonite			

Source: (ASTM C 294).

easily deformed and others are hard and rigid. They are accessible for observation at the surface and in mines and borings. Rocks are made up of small crystalline units known as minerals and a rock can thus be defined as an assemblage of particular minerals and named accordingly. For engineering purposes, however, the two terms 'rock' and 'soil' have also been adopted to define the mechanical characters of geological materials. Rock is a hard material and soil either sediment which has not yet become rock-like, or a granular residue from rock that has completely weathered (residual soil). – ((en.wikipedia.org./wiki/rock_(geology).

Blyth and Freitas (1974) gives three broad rock groups, distinguished on the basis of their origins rather than their composition or strength.

2.2 Classification of Rocks/Natural Aggregates

2.2.1 Geological Classification

Rocks are classified under three main heads based on geological formation, namely; igneous, sedimentary and metamorphic (Robert *et al,* 1996).

2.2.1.1 Igneous, Eruptive or Unstratified Rocks

These were formed by the solidification of molten materials which was in a state of fusion and is of volcanic origin. The structural features of such rocks depend upon the manner of its solidification and composition of the constituent materials (Chowdhury, 1982). They are generally strong, durable, massive and crystalline. Examples are granite, trap and basalt. Granite has large crystals as it is formed due to slow cooling. In case of basalt and trap, the rate of cooling is quicker as they are formed at the surface of the earth. As a result of this, they are not crystalline, amorphous and glassy (Chowdhury, 1982; Robert; en.wikipedia.org/wiki/rock_geology, 2011).

2.2.1.2 Sedimentary Rocks

Sedimentary rocks, mainly formed from the breakdown products of older rocks, the fragments having been sorted by water or wind and built up into deposits of sediments (e.g. sandstone, shale); some rocks in this group have been formed by chemical deposition (e.g. some limestones). The remains of organisms such as marine shells or parts of plant that once lived in the waters and on the land where sediments accumulated, can be found as fossils. By the character of formation and the composition, sedimentary rocks fall into three groups; chemical, organic and mechanical (Boggs, 2006). Mechanical deposits; physical weathering by water and temperature fluctuations resulted in the disintegration of rocks to lumps, small pieces and fine particles. Products of disintegration were transported by winds and particularly by water streams over vast distances and then settled, thus giving origin to gravels, sand, crushed stones, etc. from massive rocks. Gravel is rounded off stones measuring from 5 to 70mm. It is used as an aggregate for concrete (Komar, 1987).

2.2.1.2.1 Characteristics of Sedimentary Rocks

Sedimentary rocks can be categorized into three groups based on sediment type. Most sedimentary rocks are formed by the lithification of weathered rock debris that has been physically transported and deposited. During the transport process, the particles that make up these rocks often become rounded due to abrasion or can become highly sorted. Examples of this type of sedimentary rock include conglomerate and sandstone. Scientists sometimes call this general group of sedimentary rocks clastic. The remaining types of sedimentary rocks are created either from chemical precipitation and crystallization, or by the lithification of once living organic matter. These sedimentary rocks are identified as being non-clastic (http://www.physicalgeology.net/physqeoglos/htm,).

All sedimentary rocks are lithified into some collective mass. Lithification is any process that turns raw rock sediment into consolidated sedimentary rock. The process of lithification usually produces identifiable layering in these types of rocks. Lithification can occur by way of:

- Drying and compaction.
- Oxidation of iron and aluminum.
- Precipitation of calcium and silica.

The classification of clastic sedimentary rocks is based on the particle types found in the rock. Some types of clastic sedimentary rocks are composed of weathered rock materiallike gravel, sand, silt, and clay. Others can be constructed from the break up and deposition of shells, coral and other marine organisms by wave-action and ocean currents (Pidwirny, 2006).

2.2.1.2.2 Formation of Sedimentary Rocks

Rivers, oceans, winds, and rain runoff all have ability to carry the particles washed off of eroding rocks. Such materials, detritus, consist of fragments of rocks and mineral. When the energy of the transporting current is not strong enough to carry these particles, the particles drop out in the process of sedimentation. This type of sedimentary deposition is referred as clastic sedimentation. Another type of sedimentary deposition occurs when material is dissolved in water, and chemically precipitates from the water. This type of sedimentation is referred to as chemical sedimentation. A third can occur, wherein living organisms extract ions dissolved in water to make such things as shells and bones. This type of sedimentation is called biogenic sedimentation. Thus there are three major types of sedimentary rocks: clastic sedimentary rocks, chemical sedimentary rocks, and biogenic sedimentary rocks (Nelson, 2003). The formation of a clastic sedimentary rock according to Blatt, *et al* (1980) involves three processes:

- **Transportation** - Sediment can be transported by sliding down slopes, being picked up by the wind, or by being carried by running water in streams, rivers, or ocean currents. The distance the sediment is transported and the energy of the transporting medium all leave clues in the final sediment that tell us something about the mode of transportation.
- **Deposition** – Sediment is deposited when the energy of the transporting medium becomes too low to continue the transport process. In other words, if the velocity of the transporting medium becomes too low to transport sediment, the sediment will fall out and become deposited. The final sediment thus reflects the energy of the transporting medium.
- **Diagenesis** – Diagenesis is the process that turns sediment into rock. The first stage of the process is compaction. Compaction occurs as the weight of the overlying material increases. Compaction forces the grains closer together, reducing pore space and eliminating some of the contained water. Some of this water may carry mineral components in solution, and these constituents may later precipitate as new minerals in the pore spaces. This causes cementation, which will then start to bind the individual particles together. Further compaction and burial may cause recrystallization of the minerals to make the rock even harder (Nelson, 2003).

  Other conditions present during diagenesis, such as the presence or absence of free oxygen may cause other alterations to the original sediment. In an environment where there is excess oxygen (Oxidizing Environment) organic remains will be converted to carbon dioxide and water. Iron will change from Fe2+ to Fe3+, and will change the colour of the sediment to a deep red (rust) colour. In an environment where there is a depletion of oxygen (Reducing Environment), organic material may be transformed to solid carbon in the form of coal, or may be converted to hydrocarbons, the source of petroleum.

2.2.1.2.3 Common Clastic Sedimentary Rocks

Breccia - a coarse-grained rock made from sharp, angular fragments held together by mineralized "cement." Breccias are similar to conglomerate, but the clasts are not rounded, showing that they generally form near the site of origin of the fragments before they have been smoothed by tumbling during long-distance transport.

Conglomerate - a coarse-grained rock made of rounded pebbles or cobbles cemented together. The rounded clasts demonstrate that the material has been carried by rivers or glaciers, rounded off and smoothed by the abrasive action of the transporting medium. Conglomerates often form at the mouths of fast rivers, at the head of glaciers and in alluvial beds. Quartz makes up the pebbles in many conglomerates bonded together by a cement matrix of calcium carbonate, iron oxide, silica or clay. Puddingstone is an attractive conglomerate with a striking colour contrast between the pebbles. When cut and polished it makes a very aesthetic ornamental stone (http://www.physicalgeography.net/physqeoglos/c.html#conglomerate).

Sandstone – a medium grained rock formed by the solidification of sand. The sand is usually quartz grains held together by a binding cement such as calcium carbonate, iron oxide or silica. The rock’s hardness and durability are largely determined by the binding material. Silica makes the sandstone very hard. Sandstone shows enormous variability in colour ranging from yellow to black, largely dependent on the colour of the original sand and often by the amount of iron oxide in the binding agent. Sandstone invariably forms where sand is deposited by slowly running water, such as beaches, off-shore troughs and river deltas. Fine-grained sandstone grades off into shale, whereas coarse-grained sandstones grade into small-pebbled conglomerate (http://www.physicalgeography.net/physqeoglos/s.html#sandstone. Table 2.2 describes clastic sedimentary particles in terms of size.

Table 2.2. Clastic Sedimentary Particles as Classified in Terms of Size

Name of Particle	Size Range (mm)	Loose Sediment	Consolidated Rock
Boulder	>256	Gravel	Conglomerate or Breccia
Cobble	64 – 256	Gravel	(depending on rounding)
Pebble	2 – 64	Gravel	
Sand	1/16 – 2	Sand	Sandstone
Silt	1/256 – 1/16	Silt	Siltstone
Clay	<1/256	Clay	Claystone, mudstone and Shale

Source: EENS 111, (2003).

Pidwirny, (2006), Merriman *et al* (2003) describe others as;

Shale - a very fine-grained rock formed by the solidification of clay. The particle size is typically below 0.004mm giving the rock a very uniform texture. Shale is usually formed in still or very slow water where particles of clay can be suspended and carried for longest. The rock is usually thin-layered and can easily be split into sheets, a feature known as lamination. Although mostly grey, shale can also be brown, black, green or red depending on the original material and binding agent. If the shale contains appreciable quantities of quartz it grades towards sandstone. If it contains calcium carbonate it grades into limestone. Shale is easily scratched by a knife and may show water ripple marks. It often contains fossils of marine life that was enveloped by layers of sediment on the sea floor.

Siltstone/ Mudstone – a fine-grained rock formed by the solidification of mud or silt. The properties and characteristics are very similar to shale, except for larger particle size, greater coarseness and the lack of lamination. Table 2.3 describes some of the main types of clastic sedimentary rocks.

2.2.1.2.4 Texture of Clastic Sedimentary Rocks

According to Blatt, *et al* (1980), when sediment is transported and deposited, it leaves clues to the mode of transport and deposition. For example, if the mode of transport is by sliding down a slope, the deposits that result are generally chaotic in nature, and show a wide variety of particle sizes. Grain size and the interrelationship between grains give the resulting sediment texture. Thus, we can use the texture of the resulting deposits to give us clues to the mode of transport and deposition.

Sorting – This is the degree of uniformity of grain size. Particles become sorted on the basis of density, because of the energy of the transporting medium. High energy currents can carry larger fragments. As the energy decreases, heavier particles are deposited and lighter fragments continue to be transported. This results in sorting due to density. If the particles have the same density, then the heavier particles will also be larger, so the sorting will take place on the basis of size. This size sorting can be classified on a relative basis - well sorted to poorly sorted. Sorting gives clues to the energy conditions of the transporting medium from which the sediment was deposited. Plate 2.1 describes the sorting of the sediments.

Table 2.3. Clastic Sedimentary Rocks

Name of Rock	Fragment Type
Breccia	Coarse Fragment of Angular Gravel and Rocks
Conglomerate	Coarse Fragment of Rounded Gravel and Rocks
Sandstone	Sand Sized Particles that are 90% Quartz
Arkose	Sandstone composed of 25% Feldspar Grains
Shale	Clay Particles
Siltstone	Silt Particles
Mudstone	Mixture of Clay and Silt
Limestone	Mixture of Shells, Coral, and Other Marine Skeletons

Source: Pidwirny, (2006)

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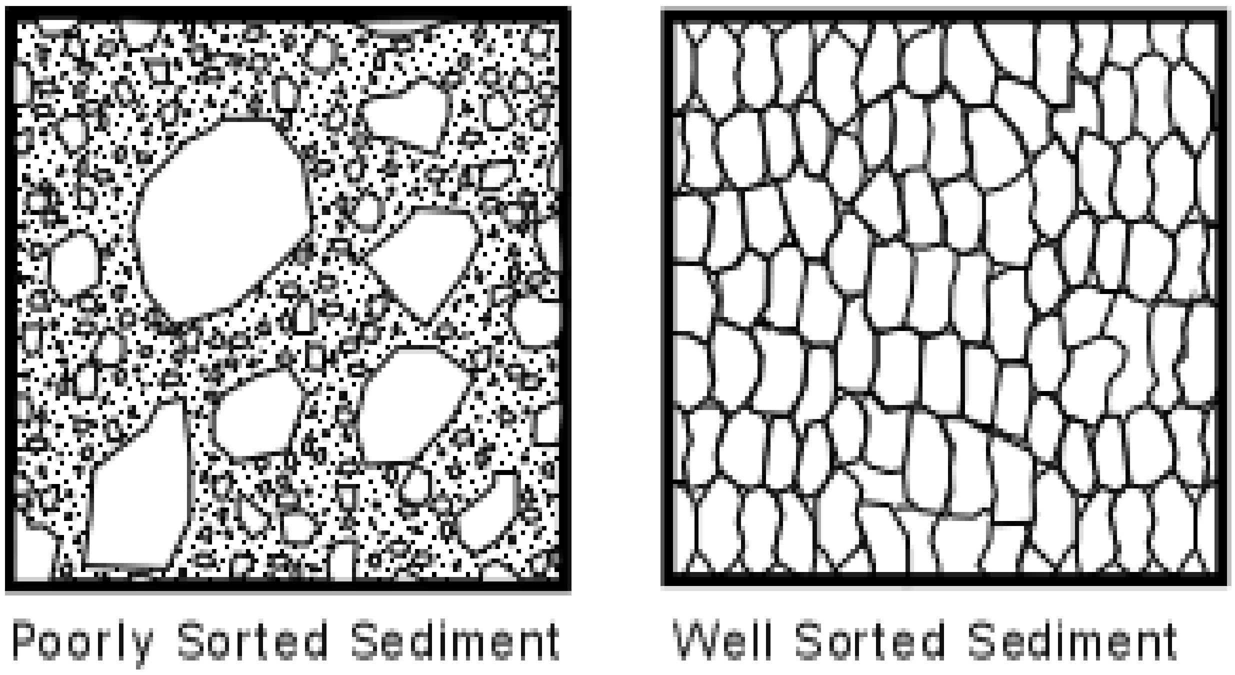

Plate 2.1 Sorting of Sedimentary Rocks.

Source: EENS 111, (2003)

Examples

- Beach deposits and windblown deposits generally show good sorting because the energy of the transporting medium is usually constant.

Stream deposits are usually poorly sorted because the energy (velocity) in a stream varies with position in the stream.

Rounding/Grain Shape – During the transportation process, grains may be reduced in size due to abrasion. Random abrasion results in the eventual rounding off of the sharp corners and edges of grains. Thus, rounding of grains gives clues to the amount of time a sediment has been in the transportation cycle. Rounding is classified on relative terms as well.

The shape of the grains in sedimentary rocks is also significant. Grains that have sharp or rough edges and corners are **angular** and have probably not been transported very far nor have they been significantly reworked. Grains that have smooth surfaces are **rounded** and have either been transported long distances or have been reworked so that their rough edges have been ground down by bumping into other grains as they moved along.

Minerals: - Another property of clastic sedimentary rocks that is important to describe is the **mineralogy** of the grains. Because quartz is resistant to both chemical and physical weathering, it is the most common mineral in clastic sedimentary rocks. Feldspar may be present but is usually less abundant than quartz because feldspar may be chemically altered to form clay minerals. Another common constituent of clastic sedimentary rocks is fragments of older rocks of any rock type.

2.2.1.2.5 Chemical Sediments and Sedimentary Rocks

www.windows2universe.org/earth/geology/sed_chemical.html gives the following types of chemical sedimentary rocks;

Evaporative or chemical sedimentary rocks are formed from the generally inorganic deposition of chemicals, usually through evaporation of a chemical rich solution.

These chemicals generally have their origin from the chemical weathering of other rocks or other sediments. The sodium and chlorine in halite (table salt) comes from the sodium and chlorine in other rocks that have dissolved over the years. Unlike clastic sedimentary rocks, the direct origin of the chemicals is rarely easy to identify. The chemicals could come from magma deep in the crust of the Earth, rocks that dissolved in the ocean billions of years ago or from an outcrop in the hillside next to a lake. Sometimes the origin can be figured out and sometimes there is no way to know the originating source (Hallsworth and Knox 1999).

No matter what type of sedimentary rock, water is almost always a key component. The only real exception to this is desert wind blown sediments. All other rock types involve water in some way. The biochemical rocks come from water born organisms. Clastic rocks are usually water transported, sorted and deposited. Evaporative rocks are of course derived from chemicals dissolved in water. Where there is water, there are sedimentary rocks being formed. Sedimentary geologists must have an understanding of hydrology in order to understand their subjects. The followings according to Merriman *et al* (2003) are chemically formed sedimentary rocks;

Cherts – Chemically precipitated SiO_2

Evaporites – formed by evaporation of sea water or lake water. Produces halite (salt) and gypsum deposits by chemical precipitation as concentration of solids increases due to water loss by evaporation. Table 2.4 describes chemical sedimentary rocks while Table 2.5 illustrates the identification of sedimentary rocks.

2.2.1.3 Metamorphic, Altered or Foliated Rocks

They are either of the above classes with alteration in form caused by great heat, pressure or both; such as clay, slate, marble, dolomite and gneiss. ‘Thermo’ dynamo or ‘hydro’ metamorphosis is responsible for their formation. As a result of metamorphosis, limestone and marl become marble, basalt and trap become schist and laterite and granite become gneiss (Abbott et al, 2000). Table 2.6 gives details of aggregate classification based on their origin.

Table 2.4. Sedimentary Rocks formed as Chemical Precipitates.

Name of Rock	Precipitate
Halite	Sodium and Chloride
Gypsum	Calcium, Sulfur and Oxygen
Silcrete	Silica
Ferricretes	Iron
Limestone	Calcium carbonate
Dolomite	Calcium Magnesium carbonate

Source: Pidwirny, (2006).

Table 2.5. Identification of Sedimentary Rocks

Hardness	Grain Size	Composition	Other	Rock Type
Hard	coarse	Clean quartz	white to brown	Sandstone
Hard	coarse	quartz and feldspar	usually very coarse	Arkose
hard or soft	mixed	mixed sediment with rock grains and clay	gray or dark and "dirty"	Wacke/ Graywacke
hard or soft	mixed	mixed rocks and sediment	round rocks in finer sediment matrix	Conglomerate
hard or soft	mixed	mixed rocks and sediment	sharp pieces in finer sediment matrix	Breccia
Hard	fine	very fine sand; no clay	feels gritty on teeth	Siltstone
Hard	fine	chalcedony	no fizzing with acid	Chert
Soft	fine	clay minerals	splits in layers	Shale
Soft	fine	Carbon	black; burns with tarry smoke	Coal
Soft	fine	calcite	fizzes with acid	Limestone
Soft	coarse or fine	dolomite	no fizzing with acid unless powdered	Dolomite rock
Soft	coarse	fossil shells	mostly pieces	Coquina
very soft	coarse	halite	salt taste	Rock Salt
very soft	coarse	gypsum	white, tan or pink	Rock Gypsum

Source: <htpp://geology.about.com/library/bl/images>

Table 2.6. Aggregate classification Based on Origin

Class	Type	Family
Sedimentary	Calcareous	Limestone
		Dolomite
	Siliceous	Shale
		Sandstone
		Chert
		Conglomerate
		Breccia
Igneous	Intrusive (Coarse grained)	Granite
		Syenite
		Diorite
		Gabbro
		Periodolite
		Pyroxenite
		Hornblendite
	Extrusive (Fine grained)	Obsidian
		Pumise
		Tuff
		Ryholite
		Trachyte
		Andesite
		Basalt
		Diabase
metamorphic	Foliated	Gneiss
		Schist
		Amphibolite
		Slate
	Non foliated	Quartzite
		Marble
		Serpentinite

Source: <htpp://geology.about.com/library/bl/images>

2.3 Engineering or Scientific Classification of Stones

According to Punmia*, et al* (2003) stones for engineering works are divided into the following classes by engineers based on chemical composition:

Siliceous; Its principal constituent is silica; such as granite, syenite, serpentine, gneiss, trap, basalt, quartzite and sandstone. It is unaffected by weathering action and is very hard and durable. The presence of weaker materials however, causes its disintegration.
Argillaceous or Clayey; Its principal constituent is clay, such as porphyry, laterite and clay slate. The chief constituent is alumina mixed with varying proportions of siliceous, calcareous and carboneous matters. They are brittle but hard and durable.
Calcareous; Its principal constituent is carbonate of lime such as limestone, dolomite, marble, kankar and gravel.

2.3.1 Practical Classification

Stones are classified under four heads to suit the practical needs of the users of stones based on physical characteristics (Satheesh, 2009);

- Granite and other igneous stones
- Slate and schist
- Sandstone
- Limestone.

2.3.2 Classification based on Hardness

Based on the hardness of stone, they may be classified as soft, medium, hard and very hard (Punmia, 2003). Its hardness can also be visualized by the hardness of its constituent materials, the scale of hardness is presented in the Tables 2.7 and 2.8.

2.3.3 Classification based on Specific Gravity/Weight

According to Sidney and Young (1981) aggregates are also classified on the basis of specific gravity. They should be hard and strong and free of undesirable impurities. Soft, porous rocks can limit strength and wear resistance; it may also break down during mixing and compacting and adversely affect workability by increasing the amount of fines. Classification of aggregates can also be based on shape and texture of the aggregates.

Table 2.7. Scale of Hardness of Stones

Soft	Medium	Hard	Very Hard
Talc	Limestone	Deccan trap	Granite
Gypsum	Dolomite	Basalt	Granite gravel
Slate		Granite	Trap rock
Sandstone		Gravel	Talconite

Source: Morh's scale of hardness

Table 2.8. Moh's Scale of Hardness of Minerals

S/N	Types of Minerals
1	Talc
2	Rock salt
3	Calcite
4	Fluorspar
5	Apatite
6	Feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

Source: Chowdbury, (1982).

Aggregates can be classified into the following categories based on these unit weights (Shirayams, 1977; ASTM STP 169B, 1978)

- Light-weight aggregates – 880 - 1120kg/m^3
- Normal aggregates – 1200 - 1760 kg/m^3
- Heavy-weight aggregates – 1760 – 4640 kg/m^3

Normal aggregates are used for ordinary work, where no additional strength is needed. They are made up of uncrushed or crushed gravel, crushed stone or rock and sand. They are usually used for the production of normal concrete which is the most common type of concrete.

Light-weight aggregates are widely produced from wide variety of both natural and artificial earth substances in such a way as to obtain a material with a very high percentage of voids (Duntarn, 1980). They are materials used to obtain concrete with unit weight usually below 1600kg/m^3. Although light-weight aggregates had been known since early days of Roman Empire, further development were deferred until early this century, when a grown impetus in the building industry brought about progressive introduction of new and improved types of light-weight construction materials on commercial basis. Compared with other specialized construction materials, the production and marketing of light-weight aggregates are largely local in scope (Pickett, 1976). Concrete made with these aggregates vary in characteristics over a wide range and they are usually suitable for non-loading bearing purposes when the unit weight is below about 640 kg/m^3 (Gutt and Newman, 1967).

Heavy-weight aggregates are materials that are used in the production of heavy-weight concrete where strength and durability are required. They have high specific gravity compared with those of normal concrete. Examples are well graded steel aggregates, magnetite, goethite and limonite (Gutt and Newman, 1967).

2.3.4 Classification according to Source

Salau, 2008 states that aggregates can also be classified according to source i.e. either natural or artificial. The artificial aggregates are either manufactured or by-product while natural aggregates are products of nature. Table 2.9 shows examples of natural and artificial aggregates.

Table 2.9. Classification according to Source

Natural Source	Artificial Source
Sand, gravel, crushed rock such as granite, Basalt, quartzite, sandstone, laterite, yoyo sand	Broken brick, air-cooled slag, sintered fly ash, and bloated clay.

Source: Salau, (2008).

2.3.5 Classification according to Size

Aggregates can be classified as coarse and fine on the basis of their size. The size of aggregate bigger than 4.75mm is considered as coarse aggregate and aggregate whose size is 4.75mm and less is considered as fine aggregate.

Spencer and Cook (1983) state that most basic classification of soils is in terms of particle size as given in Table 2.10 below. The sand and gravel content (i.e. all particles in the soil larger than 0.06mm diameter) is known as coarse fraction. The fine fraction particles less than 0.06mm diameter is further subdivided into silt and clay particles.

2.4 Characteristics of Good Stones

In selecting a stone for an engineering work, the following characteristics should be looked into, though the choice is in most cases further limited by the cost. Other things being equal, its cost depends upon the ease with which it could be quarried or mined, the proximity of the quarry to the place of use, and transport facilities available. Some of the characteristics of good stones (Satheesh, 2009; Punmia, *et al* 2003) are;

General Structure; Structure may primarily be un-stratified (granular), foliated or stratified.

Fineness of Grain; Fine-grained stones are most suitable for carved and moulding works. Stones are liable to be disintegrated if the particles are non-crystalline or amorphous.

Compactness; Compact stones are durable in general. So best stones are those of older formations found at a great depth and subjected to the pressure of earth above. Sometimes, these are brought to the surface due to earthquakes or volcanic eruptions.

Porosity and Absorption: - All stones are porous, but some stones are so porous that they are most unsuitable for exposed situation. Porous stones are destroyed by decomposition or disintegration or both combined. Stones are tested by soaking specimens in water and noting the amount of water absorbed. The mineral constituent of the rock gives the property of absorption whereas porosity depends upon the void space between the minerals and the way in which they are grouped.

Durability: - The durability of a stone depends on its chemical composition and physical structure and also its position in the building. Stones, which are crystalline in structure, homogeneous and close grained with good cementing materials, have a power to resist wear and tear due to atmospheric and other causes.

Table 2.10. Classification based on Particle Size

Description	Grain size (Equivalent Particle Diameter in mm)
Gravel	2.0 – 60
Sand	0.06 – 2.0
Silt	0.002 – 0.06
Clay	Less than 0.002

Source: Spence and Cook, (1983).

Weight: - It is to be taken into consideration especially in marine engineering works. Heavy stones are required for dams, retaining walls, etc. to add to their stability while for arches, vaulting, etc. light stones are to be preferred. Unit weight ranges from 1200 to 2800kg/m^3.

Weathering

It is the power to resist the action of weather, i.e. wear and tear due to atmospheric causes. Good weathering stones should be selected for face work in order that the previous appearance may be maintained.

Other characteristics include appearance, facility for working, season and natural bed.

2.5 Preliminary/Field Tests and Examination of Stones

Generally in ordinary atmosphere, least porous, densest and strongest stone will be most durable. The following tests may be applied to find out the suitability of stones for building purposes (Chowdhury, 1982).

Smith's Test; Put a few small chips from a freshly quarried stone into a glass one-third full of water and then stir briskly for half an hour. Stone will not be durable if the water becomes dirty.

Brard's Test; Weigh a few stone chips when damp and then immerse those in a concentrated boiling solution of sulphate of soda. The stone is suspended for a few days and reweighed. The loss in weight shows the probable effect of frost.

Acid Test; This test is performed to assess the contamination due to the exposure to industrial atmosphere charged with acid fumes for stones other than limestone. About 50gms sample of stone is immersed in 1% hydrochloric solution for 7 days. If the sharpness of edges and corners is maintained at the end of this period, it is assumed to possess satisfactory weathering properties.

Others (Punmia et al 2003) are;

Attrition Test; The purpose of this test is to determine the effect of grinding action of traffic. Deva's attrition test machine has one or more cylinders mounted diagonally at an angle of 30 ^{0} to the horizontal and rotate for about 5 hours at 30 revolutions per minute, the cylinder being fed with 5kg stone balls of 6cm size. The content is sieved through 2mm sieve at the end of the rotation and the pieces retained by the sieve are weighed and loss in weight calculated.

Percentage of wear = $w_1 - w_2 / w_1 \times 100$; w_1 and w_2 be the initial and final weights of the materials. A good stone should give 2% loss only.

Microscopic Examination; The fractured surface of a durable stone should be bright, clean and sharp with grains well cemented together. Stone likely to decay shows a dull earthy appearance. This is essentially a geologist's test.

2.6 Agents which Destroy Stones

The following agents destroy stones (Smith, 1979);

- Chemical agents – such as acids in the atmosphere.
- Mechanical agents – such as wind, dust, rain, frost, running water, pressure of sea, etc.
- Temperature changes – different materials constituting rock have different expansion and contraction which result in the deterioration of the rock.
- Other agents – lichens destroy limestone and worms or molluses destroy all stones.
- Dissimilar stones – when different types of stones such as limestone and sandstone are used, the masonry cracks.

2.6.1 Preservation of Stones

Stones may be preserved from the decaying action of the weather by the following methods (Punmia *et al* 2003);

- Moisture is expelled from pores with the help of blow lamp and the surface is covered with a coating of coal tar, colourless paraffin oil, or any drying oil as linseed oil either mixed or unmixed with paint. This coating requires renewal and also spoils the appearance of the stone.
- The stones to be preserved are to be washed with a thin solution of silicate of potash or of soda. After the silicate has become perfectly dry, the solution of calcium chloride is applied freely. The two solutions combining form silicate of lime which fills the pores and common salt is washed out. However, different types of stones require different treatment for their preservation. Plastering and painting is done in case of ordinary buildings. It is always better to use good stone rather to preserve the inferior one.

2.7 Aggregates in Concrete

Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. Earlier, aggregates were considered as chemically inert materials, but now, it has been recognized that some of the aggregates are chemically active and also that certain aggregates exhibit chemical bond at the interface of aggregate and paste. The mere fact that the aggregates occupy 70 – 80% of the volume of concrete as earlier mentioned in chapter 1.0, implies that their impact on various characteristics and properties of concrete is undoubtedly considerable.

To know more about concrete, it is very essential that one should know more about the aggregates which constitute the major volume in concrete (Salau, 2008). Cement is the only factory made standard component in concrete. Other ingredients namely water and aggregates are natural materials, generally, and they can vary to any extent in many of their properties (Shirayams, 1977). The researches and range of studies that are required to be made in respect of aggregates to understand their widely varying effects and influence on the properties of concrete cannot be underrated.

Concrete can be considered as two phase material – aggregate phase and paste phase. For aggregate phase, the following should be given consideration; classification, source, size, shape, texture, strength, specific gravity and bulk density, moisture content, bulking factor, cleanliness, soundness, chemical properties, thermal properties, durability, and grading.

In general, the more densely the aggregates can be packed, the better the strength, weather resistance, and economy of the concrete. For this reason, the gradation of the particle sizes in the aggregate; to produce close packing is of considerable importance. It is also important that the aggregate has good strength, durability and weather resistance; that its surface is free from impurities such as loam, silt and organic matter which may weaken the bond with cement paste; and that no unfavorable chemical reaction takes place between it and the cement (Mehta and Monteiro, 1993).

Aggregates must also conform to certain standards for optimum engineering use: they must be clean, hard, strong, durable particles free of absorbed chemicals, coating of clay, and other fine materials in amounts that could affect hydration and bond of cement paste. Aggregate particles that are friable or capable of being split are undesirable. Aggregates containing any appreciable amounts of shale or other shaly rocks, soft and porous materials should be avoided; certain types of chert should be especially avoided since they have low resistance to weathering and can cause surface defects such as popouts (PCA, 1985).

Identification of the constituents of an aggregate cannot alone provide a basis for predicting the behavior of aggregates in service. Visual inspection will often disclose weaknesses in coarse aggregates. Service records are invaluable in evaluating aggregates. In the absence of performance record, the aggregates should be tested before they are used in concrete. The most commonly used aggregates – sand, gravel, crushed stone, and air cooled blast-furnace slag – produce freshly mixed normal-weight concrete with a density (unit weight) of 2200 to 2400 kg/m^3. Aggregate of expanded shale, clay, slate, and slag are used to produce structural lightweight concrete with a freshly mixed density ranging from about 1350 – 1850 kg/m^3. Other lightweight materials such as pumice, scoria, perlite, vermiculite, and diatomite are used to produce insulating lightweight concretes ranging in density from about 250 – 1450 kg/m^3. Heavyweight materials such as barite, limonite, magnetite,, ilmenite, hematite, iron, and steel punchings or shot are used to produce heavyweight concrete and radiation-shielding concrete (ASTM C 637-09 and C 638-09).

2.7.1 Physical Characteristics of Aggregate

2.7.1.1 Shape

Jain and Chouhan, (2011) worked on the effect of shape of aggregate on compressive strength and permeability properties of pervious concrete. The researchers concluded that shape of aggregate shall be considered as an important parameter in deciding the suitability of coarse aggregate to prepare pervious concrete.

The shape of aggregates is an important characteristic since it affects the workability of concrete. It is difficult to really measure the shape of irregular body like concrete aggregate which are derived from various rocks. Not only the characteristic of the parent rock, but also the type of crusher used will influence the shape of aggregates. The shape of the aggregate is very much influenced by the type of the crusher and the reduction ratio i.e. the ratio of the size of material fed into crusher to the size of the finished product. Many rocks contain planes of parting or jointing which is characteristic of its formation. It also reflects the internal petrographic structure. As a consequence of these tendencies, schists, slates and shales commonly produce flaky forms, whereas, granite, basalt and quartzite usually yield more or less equidimensional particles. Similarly, quartzite which does not possess cleavage planes produces cubical shape aggregates.

From standpoint of economy in cement requirement for a given water/cement ratio, rounded aggregates are preferable to angular aggregates. On the other hand, the additional cement required for angular aggregate is offset to some extent by the higher strengths and sometimes by greater durability as a result of interlocking texture of the hardened concrete and higher bond characteristic between aggregate and cement paste.

Flat particles in concrete aggregates will have particularly objectionable influence on the workability, cement requirement, strength and durability. In general, excessively flaky aggregate makes very poor concrete (Shetty, 2001). Classification of particles on the basis of shape of the aggregate is shown in Table 2.11. One of the methods of expressing the angularity qualitatively is by a figure called Angularity Number. This is based on the percentage voids in the aggregate after compaction in a specified manner. The test gives a value termed the angularity number. The normal aggregates which are suitable for making the concrete may have angularity number anything from zero to 11. Angularity number zero represents the most practicable rounded aggregates and the angularity number 11 indicates the most angular aggregates that could be tolerated for making concrete not so unduly harsh and uneconomical.

Murdock and Brook (1979) suggested a different method of expressing the shape of aggregate by a parameter called angularity index 'fA'.

Angularity Index $$\mathbf{fA = \frac{3fH}{20} + 1.0} \quad \text{……………………………(Eq. 2.1)}$$

Where fH is the Angularity number.

There has been a lot of controversy on the subject whether the angular aggregate or rounded aggregate will make better concrete. While discussing the shape of aggregate, the texture of the aggregate also enters the discussion because of its close association with the shape. Generally, rounded aggregates are smooth textured and angular aggregates are rough textured. Some engineers prohibit the use of rounded aggregate on the plea that it yields poor concrete, due to lack of bond between the smooth surface of aggregate and cement paste. They suggest that if the rounded aggregate is required to be used for economical reason; it should be broken and then used.

Table 2.11. Particle Shape Classification

Classification	Description	Examples
Rounded	Fully water-worn or completely shaped by attrition.	River or sea-shore gravel, desert and wind blown sand.
Irregular	Naturally irregular or partly shaped by attrition and having rounded edges.	Other gravels, sand or dug flint.
Angular	Possessing well defined edges form at the intersection of roughly plannar surfaces	Crushed rocks of all types; talus, crushed slag.
Flaky	Materials of which the thickness is small relative to the other two dimensions.	Laminated rocks.
Elongated	Materials usually angular in which the length is considerably larger than the other two dimensions.	_
Flaky and Elongated	Materials having the length considerably larger than the width, and the width considerably larger than the thickness.	_

Source: BS 812: Part 1: (1975).

Meininger, (1998) is of the opinion that this concept is not fully justified for the reason that even the so called surface of rounded aggregates is rough enough for developing a reasonable good bond between the surface and the submicroscopic cement gel. But the angular aggregates are superior to rounded aggregates from the following two points of view.

- Angular aggregates exhibit a better interlocking effect in concrete, which property makes it superior in concrete used for roads and pavements.
- The total surface area of rough textured angular aggregate is more than smooth rounded aggregate for the given volume. By having greater surface area, the angular aggregate may show higher bond strength than rounded aggregates.

The higher surface area of angular aggregate with rough texture requires more water for a given workability than rounded aggregates. This means that for a given set of conditions from the point of view of water/cement ratio and the consequent strength, rounded aggregate gives higher strength. Superimposing plus and minus points in favour and against these two kinds of the aggregate it can be summed up as follows:

For water/cement ratio below 0.4 the use of crushed aggregate has resulted in strength up to 38 per cent higher than the rounded aggregate. With an increase in water/cement ratio the influence of roughness of surface of the aggregate gets reduced, presumably because the strength of the paste itself becomes paramount, and at a water/cement ratio of 0.65, no difference in strength of concrete made with angular aggregate or rounded aggregate has been observed (Shetty, 2001).

2.7.1.2 Texture

Shetty, (2001) states that surface texture is the property, the measure of which depends upon the relative degree to which particle surfaces are polished or dull, smooth or rough. Surface texture depends on hardness, grain size, pore structure, structure of the rock, and the degree to which forces acting on the particle surface have smoothed or roughened it. Hard, dense, fine-grained materials will generally have smooth fracture surfaces. Experience and laboratory experiments have shown that the adhesion between cement paste and aggregate is influenced by several complex factors in addition to the physical and mechanical properties.

As surface smoothness increases, contact area decreases, hence a highly polished particle will have less bonding area with the matrix than a rough particle of the same volume. A smooth particle, however, will require a thinner layer of paste to lubricate its movements with respect to other aggregate particles. It will therefore, permit denser packing for equal workability and hence, will require lower paste content than rough particles. It has been also shown by experiments that rough textured aggregate develops higher bond strength in tension than smooth textured aggregate. Table 2.12 shows the surface texture classification of aggregates while Table 2.13 gives the beneficial effects of surface texture of aggregate on flexural strength.

2.7.1.3 Specific Gravity

Aggregate specific gravity is useful in making weight – volume conversions and in calculating the void content in compacted HMA (Roberts *et al,* 1996). Aggregate generally contains pores, both permeable and impermeable. The meaning of the term specific gravity (or relative density) according to ASTM C 127 – 93 is defined as the ratio of mass (or weight in air) of a unit volume of material to the mass of the same volume of water at the stated temperature. BS 812: Part 107: (Draft) uses the term particle density, expressed in kilogrammes per cubic metre. Thus particle density is numerically 1000 times greater than specific gravity. AASHTO M 132 and ASTM E 12 also define specific gravity as “the ratio of the mass of a unit volume of a material at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature”. The commonly used “stated temperature” is 23^0C (73.4^0F).

www.pavementinteractive.org/coarse-aggregate-specific-gravity/ states further that the absolute specific gravity and the particle density refer to the volume of the solid material excluding all pores, whilst the apparent specific gravity and the apparent particle density refer to the volume of solid material including the impermeable pores, but not the capillary ones. It is the apparent specific gravity or apparent particle density which is normally required in concrete technology, the actual definition being the ratio of the mass of aggregate dried in an oven at 100 to 110 ^{0}C for 24 hours to the mass of water occupying a volume equal to that of the solid including the impermeable pores. The latter mass is determined using a vessel known as pycnometer (usually a one-litre jar with a watertight metal conical screwtop having a small hole at the apex) which can be accurately filled with water to a specified volume.

Table 2.12. Surface Texture Classification of Aggregates

Group	Surface Texture	Characteristics	Examples
1	Glassy	Conchoidal fracture	Black flint, obsidian, vitreous slag.
2	Smooth	Water-worn or smooth due to fracture of laminated or fine-grained rock.	Gravel, chert, slate, marble, etc.
3	Granular	Fracture showing more or less uniform rounded grains.	Sandstone, oolite.
4	Rough	Rough fracture of fine or medium grained rock containing no easily visible crystalline.	Basalt, felsite limestone
5	Crystalline	Containing easily visible crystalline constituents.	Granite, gabbro, gneiss.
6	Honey-combed	With visible pores and cavities.	Brick, pumice, foamed slag, expanded clay.

Source: BS 812: Part 1: (1975).

Table 2.13. Influence of Texture on Strength

Per cent of Particles		Water/Cement	Strength. 28 days	
Smooth	Rough	Ratio	Kg/cm^2	
			Flexural	Compressive
100	0	0.54	43	348
50	50	0.57	46	321
0	100	0.60	48	295

Source: ASTM, STP 169-A: Shape, surface texture and coatings, concrete and concrete-making materials.

The majority of natural aggregates have an apparent specific gravity of between 2.6 and 2.7, whilst the values for lightweight and artificial aggregates extend considerably from below to very much above this range. Since the actual value of specific gravity or particle density is not a measure of the quality of the aggregate, it should not be specified unless dealing with a material of a given petrological character when a variation in specific gravity or particle density would reflect a change in the porosity of the particles. An exception to this is the case of construction such as a gravity dam, where a minimum density of concrete is essential for the stability of the structure.

2.7.1.4 Particle Size Distribution

In line with http://www.engineeringcivil.com/determine-particle-size-distribution-of-soil.html. the process of dividing a sample of aggregate into fractions of same particle size is known as a sieve analysis, and its purpose is to determine the grading or size distribution of the aggregate. A sample of air-dried aggregate is graded by shaking or vibrating a nest of stacked sieves, with the largest sieve at the top, for a specified time so that the material retained on each sieve represents the fraction coarser than the sieve in question but finer than the sieve above. Table 2.14 lists the sieve sizes normally used for grading purposes for coarse aggregate according to BS 812: Part 1: 1975 and ASTM C 136-92. When determined in accordance with BS 812: section 103.1 using test sieves of the sizes given in Table 2.14, complying with BS 410, full tolerance, the grading of coarse aggregate shall be within the appropriate limits given in Table 2.15.

The results of a sieve analysis can be reported in tabular form with columns showing the mass retained on each sieve, quantity expressed as a percentage of the total mass of the sample, the cumulative percentage passing each sieve which is used in the plotting of the grading curve. Such a curve is plotted on a grading chart, where the ordinates represent the cumulative percentage passing and the abscissae are the sieve apertures plotted to a logarithmic scale, which gives a constant spacing for the standard series of sieves.

There is the need to determine whether or not a particular grading is suitable to produce a good concrete. In the first instance, grading is of importance only in so far as it affects workability, because strength is independent of the grading. However, high strength requires a maximum compaction with a reasonable amount of work, which can only be achieved in a sufficiently workable mix.

Table 2.14. Sieve Sizes normally used for Grading of Coarse Aggregate

BS			ASTM		
Aperture		**Previous**	**Aperture**		**Previous**
mm	**in.**	**designation**	**mm**	**in.**	**designation**
75	3	3 in.	75	3	3 in.
-	-	-	63	2.5	2.5 in.
50	2	2 in.	50	2	2 in.
37.5	1.5	1½ in.	37.5	1.5	1½ in.
-	-	-	25.0	1	1 in.
20.0	0.786	¾ in.	19.0	0.75	¾ in.
-	-	-	12.5	0.5	½ in.
14.0	0.551	½ in.	-	-	-
10.0	0.393	3/8 in.	9.5	0.374	3/8 in.

Source: BS 812: Part 1: (1975) and ASTM C 136-92

Table 2.15. Coarse Aggregates

Sieve Size (mm)	Percentage by mass passing BS sieves for nominal sizes							
	Graded aggregates			Single-sized aggregate				
	40mm - 5mm	20mm - 5mm	14mm - 5mm	40mm	20mm	14mm	10mm	5mm*
50.0	100	-	-	-	-	-	-	-
37.5	90-100	100	-	85-100	100	-	-	-
20.0	35-70	90-100	100	0-25	85-100	100	-	-
14.0	25-55	40-80	90-100	-	0-70	85-100	100	
10.0	10-40	30-60	50-85	0-5	0-25	0-50	85-100	100
5.0	0-5	0-10	0-10	-	0-5	0-10	0-25	45-100
2.36	-	-	-	-	-	-	0-5	0-30

*used mainly in precast concrete products.

Source; BS 882: (1992).

In fact, there is no ideal grading because of the interacting influences of the main influencing factors on workability: the surface area of the aggregate, which determines the amount of water necessary to wet all the solids; the relative volume occupied by the aggregate; the tendency to segregation; and the amount of fines in the mix. Some terminologies used in particle size analysis according to www.ecs.umass.edu/cee/.. are;

a) Effective size (D_{10}); The particle size for which 10% of particles are finer, and 90% are coarser.
b) Uniformity coefficient (Cu); The ratio of the 60% particle size to the 10% particle size, i.e. $U = D_{60}/D_{10}$. It is a measure of the slope of the line joining these two points.
c) Curvature coefficient (Cz); This is expressed as $Cz = D_{30}^2/(D_{10})(D_{60})$.

The author further states that for a soil to be classified as being well graded, the following conditions must be satisfied;

$C_u > 5$; and $1 \leq C_z \leq 3$

While poorly or uniformly graded samples must meet these conditions;

$C_u < 5$; and $C_z \leq 0.5$

2.7.1.4.1 Fineness Modulus

According to ACI Education Bulletin EI-99, using the sieve analysis results, a numerical index called the fineness modulus (FM) is often computed. The FM is the sum of the total percentages coarser than each of a specified series of sieves, divided by 100. The specified sieves in US are 150mm 75.0mm, 37.5mm, 19.0mm, and 9.5mm and 4.75 mm, 2.36 mm, 1.18 mm, 600 μm, 300 μm, and 150 μm. Note that the lower limit of the specified series of sieves is the 150 μm sieve and that the actual size of the openings in each larger sieve is twice that of the sieve below. The coarser the aggregate, the higher the FM. For fine aggregate used in concrete, the FM generally ranges from 2.3 to 3.1 as called for in ASTM C 33, but in some cases, fine sands are used with FM less than 2.0 (for example, some Florida deposits) and in other cases, a coarser fine aggregate with FM higher than 3.1 (for example, some western coarse sands or manufactured fine aggregate that are used in concrete with a finer natural sand).

Although the FM is most commonly computed for fine aggregates, the FM of coarse aggregate is needed for some proportioning methods. It is calculated in the same manner, while taking care to exclude sieves that are not specified in the definition (for

example, 25.0 and 12.5 mm sieves) and to include all of the specified finer sieves.
Even though the 25 and 12.5 mm sieves were used in the sieve analysis, they are not included in the calculation. Since the total percent retained on the 2.36 mm sieve is 100%; 100% will also be retained on the smaller sieves specified in the FM definition, so all of them should be included in the calculation.

FM is used as a numerical indication of grading characteristics, and is applied only to concrete aggregates. ASTM C 125 also describes fineness modulus as a single number used to describe a gradation curve. The larger the fineness modulus, the more coarse the aggregate. A typical fineness modulus for fine aggregate used in PCC according to Aitcin, (1998) is between 2.70 and 3.00, because the use of such sands decreases the amount of mixing water required, while coarse aggregate value ranges from 3.00 up to about 7.00.

2.7.1.4.2 Applications of Particle Gradation/Sieve Analysis

The analysis of aggregates by particle size provides a useful engineering classification system for aggregates. For engineering purposes in Britain, soils are divided on the basis of particle size into six categories viz; boulders, cobbles, gravel, sand, silt and clay. In practice, most natural soils do not fall entirely within one of these main size ranges, but consist of a mixture of two or more of these categories.
Grading curves enable sands and gravels to be identified as being of three main types, based on the distribution of particle sizes such as;
(i) Uniform soils, in which the majority of the grains are very nearly the same size. The grading curve is very steep for uniform aggregate. The uniformity coefficient is not much more than 1.0 (the lowest theoretically possible). A synonymous description is narrowly graded.
(ii) Well-graded soils contain a wide and even distribution of particle size. Smooth concave upward grading curve is typical of well graded aggregate.
(iii) Poorly graded soils, deficient in certain sizes. The grading curve has two distinct sections separated by a near-horizontal portion. This is described as a gap-graded material, and in natural soils the deficiency usually occurs in the coarse sand to fine gravel range. Some applications of particle size analysis in geotechnology and construction are; selection of fill materials, road sub-base materials, drainage filters, concreting materials and dynamic compaction (http://www.en.wikipedia.org/wiki/sieve_analysis).

2.7.1.5 Water Absorption Capacity and Moisture Content

2.7.1.5.1 Water Absorption Capacity.

Some of the aggregates are porous and absorptive. Porosity and absorption of aggregate will affect the water/cement ratio and hence the workability of concrete. The porosity of aggregate will also affect the durability of concrete when the concrete is subjected to freezing and thawing in temperate environment and also when the concrete is subjected to chemically aggressive liquids (www.engineeringcivil.com/water-absorption-of-aggregates.html).

The water absorption of aggregate is determined by measuring the increase in weight of an oven dried sample when immersed in water for 24 hours. The ratio of the increase in weight to the weight of the dry sample expressed in percentage is known as absorption of aggregate. But when dealing with aggregates in concrete the 24 hours absorption may not be of significance, on the other hand, the percentage of water absorption during the time interval equal of final set of cement may be of more significance. The aggregate absorbs water in concrete and thus affects the workability and final volume of concrete. The rate and amount of absorption within a time interval equal to the final set of the cement will only be a significant factor rather than the 24 hours absorption of the aggregate. It may be more realistic to consider that absorption capacity of the aggregates which is going to be still less owing to the sealing of pores by coating of cement particle particularly in rich mixes. In allowing for extra water to be added to a concrete mix to compensate for the loss of water due to absorption, proper appreciation of the absorption in particular time interval must be made rather than estimating on the basis of 24 hours absorption.

Some aggregates with higher absorption capacities have been observed to break down during the mixing and placing of concrete structures, mainly because of the lower strengths associated with their inherent higher porosities (Meininger, 1998). The breaking down of the aggregates during the construction phases create additional microfines (materials passing #200 sieve) that reduce workability and often lead to the addition of water to obtain the desired workability. This excess of microfines and increase in mix water tend to increase the drying shrinkage of concrete that contribute to the increased transverse (and longitudinal) cracking of the structure.

In proportioning the materials for concrete, it is always taken for granted that the aggregates are saturated and surface dry. In mix design calculation the relative weight of the aggregates are based on the condition that the aggregates are saturated and surface dry. But in practice, aggregates in such ideal condition are rarely met with. Aggregates are either dry or absorptive to various degrees or they have surface moisture. The aggregates may have been exposed to rain or may have been washed in which case they may contain surface moisture or the aggregate may have been exposed to the sun for a long time in which case they are absorptive. It should be noted that if the aggregates are dry, they absorb water from the mixing water and thereby affect the workability and, on the other hand, if the aggregates contain surface moisture they contribute extra water to the mix and thereby increase the water/cement ratio. Both these conditions are harmful for the quality of concrete. In making quality concrete, it is very essential that corrective measures should be taken both for absorption and for free moisture so that the water/cement ratio is kept exactly as per the design.

Local experience and familiarity with a specific aggregate type or source should be considered in assessing the relationship of absorption to aggregate durability. Some researchers (Pigeon and Pleau, 1995) have suggested a maximum absorption capacity value as necessary for preventing aggregate-related damage from freezing and thawing cycles, and several DOTs have imposed limits on absorption for concrete aggregates. For example, Minnesota Department of Transportation MnDOT has set absorption criterium to be ≤ 1.75% for accepting aggregate for concrete.

2.7.1.5.2 Moisture Content

Determination of moisture content in aggregate is of vital importance in the control of the quality of concrete particularly with respect to workability and strength. The measurement of the moisture content of aggregates is basically a very simple operation. But it is complicated by several factors. The aggregate will absorb a certain quantity of water depending on its porosity. The water content can be expressed in terms of the weight of the aggregate or the total water content which includes the absorbed water plus the free water, or the water held in that interior portion of aggregate particles. There are many methods being used for determination of moisture content of aggregate (www.engr.psu.edu/ce/courses/..../aggregate/moisture-content.htm). These are drying, displacement, calcium carbide and measurement by electric meter methods. For the purpose of this research, drying method was adopted.

Drying method – The application of drying method is fairly simple. Drying is carried out in an oven and the loss in weight before and after drying will give the moisture content of the aggregate. If the drying is done completely at a high temperature for a long time, the loss in weight will indicate not only the surface water but also the absorbed water. Appropriate corrections may be made for the saturated and surface dry condition. The oven drying method is too slow for field use. A fairly quick result can be obtained by heating the aggregate quickly in an open pan. The process can also be speeded up by pouring inflammable liquid such as methylated spirit or acetone over the aggregate and igniting it.

2.7.2 Mechanical Properties of Aggregates

The various tests described below give an indication of the quality of the aggregates in relation to their mechanical characteristics. www.ele.com/usa/pdfs/1 narrates the procedures and equipment needed to carry out mechanical properties of aggregates.

2.7.2.1 Bond of Aggregate Particles

Both the shape and the surface texture of aggregate influence considerably the strength of concrete, especially so for high strength concretes; flexural strength is more affected than compressive strength. A rougher texture results in a greater adhesion or bond between the particles and the cement matrix. Likewise, the larger surface area of a more angular aggregate provides a greater bond. Generally, texture characteristics which permit no penetration of the surface of the particles by the paste are not conducive to good bond, and hence softer, porous and mineralogically heterogeneous particles result in a better bond.

The determination of the quality of bond is rather difficult and no accepted test exists. Generally, when bond is good, a crushed concrete specimen should contain some aggregate particles broken right through, in addition to the more numerous ones separated from the paste matrix. However, an excess of fractured particles suggests that the aggregate is too weak.

2.7.2.2 Strength and Aggregate Crushing Value (ACV)

The compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained therein, although it is not easy to determine the crushing strength of the aggregate itself. The required information about the aggregate particles has to be obtained from indirect tests: crushing strength of prepared rock samples, crushing value of bulk aggregate, and performance of aggregate in concrete (ACI COMMITTEE 221, 1994). Tests on prepared rock samples are little used, but it may be noted that a good average value of crushing strength of such samples is about 200 MPa, although many excellent aggregates range in strength down to 80 N/mm^2. It should be observed that the required aggregate strength is considerably higher than the normal range of concrete strength because the actual stresses at the points of contact of individual particles may be far in excess of the nominal applied compressive stress.

The aggregate crushing value (ACV) test is prescribed by BS 812: Part 110: 1990, and is useful guide when dealing with aggregates of unknown performance.
Strength need not be considered for ordinary building works, but it is to be taken into consideration when the stone is subjected to excessive stress such as in roads. The resistance to crushing of stones ranges from 14.7 N/mm^2 to 98 N/mm^2 (BS 812: Part 110, (1990)). Table 2.16 shows average crushing strength of building stones.

The weakest variety of stone is quite safe for residential buildings, for example the maximum compressive stress in a three storeyed residential building could be only 0.4 N/mm^2. In the case of structures like dams, retaining walls, major bridges, etc. however, the stresses developed may be considerable and it should be ensured that this stress does not exceed one-tenth of the crushing strength of the stone.

The crushing value of aggregate is restricted to 30 per cent for concrete used for roads and pavements and 45 per cent may be permitted for other structures (Shetty, 2001). Table 2.17 shows the compressive strength of stones.

2.7.2.3 Toughness/Aggregate Impact Value (AIV)

Toughness can be defined as the resistance of aggregate to failure by impact, and it is usual to determine the aggregate impact value of bulk aggregate. Full details of the prescribed tests are given in BS 812: Part 112: 1990. Toughness determined in this manner is related to the crushing value, and can, in fact, be used as an alternative test. In

Table 2.16. Average Crushing Strength of Building Stones

S/N	Name of Stone	Crushing Strength (N/mm^2)
1	Medium grained granite	98.1
2	Fine grained granite	78.5
3	Doleritic basalt	98.1
4	Deccan trap	39.2
5	Diorites	98.1
6	Hard sandstone	58.9
7	Medium sandstone	39.2
8	Coarse medium marble	29.4
9	Hard limestone	39.2
10	Soft limestone	9.8
11	Slate fine hard	78.5
12	Clay slate hard	58.9
13	Clay slate normal	39.2

Source: BS 812: Part 110: (1990).

Table 2.17. Compressive Strength of Stones

S/N	Name of Stone	Compressive Strength (N/mm^2)
1	Trap	294.3 – 392.4
2	Sandstone	68.7
3	Basalt	147.2 – 196.2
4	Diorite	78.5 – 147.2
5	Granite	68.7 – 127.5
6	Syenite	78.5 – 147.2
7	Limestone	49.1
8	Gneiss	196.2 – 392.4
9	Slate	68.7 – 196.2
10	Laterite	2 - 3

Source: Concrete Research Vol. 5; Suitability of Light-weight Aggregate for Structural Use (2004).

this standard, the aggregate may also be tested in a saturated and surface dry condition. The size of the particles tested is the same as in the crushing value test, and the permissible values of the crushed fraction smaller than a 2.36 mm (No. 8 ASTM) test sieve are also the same. The impact is provided by a standard hammer falling 15 times under its own weight upon the aggregate in a cylindrical container. This results in fragmentation similar to that produced by the plunger in the crushing value test. BS 882: (1992) prescribes maximum values of the average of duplicate samples presented in Table 2.18.

2.7.2.4 Hardness/Aggregate Abrasion Value (AAV)

Hardness is determined by Morh's scale of hardness. Hardness is to be taken into consideration when it is subjected to a considerable amount of wear and friction as in the case of floors and pavements. A scratch with finger nail indicates a hardness of H = 2. Hardness of limestone may be taken as H = 3. Siliceous rock not scratched by knife represents a hardness of H = 7 (en.wikipedia.org/wiki/morhs_scale_of_hardness. Accessed Jan. 2010).

Hardness, or resistance to wear, is an important property of concrete used in roads and in floor surfaces subjected to heavy traffic. The aggregate abrasion value of the bulk aggregate is assessed using BS 812: Part 113: (1990). Aggregate particles between 14.0 and 20.0 mm are made up in a tray in a single layer, using a setting compound. The sample is subjected to abrasion in a standard machine, the grinding lap being turned 500 revolutions with single-size sand fed continuously at a prescribed rate; the sand is not re-usable. The aggregate abrasion value is defined as the percentage loss in mass on abrasion, so that a high value denotes a low resistance to abrasion.

The Loss Angeles test combines the processes of attrition and abrasion, and gives results which show a good correlation not only with the actual wear of the aggregate in concrete, but also with the compressive and flexural strengths of concrete when made with the same aggregate.

Table 2.18. Limiting Values on Mechanical Properties for Different Types of Concrete.

Type of Concrete	10% Fine Value (min.) kN	Alternatively, Aggregate Impact Value (max.) %
Heavy duty concrete floor finishes	150	25
Pavement wearing surfaces	100	30
Others	50	45

Source: Table 2 of BS 882 : (1992).

2.7.3 Alkali-Aggregate Reaction

For a long time aggregates have been considered as inert materials but later on, particularly, after 1940's it was clearly found out that the aggregates are not fully inert. Some of the aggregates contain reactive silica, which reacts with alkalies present in cement i.e. sodium oxide and potassium oxide (Thauma, 2000).

Alkali-aggregate reaction is a chemical reaction between certain types of aggregates and hydroxyl ions (OH-) associated with alkalis in the cement. Usually, the alkalis come from the Portland cement but they may also come from other ingredients in the concrete or from the environment. Under some conditions, the reaction may result in damaging expansion and cracking of the concrete. Concrete deterioration caused by alkali-aggregate reaction is generally slow, but progressive (Grattan and Lyndon, 2002).

In Canada, cracking due to alkali-aggregate reaction generally becomes visible when concrete is 5 to 10 years old. The cracks facilitate the entry of de-icing salt solutions that may cause corrosion of the reinforcing steel, thereby accelerating deterioration and weakening a structure.

2.7.3.1 Alkali-Silica Reaction

This is the most common form of alkali-aggregate reaction and results from the presence of certain siliceous aggregates in the concrete found in some granites, gneisses, volcanic rocks, greywackes, argillites, phyllites, hornfels, tuffs, and siliceous limestones. The product of the alkali-silica reaction is a gel that absorbs water and increases in volume. Pressure generated by the swelling gel ruptures the aggregate particles and causes cracks to extend into the surrounding concrete (Thauma, 2000).

2.7.3.2 Alkali-Carbonate Reaction

This is less common and cases in Canada to date are limited to parts of Eastern Ontario. With the alkali-carbonate reaction, certain dolomitic limestone aggregates react with the hydroxyl ions in the cement (or other sources such as de-icing salts) and cause swelling. The swelling of the limestone particles causes the concrete to expand and crack. Despite 50 years of research, the mechanism of the reaction is still not well understood but it is known that the alteration of dolomite to calcite is involved and clay minerals may also have a role in the reaction. The reaction results in cracks in the concrete. It should be noted that limestone aggregates may be susceptible either to alkali-silica reaction, or alkali-carbonate reaction, or a combination of the two (CJCE, 2000).

2.7.3.3 Factors Promoting the Alkali-Aggregate Reaction

- Reactive type of aggregate
- High alkali content in cement
- Availability of moisture and
- Optimum temperature conditions.

It is not easy to determine the potential reactivity of the aggregates. The case history of aggregates may be of value in judging whether a particular source of aggregate is deleterious or harmless. The petrographic examination of thin rock sections may also immensely help to assess the potential reactivity of the aggregate. This test is often required to be supplemented by other tests.

Mortar Bar Test devised by Stanton has proved to be very reliable test in assessing the reactivity or otherwise of the aggregate. A specimen of size 25 mm x 25 mm and 250 mm length is cast, cured and stored in a standard manner. The length of the specimen is measured periodically, at the ages of 1, 2, 3, 6, 9, and 12 months. Find out the difference in the length of the specimen to the nearest 0.001 per cent and record the expansion of the specimen. The aggregate under test is considered harmful if it expands more than 0.05 per cent after three months or more than 0.1 per cent after six months (ASTM C 1293).

2.7.3.4 High Alkali Content in Cement

The high alkali content in cement is one of the most important factors contributing to the alkali-aggregate reaction. Since the time of recognition of the importance of alkali-aggregate reaction phenomena, a serious view has been taken on the alkali content of cement. Many specifications restrict the alkali content to less than 0.6 per cent expressed as soda equivalent. A cement, meeting this specification is designated as a low alkali cement. Field experience has never detected serious deterioration of concrete through the process of alkali-aggregate reaction when cement contained alkalies less than 0.6 per cent. In exceptional cases, however, cement with even lower alkali content has caused objectionable expansion (ASTM C 289 - 94).

2.7.3.5 Control of Alkali-Aggregate Reaction

The alkali-aggregate reaction can be controlled by the following methods:

- Selection of non-reactive aggregates
- By the use of low alkali cement
- By the use of corrective admixtures such as pozzolanas
- By controlling moisture condition and temperature

Nixon and Simson (2000) state that it is possible to identify potentially reactive aggregate by petrographic examination, mortar bar test or by chemical method. Avoiding the use of the reactive aggregate is one of the sure methods to inhibit the alkali-aggregate reaction in concrete.

In case avoidance of suspicious reactive aggregate is not possible due to economic reasons, the possibility of alkali-aggregate reaction can be avoided by the use of low alkali cement. Restricting the alkali content in cement to less than 0.6 per cent or possibly less than 0.4 per cent, is another good step.

It has been pointed out earlier that generally the aggregate is found to be reactive when it contains silica in a particular proportion and in particular fineness. It has been seen in the laboratory that if this optimum condition of silica being in particular proportion and fineness is disturbed, the aggregate will turn to be innocuous. This disturbance of optimum content and fineness of silica can be disturbed by the addition of pozzolanic materials such as crushed stone dust, diatomaceous earth, fly ash and surkhi. The use of pozzolanic mixture has been found to be one of the practical solutions for inhibiting alkali-aggregate reaction.

According to Thauma (2000), the development of osmotic pressure on the set-cement gel by the subsequently formed alkali-silica gel is responsible for the disruption of concrete. If a system is introduced to absorb this osmotic pressure, it is probable that this disruption could be reduced. The use of air-entraining agent has frequently been recommended as a means of absorbing the osmotic pressure and controlling expansion due to alkali-aggregate reaction in mortar and concrete.

For the growth of silica gel a continuous availability of water is one of the requirements. If such continuous supply is not made available, the growth of silica gel is reduced. Similarly, if the correct range of temperature is not provided, the extent of expansion is also reduced.

2.7.4 Impurities in Aggregates

There are no records as at now of any investigation on the chemical properties of the aggregates, particularly coarse aggregates. Furthermore, there is no record of structural failure that has been traced to the type of aggregates used in concrete mixes. This is as a result of the fact that many people are not aware that certain types of aggregates are unsuitable for plain and reinforced concrete works (Salau, 2008). Failure of dams can be caused by failure of aggregates due to easy percolation of water through the crevices at the interface of matrix and the coarse aggregate. A good design may fail during construction or in service if the materials used are defective.

2.7.4.1 Sulphate Content

(Smith, *et al* 2001). State that aggregates with high sulphate content are not suitable for plain or reinforced concrete. This is because sulphates react with cement after diffusion from the pores and the reaction may cause concrete to swell and thereby initiate formation of cracks in hardened concrete. The cracks can be enlarged quite easily in wet weather, especially during a heavy rainfall.

The sulphate content usually refers to the total acid soluble sulphate content expressed as a percentage of SO_3 and methods for carrying this out are included in several British Standards for testing aggregates and related materials (e.g. BS 812: Part 118; BS 1047, BS 1377: Part 3: 1995). All the methods involve the extraction of the sulphates with hydrochloric acid and the gravimetric determination of the sulphate ions by precipitation with barium chloride. The determination of the total sulphate content can give a false impression of the potential damage to concrete since if all the sulphate is present as the sparingly soluble calcium sulphate the risk of sulphate attack is much reduced because of its low solubility. For this reasons, several of the standards include a method that involves the extraction of the sulphate ions with a limited amount of water (usually two parts by mass of water to one part of aggregate) because this limits the importance attached to calcium sulphate. If calcium sulphate is the only sulphate present then the water extraction can only give a value for sulphate content up to 1.2g SO_4/litre as this is the solubility of calcium sulphate.

The sulphate salt most likely to be found in mineral aggregates is calcium sulphate (gypsum). Other sulphates are infrequent in mineral aggregates but often occur in waste minerals and by-products such as colliery spoil and PFA. These may also contain sulphides which given right conditions can oxidize to sulphates.

The presence of large amounts of soluble sulphate in concrete made with ordinary portland cement may result in cracking and expansion. This is because of their ability in the presence of excess water to react with the calcium aluminates in the cement to form calcium sulphoaluminate (ettringite). The accompanying increase in volume creates forces within the hardened concrete which can lead to its complete disintegration. BS 5328: 1976 requires that the total amount of sulphate in PCC, including that contributed by the cement, should generally not exceed 4% of cement. No limits for the sulphate content of naturally occurring aggregates are given in BS 812: Part 118, but BS 1047 for blast furnace slag used in concrete sets the limits of 2.0% of total sulphur and 0.7% acid soluble sulphate (Smith, *et al* 2001).

2.7.4.2 Carbonate Content

The carbonate minerals consist of those minerals containing the anion $(CO_3)^{2-}$ and include calcite and aragonite (both calcium carbonate), dolomite (magnesium/calcium carbonate and siderite (iron carbonate). Carbonates are commonly deposited in marine settings when the shells of dead planktonic life settled and accumulate on the sea floor. Carbonates are also found in evaporitic settings (e.g. the Great Salt Lake, Utar) and also in Karst regions, where the dissolution and re-precipitation of carbonates lead to the formation of Caves, Stalacites and Stalagmites. The carbonate class also includes the nitrate and borate minerals (Hurlbut and Klein, 1985; Stuart *et al*, 2009).

Carbonates are undesirable in aggregate. The effect of carbonate is to absorb water from the wet mix. The aggregate will absorb the water which the cement should have used for hydration. This will result in concrete mixes of lesser strength than the designed strength. A mix with less water may suffer from inadequate compaction. This may well be another source of structural failure especially in mass concrete like dam.

For class C aggregates Minnesota Department of Transportation (MnDOT) has set criterium for carbonate aggregate content to be ≤ 30% for them to be accepted as aggregate in concrete. Class C aggregate shall consist of natural or partly crushed natural gravel obtained from a natural gravel deposit. It may contain a quantity of material obtained from crushing the oversize stone in a deposit, provided such crushed material is uniformly mixed with the natural, uncrushed particles (Thomas, 2010; TRB, 2013).

2.7.4.3 Chloride Content

A test method for measuring the amount of water soluble chloride present in aggregate is given in BS 812: Part 117: 1988. The method is based on that of Volhard where an excess of standard silver nitrate solution is added to the chloride solution acidified with nitric acid, and the excess silver nitrate is back-titrated with potassium thiocyanate using ferric ammonium sulphate as an indicator.

Other methods are the Mohr direct titration method in neutral solution, using potassium chromate as an indicator; measurement of chloride concentration by specific ion electrode or, for field work and production control work of saline aggregates, the use of test strips (Figg and Lees 1975). The method given in BS 812, and that of Figg and Lees, is designed particularly for testing those aggregates, such as marine-dredged flint, where the chloride is a surface contamination only. With porous aggregates, or those of sedimentary or evaporate origin, where the chloride can be disseminated throughout the particles, complete water extraction may be achieved unless the aggregates are finely ground before test.

The presence of chlorides in concrete can present potential hazards with some cements, e.g. by reducing sulphate resistance, and can considerably increase the risk of corrosion of embedded metal. Chloride can also contribute to the alkali-silica reaction.

Chlorides are present in the pores of coarse aggregates and at times adhere to the surfaces of coarse aggregate. Chlorides are easily found in sea sand and gravels or even in river sand and gravels where the sea can encroach. The main effect of chlorides is the corrosion of steel reinforcement. This shows clearly that aggregates that contain chlorides should not be used in reinforced concrete. The sand that is obtained from rivers near the Lagos sea shores is therefore questionable. If salt can enter the water supply at Ishashi water works, what evidence have we to exclude chlorides from sand and gravels dug from the lagoon and rivers near Lagos shores. Table 2.19 shows the recommended limits for total sulphate and chloride content in concrete (from all sources) before exposure (Thomas, 1986).

When people talk of plain or reinforced concrete, they often talk of organic impurities and sugar as the main danger. It should be noted that sulphates, carbonates, chlorides

Table 2.19. Recommended Limits for Total Sulphate and Chloride Content in Concrete (from all sources) before Service exposure.

Types of concrete	Max. Sulphate (SO3) Content. % by wt of cement	Max. Chloride (Cl) Content. % by wt. of cement
Plain Concrete	4.0	-
Reinforced Concrete	4.0	0.15
Prestressed Concrete	4.0	0.10

Source: Telford Thomas (1986).

and combined water are not the only danger to plain and reinforced concrete. There are other factors of minor importance such as soluble lead and zinc compounds.

2.7.4.4 Organic Content

Lado, *et al*, (2004) explains that the presence of organic matter in aggregates can have two separate and unrelated effects. If present in significant amounts in fine aggregate to be used for mortar rendering or concrete, it may cause disfigurement without necessarily affecting durability. More serious is the possible presence of organic compounds which may retard, or completely inhibit the hydration of portland cement. Simple measurement of the total amount of organic matter present is of little value as it is the type of organic compound, rather than the total amount present which is the controlling factor. Many of the organic retarders which occur in aggregates can be detected by their ability to discolour an aqueous solution of sodium hydroxide. In some circumstances, the degree of discolouration in a standard test can provide a rough guide to the degree of contamination of the aggregate. The weakness of the test is that it assumes that all retarders will give a brown colouration and that if a brown colouration is obtained, retarders must be present. Neither of these assumptions is necessarily true but as the test is so easy to carry out, it has some value as a rapid indication of whether or not a problem is likely to arise. A limitation to the quantity of such impurities is shown in Table 2.20.

The concrete aggregates should be free from impurities and deleterious substances which are likely to interfere with the process of hydration, prevention of effective bond between the aggregates and matrix. The impurities sometimes reduce the durability of the aggregate (Evans and Dougre, 1963). Generally, the aggregate obtained from natural sources are likely to contain organic impurities in the form of silt and clay. The manufactured aggregate does not normally contain organic materials but it may contain excess of fine crushed stone dust.

Coarse aggregate stacked in the open and unused for long time may contain moss, and mud in the lower level of the stack. Sometimes, excessive silt and clay contained in the fine or coarse aggregate may result in increased shrinkage or increased permeability in addition to poor bond characteristics. The excess silt and clay may also necessitate greater water requirements for given workability. Aggregates from some source may

Table 2.20. Limits of Deleterious Materials in Aggregates

S/N	Deleterious Substances	Fine aggregate percentage by weight maximum		Coarse aggregate percentage by weight maximum	
		Uncrushed	Crushed	Uncrushed	Crushed
(1)	(2)	(3)	(4)	(5)	(6)
i	Coal and lignite	1.00	1.00	1.00	1.00
ii	Clay lumps	1.00	1.00	1.00	1.00
iii	Materials finer than 75-micron sieve.	3.00	15.00	3.00	3.00
iv	Soft fragments	-	-	3.00	-
v	Shale	1.00	-	-	-
vi	Total of percentage of all deleterious materials (expect mica) including s/n (i) to (v) for columns (4) and (6) and s/n (i) and (ii) for column (5) only.	5.00	2.00	5.00	5.00

Source: Salau, (2008).

contain iron, pyrites, clay nodules, soft shale particles and other impurities which are likely to swell when wetted. These particles also get worn out when concrete is subjected to abrasion and thereby cause pitting in concrete. Such unsound particles cause damage to the concrete particularly, when subjected to alternate wetting and drying or freezing and thawing.

2.8 Quality Control Requirements of Aggregates

Aggregate testing laboratories, in common with much of the construction industry, have moved towards the adoption of quality assurance scheme. Quality assurance is defined in EN ISO 8402: 1995 as "All those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality". The advantages of implementing quality assurance are seen as increasing confidence in the fitness for purpose of products and services, reducing the client's need for and desire to check the product for compliance, and increasing overall efficiency and competitiveness. Since the adoption of BS 5750 as an International Standard (ISO 9000: 1994 series), world-wide development of quality has been based on a single model.

There are three basic elements in a quality assurance scheme. Firstly, for any test there must be a written specification of how the test is carried out. These are usually BS, ASTM, ISO, NIS, etc. or if a standard does not exist for the test, the laboratory can write its own specification or the client can prepare one. Secondly, the staff carrying out the test must be properly trained and registered. Thirdly, all apparatus used in the test must be traceable in their calibration to national standards; in Great Britain these are National Physical Laboratory Standards.

In principle, there are three methods by which a quality assurance scheme may be implemented. In first-party quality assurance, the laboratory itself monitors the operation of the scheme as well as setting it up and running it. In second-party quality assurance the client for the test monitors the scheme, and in third-party quality assurance an independent authority monitors the scheme.

To meet quality requirements, aggregate should consist of fine and coarse aggregates. All aggregates shall be hard, perfectly clean and free from dust and clay, organic or other deleterious materials. All aggregates should be thoroughly washed before use.

2.8.1 Grading of Aggregates

The grading of aggregate should be such as to produce a concrete of the specified proportions which will work readily into position without segregation and without the use of excessive water content. The grading should be controlled throughout the work so that it conforms closely to that used for the preliminary test (Neville, 2003).

Separate storage bins with adequate provision for the drainage should be provided for each size range of aggregates used, e.g. for the following nominal single sizes where applicable; 38 – 19mm, 19 – 10mm, 10 – 5mm and 5mm down.

The grading of the coarse and fine aggregates should be determined at least once a week to check whether the gradings are similar to those of the samples used in the trial mixes or of those used as the basis for the selection of the weights of aggregates and in the case of standard mixes (NCP 1, 1973).

For any given maximum size, the grading of the coarse aggregate)provided this is within the appropriate limits of NIS 13) is unlikely to affect the properties of concrete unless a high degree of control is exercised. Where the range permitted by NIS 13 for graded aggregate is considered to be too wide, it is recommended that single-sized aggregates are used, the relative proportions being determined on the basis of the trial mixes (BS 812, 1990).

Aggregate comprises about 55 per cent of the volume of mortar and about 85 per cent volume of mass concrete. Mortar contains aggregate of size 4.75 mm and concrete contains aggregate up to a maximum size of 150 mm (Shetty, 2001). Thus it is not surprising that the way particles of aggregate fit together in the mix, as influenced by the gradation, shape, and surface texture, has an important effect on the workability and finishing characteristic of fresh concrete, consequently on the properties of hardened concrete. A lot has been written on the effects of the aggregate grading on the properties of concrete and many so called “ideal” grading curves have been proposed. In spite of the extensive studies, there has not been a clear picture of the influence of different types of aggregates on the plastic properties of concrete. It has been this much understood that there is nothing like “ideal” aggregate grading, because satisfactory concrete can be made with various aggregate gradings within certain limits.

It is well known that the strength of concrete is dependent upon water/cement ratio provided the concrete is workable. In this statement, the qualifying clause “provided the concrete is workable” assumes full importance. One of the most important factors for producing workable concrete is good gradation of aggregates. Good grading implies that a sample of aggregate contains all standard fractions of aggregate in required proportion such that the sample contains minimum voids. A sample of the well graded aggregate containing minimum voids will require minimum paste to fill up the voids in the aggregates. Minimum paste will mean less quantity of cement and less quantity of water, which further mean increased economy, higher strength, lower shrinkage and greater durability.

The advantages due to good grading of aggregates can also be viewed from another angle. If concrete is viewed as a two phase material, paste phase and aggregate phase, it is the paste phase which is vulnerable to all ills of concrete. Paste is weaker than average aggregate in normal concrete with rare exceptions when very soft aggregates are used. The paste is more permeable than many of the mineral aggregates. It is the paste that is susceptible to deterioration by the attack of aggressive chemicals. In short, it is the paste which is a weak link in a mass of concrete. The lesser the quantity of such weak material, the better will be the concrete. This objective can be achieved by having well graded aggregates. Hence the importance of good grading.

Many researchers in the field of concrete technology, having fully understood the importance of good grading in making quality concrete being consistent with economy, have directed their studies to achieve good grading of aggregates at the constructional site. Neville (2003), concluded that grading for maximum density gives the highest strength, and that the grading curve of the best mixture resembles a parabola. Varshney (1982) in his work found that aggregate graded to produce maximum density gave a harsh mixture that is very difficult to place in ordinary concreting operations. He then proposed a method of proportioning based on the surface area of aggregate to be wetted.

Other things being equal, it was concluded that the concrete made from aggregate grading having least surface area will require least water which will consequently be the strongest. On the contrary, investigations have also revealed that the surface area of the aggregate may vary widely without causing much appreciable difference in the concrete strength, and that water required to produce a given consistency is dependent more on other characteristics of aggregate than on surface area. Therefore, a parameter known as “fineness modulus” for arriving at satisfactory grading is introduced. It is concluded that any sieve analysis curve of aggregate that will give the same fineness modulus will require the same quantity of water to produce a mix of the same plasticity and gives concrete of the same strength, so long as it is not too coarse for the quantity of cement used. The fineness modulus is an index of the coarseness or fineness of an aggregate sample, but, because different gradings can give the same fineness modulus, it does not define the grading (Shetty, 2001).

Many other methods have been suggested for arriving at an optimum grading. All these procedures, methods and formulae point to the fact that none is satisfactory and reliable for field application. At the site, a reliable satisfactory grading can only be decided by trial and error, which takes into consideration characteristics of the local materials with respect to size fraction, shape, surface texture, flakiness index and elongation index. The widely varying peculiarities of fine and coarse aggregates cannot be brought under formulae and set procedure for practical application.

One of the practical methods of arriving at the practical grading by trial and error method is to mix aggregates of different size fractions in different percentages and to choose the one sample which gives maximum weight or minimum voids per unit volume, out of all the alternative samples. Fractions which are actually available in the field, or which could be made available in the field including that of the fine aggregate will be used in making samples.

2.8.1.1 Gap Grading

The grading pattern of aggregates in which all particle sizes are present in certain proportion in a sample of aggregate has been discussed above. Such pattern of particle size distribution is referred to as continuous grading.

Neville and Brooks, (2003) state that, originally in the theory of continuous grading, it was assumed that the voids present in the higher size of the aggregate are filled up by the next lower size of aggregate, and similarly, voids created by the lower size are filled up by one size lower than those particles and so on. It was realized later that the voids created by a particular fraction are too small to accommodate the very next lower size. If the next lower size is to occupy the voids, it will create what is known as “particle size interference”, which prevents the large aggregates compacting to their maximum density. It has been seen that the size of voids existing between a particular size of aggregate is of the order of two or three size lower than the fraction. In other words, the void size existing between 40 mm aggregate is of the size equal of 10 mm or possibly 4.75 mm or the size of voids occurring when 20 mm aggregate is used will be in the order of say 1.18 mm or so. Therefore, along with 20 mm aggregate, only when 1.18 mm aggregate size is used, the sample will contain least voids and concrete requires least matrix. The following advantages (Neville and Brooks, 2003) are claimed for gap graded concrete aggregate:

- Sand required will be of the order of about 26 per cent as against about 40 per cent in the case of continuous grading.
- Specific surface area of the gap graded aggregate will be low as a result of high percentage of coarse aggregate and low percentage of fine aggregate.
- Requires less cement and lower water/cement ratio.
- Because of point contact between coarse aggregate to coarse aggregate and also on account of lower cement and matrix content, the drying shrinkage is reduced.

It was also observed that gap graded concrete needs close supervision, as it shows greater proneness to segregation and change in the anticipated workability. In spite of many claims of the superior properties of gap graded concrete, this method of grading has not become more popular than conventional continuous grading.

2.8.2 Maximum Size of Coarse Aggregate

CT 382 (2003) defines maximum aggregate size as the smallest sieve size that allows 100% passing of the material.

The largest maximum size of aggregate practicable to handle under a given set of conditions should be used. Perhaps, 80 mm size is the maximum size that could be conveniently used for concrete making. Using the largest possible maximum size will result in (i) reduction of the cement content, (ii) reduction in water requirement and (iii) reduction of drying shrinkage (Neville, 2003). However, the maximum size of aggregate that can be used in any given condition may be limited by the following conditions:

a) Thickness of the section
b) Spacing of reinforcement
c) Clear cover and
d) Mixing, handling and placing techniques

Generally, maximum size of coarse aggregate should be as large as possible within the limits specified (say 5mm to 40mm), but in no case greater than one-quarter of the minimum thickness of the member, provided that the concrete can be placed without difficulty so as to surround all reinforcement thoroughly and to fill the corners of the formwork. For heavily reinforced concrete members e.g. the ribs of main beams, the nominal maximum size of the aggregate should usually be restricted to 5mm less than the minimum lateral distance between the main bars or 5mm less than the minimum cover to the reinforcement, whichever is smaller.

Where, however, as in solid slabs, the reinforcement is widely spaced, limitation of the size of aggregate is not so important and the nominal maximum size may sometimes be as great as, or greater than the minimum cover, except where porous aggregates are used. For general purposes, a maximum size of 20mm is usually satisfactory. BS 5328 (1976) stipulates the preferred nominal maximum sizes of aggregates as 40mm, 20mm, 14mm and 10mm.

The larger the aggregate particle the smaller the surface area to be wetted per unit mass (i.e. specific surface). Thus, extending the grading of aggregate to a larger maximum size lowers the water requirement of the mix so that, for specified workability and richness of mix, water/cement ratio can be reduced with a consequent increase in strength. However, there is a limit of maximum aggregate size above which the decrease in water demand is offset by the detrimental effects of a lower bond area and of discontinuities introduced by the very large particles. In consequence, concrete becomes grossly heterogeneous, with a resulting lowering of strength.

The adverse effect of an increase in size of the largest particles in the mix exists, in fact, throughout the range of sizes, but below 40 mm the advantage of lowering of the water requirement is dominant. For larger sizes, the balance of the two effects depends on the richness of the mix. For example, in lean concrete containing 170kg/m^3 of cement, the use of 150 mm aggregate is advantageous (Neville, 2003). However, in structural concrete, the maximum size is usually restricted as already mentioned above.

Aggregates are divided into two categories from the consideration of size; (i) Coarse aggregate and (ii) Fine aggregate. The size of aggregate bigger than 4.75 mm is considered as coarse aggregate and aggregate whose size is 4.75 mm and less is considered as fine aggregate.

2.9 Unsoundness due to Impurities/Test Limits

There are two types of unsound aggregate particles: those that fail to maintain their integrity due to non-durable impurities, and those that lead to disruptive action on freezing or even on exposure to water, i.e. due to changes in volume as a result of changes in physical conditions (Neville and Brooks, 2003). Shale and other particles of low density are regarded as unsound, and so are soft inclusions, such as clay lumps, wood, shell and coal, as they lead to pitting and scaling. If present in large quantities (over 2 to 5 per cent of the mass of the concrete) these particles may adversely affect the strength of concrete and should certainly not be permitted in concrete which is exposed to abrasion. The presence of coal and other materials of low density can be determined by the method prescribed by ASTM C 123 – 92. Mica, gypsum and chlorides and other sulphates should be avoided, as well as sulphides (iron pyrites and marcasite). The permissible quantities of unsound particles laid down by BS 812 and ASTM C 33 – 92a are summarized in Table 2.21.

2.10 Mix Design of Concrete

ACI 211.1-91 (1994) defines mix design as the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible. The economic and technical factors and the procedures of estimating the mix quantities are very essential. Virtually always, the strength of concrete has to be considered. The actual cost of concrete is related to the materials required to produce a certain mean strength, but it is the minimum strength which is specified by the structural engineer (Shilstone, 1990). Normally, the strength for structural purposes is required at 28 days, but other considerations may dictate the strength at other ages, e.g. formwork striking times. Slow curing concretes, like those with pozzolanic portions, may require strengths at higher ages, e.g. 56, 90 and 116 days, depending on percentage of substance.

2.10.1 Variables in Proportioning

Abrams, (1981) states that with the given materials, the four variable factors to be considered, in connection with specifying concrete mixes are:-

- Water-Cement ratio
- Cement content or cement-aggregate ratio
- Gradation of the aggregates and consistency.

Table 2.21. Permissible Limits for Physical, Chemical and Mechanical Properties of Aggregates for Concrete.

Kind of Requirement	Test Method		Permissible Limits	
	BS 812	ASTM	Fine	Coarse
Grading	Part 103		STD	STD
Minerals finer than 0.075mm	Part 103			
Natural, Uncrushed/Crushed			Max. 3%	Max. 1%
Crushed Rock			Max. 7%	Max. 1%
Clay lumps & Friable Particles		C 142	Max. 1%	Max. 1%
Light weight pieces		C123	Max. 0.5%	Max. 0.5%
Organic Impurities, Test 8 of BS 1377			Max. 0.05%	
Water Absorption		C128/C127	Max. 2.3%	Max. 2%
Specific Gravity (Apparent)		C128/C127	Min. 2.6	Min. 2.6
Shell Content in Aggregates	Part 106			
Coarser than 10mm				Max. 5%
Between 5mm and 10mm				Max. 15%
Between 2.36mm and 5mm			Max. 10%	
Finer than 2.36mm			Note 1	
Particle Shape	Part 105.1			Max. 25%
Flakiness Index	& 105.2			Max. 25%
Elongation Index				
Acid Soluble Chlorides, CL for Reinforced Concretes.	Part 117 Appen. C			
Made with SRPC Cements			Max. 0.03%	Max. 0.01%
OPC & MSRPC Cements			Max. 0.05%	Max. 0.02%
For Mass Concrete made with SRPC			Max. 0.03%	Max. 0.02%
OPC & MSRPC Cements			Max. 0.05%	Max. 0.04%
For Prestressed & Concrete & Steam Cured Structural Concrete.			Max. 0.01%	Max. 0.01%
Acid Soluble Sulphates, SO_3	Part 118		Max. 0.3%	Max. 0.3%
Soundness $MgSO_4$ (5 cycles)		C88	Max. 12%	Max. 12%

Mechanical Strength	Part 111			Min. 100kN
10% Fine Value or	Part 112			Max. 30%
Impact Value		C131/C535		Max. 30%
Los Angeles Abrasion	Part 120			Max. 0.05%
Drying Shrinkage		C289	Innocuous	Innocuous
Potential Reactivity, Note 2 of Aggregate Chemical Method of Cement-Aggregate Combination		C227	6 months Expansion 0.10% Max.	6 months Expansion 0.10% Max

- **Note 1**: There is no requirement of shell content in sands passing 2.36mm size sieve.
- **Note 2:** Aggregates may initially be stressed for its reactivity in accordance with ASTM C289 and if potential reactivity is indicated, then mortar bar tests in accordance with ASTM C227 shall be carried out.

- **Sources: BS 812, BS 1377 (1994) and ASTM C142, C123, C127(1993)**

In general all four of these inter-related variables cannot be chosen or manipulated arbitrarily. Usually two or three factors are specified, and the other are adjusted to give minimum workability and economy. Water/cement ratio expresses the dilution of the paste (cement content varies directly with the amount of paste). Gradation of aggregate is controlled by varying the amount of given fine and coarse aggregate. Consistency is established by practical requirements of placing.

In brief, the effort in proportioning is to use a minimum amount of paste (and therefore cement) that will lubricate the mass while fresh and after hardening will bind the aggregate particle together and fill the space between them. Any excess of paste involves greater cost, greater drying shrinkage, greater susceptibility to percolation of water and therefore attack by aggressive waters and weathering action. This is achieved by minimising the voids by good gradation. For adequate consolidation of concrete, the desirable amount of fine aggregate content is usually 35% to 45% by mass or volume of the total aggregate content (ACI 201, 1992; Krell and Wischers, 1988).

2.10.2 Slump Test.

This is a test used extensively on site works all over the world. The slump test does not measure the workability of concrete, although ACI 116R – 90 (1994) describe it as a measure of consistency, the test is very useful in detecting variations in the uniformity of a mix of a given nominal proportions.

The slump test is prescribed by ASTM C 143 – 90a and BS 1881: Part 102: 1983. The approximate magnitude of slump for different workabilities (in a modified form of Bartos' proposal, 1992) is given in Table 2.22. Murdock, (1960) states that an increase in slump may mean, for instance, that the moisture content of aggregate has unexpectedly increased; another cause would be a change in the grading of the aggregate, such as a deficiency of sand. Too high or too low a slump gives immediate warning and enables the mixer operator to remedy the situation. This application of the slump test, as well as its simplicity, is responsible for its widespread use.

2.10.3 Density of Concrete

The density of concrete is a measurement of concrete's solidity. The process of mixing concrete can be modified to form a higher or lower density of concrete end product. A very high density of concrete is that made around steel cables that have been stretched

Table 2.22. Description of Workability and Magnitude of Slump.

Description of Workability	Slump mm
No Slump	0
Very low	5 – 10
Low	15 – 30
Medium	35 – 75
High	80 – 155
Very high	160 to collapse

Source: Bartos, (1992).

by hydraulic jacks. The concrete is allowed to harden and then the jacks are released. As the cables contract, they compress the concrete: a process known as prestressing. Compressed concrete is the strongest concrete there is and is used for bridges, roofs, and floors. On the other hand, concrete with air entrained in it works well in harsh weather and is used in roads and airport runways. Lightweight concrete uses pumice, a very lightweight mineral, as aggregate (www.aggregateresearch.com/articles/17902/understanding-the-density-of-oncrete.aspx.).

One way to determine the density of concrete is to first determine the density of the materials that go into it. Cement weighs 830 to 1,650 kilograms per cubic meter. Cement that is pneumatically loaded into cement silos is less dense, while cement that has been stored and exposed to vibration (as it would be if transported by truck) is more dense. The rule of thumb is to consider that a (50 kg*) bag of cement will make 0.028 cubic meter when it is freshly packed. It will naturally compress during transport.
Clearly, because of the large difference in bulk volume, cement should be measured by mass rather than volume.

As for concrete itself, the density of concrete of normal weight ranges from 2240 to 2400 kg/m^3. The concrete density varies depending on the amount and density of the aggregate, how much air is entrapped or purposely entrained, the cement concentration, and the maximum size of aggregate used. Lightweight concrete has a density of between 160 to 1920 kg/m^3 (Powers, 1968).
The concrete density is usually calculated by measuring some fresh concrete into a container of known volume and weighing it. Density is simply a mass to volume ratio.

$$\boldsymbol{\rho = m/V} \quad \text{……………………………………………..………..(Eq. 2.2)}$$

2.10.4 Compressive Strength of Concrete

The compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained therein (Neville and Brooks, 2003). The most common of all tests on hardened concrete is the compressive strength test, partly because it is an easy test to perform, and partly because many, though not all, of the desirable characteristics of concrete are qualitatively related to its strength; but mainly because of the intrinsic importance of the compressive strength of concrete in structural design.

**Note; 50kg bag of cement is equivalent to 110 Ib. bag of cement.*

According to Oladapo (1981), the strength test results may be affected by variation in: type of test specimen; specimen size; type of mould; curing; preparation of the end surface; rigidity of testing machine; and rate of application of stress. For this reason, testing should follow a single standard, with no departure from prescribed procedures. Compressive strength tests on specimens treated in a standard manner which includes full compaction and wet curing for a specified period give results representing the potential quality of the concrete.

Reynolds and Steedman, (1981) state that the compressive strengths vary from less than $10N/mm^2$ for lean concretes to more than $55N/mm^2$ for special concretes: the minimum characteristic strength of concrete made with dense aggregate, according to BS 8110: 1985, is $20N/mm^2$; for concrete made with lightweight aggregate, it is $15N/mm^2$.

BS 8110: Part 1: 1985, further states that for reinforced concrete, the lowest grade that should be used is C15 for concrete made with lightweight aggregates, and C25 for concrete made with normal-weight aggregates. Concerning age allowance for concrete, the standard stipulates that the design should be based on the 28 day characteristic strength unless there is evidence to justify a higher strength for a particular structure. Table 2.23 shows the cube strength of concrete at various ages.

2.10.5 Tensile Strength of Concrete

In design, tensile strength is used in both serviceability and ultimate limit state calculations. Bamforth *et al*, (2008), illustrate the following examples:

-In general, considerations of cracking, shear, punching shear, bond and anchorage.

-The evaluation of the cracking moment for pre-stressed elements.

-The design of reinforcement to control crack width and spacing resulting from restrained early-age thermal contraction.

-Developing moment-curvature diagrams and in the calculation of deflection. In the calculation of deflection, high tensile strengths lead to lower levels of cracking and lower deflection.

-The design of fibre-reinforced concrete.

-It is also used in the design of unreinforced concrete sections, for examples, concrete pavements.

Table 2.23. Compressive Strength of Concrete.

Grade	Characteristic Strength f_{cu} N/mm^2	Cube Strength at an age: 7 days N/mm^2	1 months N/mm^2	2 months N/mm^2	6 months N/mm^2	1 year N/mm^2
20	20.0	13.5	22	23	24	25
25	25.0	16.5	27.5	29	30	31
30	30.0	20	33	35	36	37
40	40.0	28	44	45.5	47.5	50
50	50.0	36	54	55.5	57.5	60

Source: BS 8110 – 2: (1985).

It should be noted that increasing the tensile strength may not necessarily be advantageous. For example, in the case of early thermal cracking, higher tensile strength requires an increased minimum steel ratio to accommodate the higher stress transferred to the steel when a crack occurs. In addition, higher strength normally requires concrete with a higher binder content and hence higher temperature rise and thermal strain (Bamforth *et al*, 2008).

Tensile strength is commonly defined in one of three ways: direct tensile strength, splitting tensile strength and flexural strength (BS EN 1992 1-1). Values derived from this Standard are shown in Table 2.24.

2.10.5.1 Flexural Tensile Strength of Concrete (Modulus of Rupture)

There is little influence of the type of the aggregate on the direct and splitting tensile strengths, but the flexural strength of concrete is greater when angular crushed aggregate is used than with rounded natural gravel. The explanation is that the improved bond of crushed aggregate holds the material together but is ineffective in direct or indirect tension (Neville, 2003).

The tensile strength is one of the basic and important properties of concrete. The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of concrete is necessary to find the load at which the concrete members may crack. When flexural tensile stresses are induced in the in-situ concrete by imposed service loading, the design tensile stresses are limited to the values given in Table 2.25 (BS 8110, Part 1: 1985).

The tensile strength of concrete is much lower than the compressive strength, largely because of the ease with which cracks can propagate under tensile loads. The tensile strength of concrete is measured in three ways: direct tension, splitting tension and flexural tension. Splitting tensile strength is generally greater than direct tensile strength and lower than flexural strength (modulus of rupture). It is difficult to test concrete in direct (uniaxial) tension because of the problem of gripping the specimen satisfactorily and because there must be no eccentricity of the applied load. Therefore, direct tensile test is not standardized and rarely used. Modulus of rupture (flexure) and splitting tests are commonly used to determine the tensile strength of concrete (Hannant, 1972).

Table 2.24. Values of Tensile Strength in relation to Strength class

Mix designation	**C12/16**	**C16/20**	**C20/25**	**C25/30**	**C30/37**	**C35/45**	**C40/50**	**C45/55**	**C50/60**	**C55/67**	**C60/75**	**C70/85**	**C80/95**	**C90/105**
Mean axial tensile strength f_{ctm} (N/mm^2)	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1	4.2	4.4	4.6	4.8	5.0
Mean splitting tensile strength $f_{ctm,sp}$ (N/mm^2)	1.7	2.1	2.5	2.8	3.2	3.6	3.9	4.2	4.5	4.7	4.8	5.1	5.4	5.6
Mean flexural tensile strength $f_{ctm,fl}$ (N/mm^2)	2.4	2.9	3.3	3.8	4.3	4.8	5.3	5.7	6.1	6.3	6.5	6.9	7.3	7.6

Source: BS EN 1992 1-1

Table 2.25. Design Flexural Tensile Stresses in In-Situ Concrete.

Grade of In-Situ Concrete	Maximum Tensile Stress (N/mm^2)
25	3.2
30	3.6
40	4.4
50	5.0

Source: Table 5.4 BS 8110 : Part 1 : (1985).

2.10.5.2 Split Tensile Strength of Concrete.

Splitting tensile strength is used in the design of structural lightweight concrete members to evaluate the shear resistance provided by concrete and to determine the development length of reinforcement (ASTM C496/C496M – 11). Compressive strength f_c and splitting tensile strength f_{spt} are two significant indexes in the design of concrete structures. Tensile strength is an important property of concrete because concrete structures are highly vulnerable to tensile cracking due to various kinds of effects and applied loading itself. However, tensile strength of concrete is very low if compared to its compressive strength (Zain *et al* 2002). Tensile strength is important for plain concrete structures such as dam under earthquake excitations. Other structures, for example, pavement slabs and airfield runways, which are designed based on bending strength are subjected to tensile stresses. Therefore, in the design of these structures, tensile strength is more important than compressive strength (Xu and Shi, 2009).

Due to difficulty in applying uniaxial tension to a concrete specimen, the tensile strength of concrete is determined by indirect test methods; split test and flexure test (Oluokun *et al* 1991). The splitting tests are well known indirect tests used for determining the tensile strength of concrete sometimes referred to as split tensile strength of concrete. The test consists of applying a compressive line load along the opposite generators of a concrete cylinder placed with its axis horizontal between the compressive platens. Similar to the splitting of cylinder, cubes can also be split either (a) along its middle parallel to the edges by applying opposite compressive forces through 15mm square bar of sufficient length or (b) along one of its diagonal planes by applying compressive forces along two opposite edges (Franklin and King, 1971). In the side splitting of cubes the tensile strength is obtained from;

$$\mathbf{f_{spt} = 0.642P/a^2} \qquad \text{(Eq. 2.3a)}$$

and in diagonal splitting, it is determined from;

$$\mathbf{f_{spt} = 0.5187P/a^2} \qquad \text{(Eq. 2.3b)}$$

where P is the failure load and 'a' is the length of the cube.

2.11 Gravel Mining, Supply and Demand

2.11.1 Mining and Environmental Effects

For thousands of years, gravel had been used in the construction of roads, dams and buildings (The Ojos Research Group, 2008). Major constituents of any of these structures, by volume or weight, are the aggregates. Very few structures in their permanent forms are made without the aggregates. Today demand for sand and gravel continues to increase at a geometric dimension (Lawal, 2011). Before these aggregates get incorporated into the structures, they undergo series of processes which entail multiple handling, involving various types of grades of labour and machines. This doubtlessly gives rise to a multiplier effect on the socio economic life of the society (Idiake, 2006). Many people get employed, more families have increased income and so on. As a matter of facts, it was asserted that in 2001 alone, a total of 7,131 sand and gravel mining operations reported employment statistics to the Mine Safety and Health Administration (MSHA) in its area of jurisdiction (NIOSH, 2003). However, it must be noted that this multiplier effects are being achieved at a costly expense to the environment and consequently to the inhabitants and other stakeholders. These stakeholders include the land owners of the mining sites, the local government authorities (LGAs) in whose jurisdictions the sites are domiciled, the respective state government of Nigeria, the farmers who might cultivate the land for crops or graze their cattle therein, the wildlife community whose habitat is the subject of mining activities and who eventually have to migrate, the aquatic community members in the affected rivers and finally, the miners.

Although, mining is expected to be regulated by law in many places, Whitehead (2007) opined that it is still many a times done illegally. It is rapidly becoming an ecological problem as the demand for gravel increases in construction industry. The environmental devaluation that is an aftermath of man's activities such as gravel mining on land include disturbance of landscape, ugly/distorted topography, agriculturally unproductive terrain, creation of pools of water for breeding pests, deforestation and general degrading of the ecosystem with air/land/water pollution.

Environment as used in this context has three components namely:

- The sum total of external condition in which the organisms exist.
- The organisms themselves including the floral and faunal community and
- The physical surroundings such as land forms.

All of these three including water, human and geo-morphological features are adversely affected by the gravel mining activities. Wikipedia (2008) and Alexander and Hansen (1983) listed as part of negative impact on the environment, the following: (a) disturbance to aquatic ecosystem, (b) increase in turbidity which in turns can affect aquatic species metabolism and interfere with spawning and (c) tertiary impacts to fauna.

Apart from petroleum exploration which brings the greatest pollution to the Niger Delta region, hazards on the environment brought about by sand/gravel mining activities are also very big and damaging (Adekoya, 1995; UNESCO/Mab, 1995; Aigbedon, 2005). The deliberate deforestation of an area for mine development may cause the elimination of some plants and exodus of some animal/bird species that feed on such plants or depend on them for cover (Adepelumi *et al*, 2006; Aigbedon and Iyayi, 2007).

The extensive mining of these building materials in southwestern Nigeria naturally results in fluctuation of ground water level which in turn leads to considerable variations in the concentration of geo-chemical and bacteriological pathogens in the water. Very importantly, this extensive mining brings about the lowering of alluvial water tables, channel destabilization and loss of aquatic and riparian habitat (Kondolf *et al,* 2001). Table 2.26 shows some of the registered companies mining gravel in south-western Nigeria. These exclude thousands of illegal miners spread all over the zones.

2.11.2 Factors Affecting Gravel Availability

Three factors affect the local availability of construction aggregates (gravel).

1) Demand; Consumption of gravel.
2) Supply; Natural distribution of aggregate resources.
3) Land-use conflicts
    a) Encroachments around existing gravel mining areas.
    b) Developments around existing gravel mining areas.
    c) Difficulty of permitting new mines
    d) Competing land uses such as perpetual conservation easements.

2.11.2.1 Demand

According to Mineral Information Institute (2006), "People use resources in everyday life." Aggregate makes up to 80% of concrete and 90% of asphalt and is demanded in the following applications; highways, homes and buildings, sewers/water system, sidewalks, bike paths, bridges and trails – a path through the countryside, roads, bike paths and trails, parking areas and recreation development. Future demand of gravel can

Table 2.26. Some Mining Companies of Gravel in Southwestern Nigeria.

S/N	**Company**	**Address**	**Zip/Postal Code**	**City/Region**	**Country**	**Phone No**
1	2nd Royal Gold Ent.	6 Alafia Street	23401	Lagos	Nigeria	+234-08034313582
2	Cobel Nig Ltd	Lagos	Lagos	Lagos	Nigeria	+234-08191938482
3	CV Nig Ltd	Ado-Ekiti	Ado-Ekiti	Ekiti State	Nigeria	+234-07064319446
4	Ezeg Ind. Ltd	Iwaraja, Along Ife/Akure Exp. Road	1005	Ilesha Osun State	Nigeria	+234-07033888631

Source: htpp://www.nipc.gov.ng (2012)

be influenced by population growth, personal income, statewide economic growth, state infrastructural needs and personal interest.

2.11.2.2 Supply

Aggregate occurs where nature placed it, not where people need it. Supply of aggregate near populated areas can be limited due to land use conflicts, sterilization; building over a deposit as cities grow or extend into rural areas, encroachment; new residential development near existing quarries and gravel pits and depletion; extracting the resource in existing mines at a higher rate. (Langer and Glanzman, 1993).

2.11.2.3 Effects of Transportation

Berek, (2005) narrates the impacts of transportation on the cost of aggregate as follows;

1) On average, for every 16 to 22.5km of haul distance, the cost of aggregate double in price.
2) Aggregate is a high bulk, low-value commodities.
3) Transportation accounts for a considerable amount of the delivered price.
4) Finding and accessing aggregate close to the market reduces the cost of publicly and privately funded construction projects.

2.12 Statistical Analysis

Dodge, (2006) defines statistics as the study of the collection, organization, analysis, interpretation and presentation of data. Statistical methods can summarise or describe a collection of data: this is called descriptive statistics. This is particularly useful in communicating the results of experiments and research. In addition, data patterns may be modeled in a way that accounts for randomness and uncertainty in the observations. These models can be used to draw inferences about the process or population under study – a practice called inferential statistics (Anderson, *et al* 1994).

2.12.1 Coefficient of Variation

The normalized measure of dispersion of a probability distribution is called coefficient of variation often abbreviated as CV. In probability theory and statistics, it is also known as unitised risk (en.wikipedia.org/wiki/statistics, accessed 20th December, 2012). When comparing between data sets with different units or widely different means, CV should be used for comparison.

Coefficient of variation provides a general feeling about the performance of a method. CVs of 5% or less generally give a feeling of a good performance, whereas, CVs of 10% and higher sound bad. However, one should look carefully at the mean value before judging a CV. At very low concentrations, the CV may be high and at high concentrations, the CV may be low (www.westgard.com/lesson34.htm,). The CV for a single variable aims to describe the dispersion of the variable in a way that does not depend on the variable's measurement unit. The higher the CV, the greater the dispersion in the variable. The CV for a model aims to describe the model fit in terms of the relative sizes of the squared residuals and outcome values. The lower the CV, the smaller the residuals relative to the predicted value. This is suggestive of a good model fit. Other application include knowledge of data consistency or data uniformity (www.ats.ucla.edu/statis/mult_pkg/fag/coefficient_of_variation.htm, accessed 22nd December 2012).

2.12.2 Correlation Coefficient

http://www.en.wikipedia.org/wiki/statistics. stresses that correlation coefficient is a vital aspect used to calculate the strength of correlation of two quantities. The dependence between two measures is obtained by dividing the covariance of the two variables by the multiplication of their standard deviations and is represented mathematically by; (Microsoft Excel 2007)

$$corr(x, y) = \frac{\Sigma(x - \bar{x})(y - \bar{y})}{\sqrt{\Sigma(x - \bar{x})^2 \Sigma(y - \bar{y})^2}} \quad \text{.................(Eq. 2.4)}$$

Where x and y are the sample means average(array 1) and average (array 2).

The well known measure of dependence is Pearson's correlation. The μ_x and μ_y represent the mean of the data set X and Y respectively.

www.ncalculators.com/statistics/correlation-coefficient-calculator.htm., states that if the magnitude of the correlation coefficient 'r' lies between 0.9 and 1.0, the variables of a data set are very highly correlated; if the correlation coefficient 'r' lies between 0.7 and 0.9, they are moderately correlated; if between 0.5 and 0.7, low correlation; linear correlation for 'r' between 0.3 and 0.5 and linear correlation if the magnitude is less than 0.3.

Furthermore, http://www.fao.org/docrep/w7295e/...../htm.statisticaltests. states that the correlation coefficient r is expressed as r^2, the coefficient of determination or coefficient of variance. The advantage of r^2 is that, when multiplied by 100, it indicates the percentage of variation in Y associated with variation in X. Thus for example, when r = 0.71 about 50% (r^2 = 0.504) of the variation in Y due to variation in X.

2.12.3 Regression Analysis

A linear regression line formula of Y = A + BX where X is the explanatory variable and Y is the dependent variable. The slope of the line is B and A is the intercept (the value of Y when X = 0). Linear functions are used to model the data in linear regression and the unknown model parameters are estimated from the data. Such method of modelling data is known as linear model. Generally, linear regression assign to a model in which the conditional linear of Y given the value of X is an affine function of X (http://www.en.wikipedia.org/wiki/statistics). The general purpose of multiple regression is to learn more about the relationship between several independent or predictor variables and a dependent variable. The equation is of the form;

$\mathbf{Y = a + b_1{*}X_1 + b_2{*}X_2 + \ldots\ldots b_p{*}X_p}$ ....(Eq. 2.5)

(www.statsoft.com/textbook/M1.)

CHAPTER THREE

3.0 METHODOLOGY

This is the process used to collect information and data for the purpose of making research decisions. The methodology includes publication research, interviews, surveys, collection of samples, laboratory experiments and other research techniques.

3.1 Administration of Questionnaires

In order to select gravel pits for the collection of samples for this study, the research instrument adopted for the work was two structured questionnaires which consisted of 18 and 16 questions that were targeted at gravel suppliers and bricklayers respectively. For both questionnaires, nine questions were based on demographic/social variables while the remaining questions were based on the perceived technical characteristics of gravel. The questionnaire was in English language but interpretations were made for illiterate respondents.

3.1.1 Population of the Survey

The objective of using questionnaire was to analyze people's views on location, availability, perceived qualities, areas of application, cost, etc of gravel in different parts of Southwestern Nigeria and to select sites for the study based on these views.

As a result of this, gravel suppliers (tipper drivers, association of gravel suppliers, etc) and the bricklayers who use these gravels on daily basis in construction were randomly selected as population for the study.

3.1.2 Sample Size and Sampling Procedure

In each of the six states under review, 400 copies of questionnaires were administered; 200 copies each were distributed to gravel suppliers and bricklayers making a total sample size of 2,400 copies.

The sampling procedure employed was purposive sample procedure which had a clear and definite purpose.

The outcome of this survey was generated from the responses gathered through the questionnaires designed and administered to gravel suppliers and bricklayers as respondents. The collated data was analysed based on quantitative method through the use of simple percentage (%) method of data analysis (Appendix B).

3.2 Field Work

Field work included inventory, identification/photographs and location of gravel pits to cover Southwestern Nigeria made up of Lagos, Oyo, Ogun, Osun, Ondo and Ekiti states. The age, profile and methods of quarrying and estimation of commercial availability at each pit were taken into consideration in the study. Samples were collected at selected pits and locations. Based on the outcome of this field work, 70 major commercially operated pits or sites were identified. The followings pits were selected for further studies;

State	**Location of Pits**
Ogun:-	Ago-Iwoye, Obafemi Owode and Abeokuta
Oyo:-	Igbo-ora, Ibadan and Iseyin
Osun;-	Ikire, Osogbo and Modakeke
Ondo:-	Laje road Ondo, Iju Itagbolu and Oke-Igbo
Ekiti:-	AdoEkiti,_Ikole-Ekiti and Igbara_Odo

The collected samples were marked for identification purpose e.g. OY 01 IB with OY representing Oyo State, 01 representing sample number and IB indicating town or local government area of collection.

3.2.1 Collection and Treatment of Samples

After the selection of gravel pits as identified in section 3.1.2 the sites were visited. The visit was made possible with the assistance of officials at tipper garages in each state and responses in the questionnaire. On getting to each site, the process of mining of gravels was evaluated and through these studies, it was realized that in all the sites, these processes were similar. The operations involved uprooting of trees, shrubs, stumps and clearing of grasses. Thereafter, the top soils were removed to a depth ranging from 1.0m to 3.0m depending on thickness of gravels. The pictures of the mining profiles, a depot and a tipper garage at selected locations in Southwestern Nigeria were shown in Plate 3 (a – k), Appendix C.

The gravel samples were collected at different levels both vertically and horizontally ensuring that there was a fair representation of samples in a particular location. They were kept in polythene bags which were sealed to prevent the moisture from drying up so as not to affect the natural conditions of the samples. After collection, these samples naturally contained stumps and dry leaves of trees, grasses and coated with silts and clays in some cases. These deleterious materials were removed by handpicking, sieving and thorough washing to prevent them from interfering with the natural characteristics values of the aggregates. Thereafter, the samples were carried to Nigerian Building and Road Research Institute Laboratory Complex at Ota Ogun State for physical tests, Chemistry Department of Yaba College of Technology for chemical tests, Oyo State Ministry of Works and Transport Ibadan for mechanical tests on gravel aggregates. Tests on fresh and hardened concrete were performed at Department of Civil Engineering, Covenant University, Ota.

3.3 Laboratory Tests of Gravels and Concrete Specimens

The following tests were conducted on all the gravel samples collected and all concrete specimens.

Physical Characteristics of Gravels;

- Sieve analysis to determine gradation or size distribution of gravel.
- Moisture content of gravel.
- Specific gravity that will help in the determination of mix design and to know the group that the aggregates falls into whether normal, lightweight or heavyweight aggregates..
- Shape and Texture of gravel aggregate
- Water absorption capacity of gravel aggregates.

Mechanical Characteristics;

- Aggregate abrasion values
- Aggregate crushing values and
- Aggregate impact values

Chemical Characteristics;

Among the chemical properties of the aggregates investigated were the followings;

- pH values to determine the degree of acidity or basicity (alkalinity) of the aggregates
- Carbonates content
- Chlorides content
- Sulphates content

- Organic content
- Alkali reactivity of gravel

Engineering Properties of Concrete using Gravel as Aggregates

Engineering properties determined on the concrete cubes and beams cast with the aggregates to measure the influence of the aggregate characteristics on concrete were;

- Slump test
- Compressive strength
- Flexural Tensile Strength (modulus of rupture)
- Splitting Tensile Strength
- Water Absorption test
- Densities

3.3.1 Physical Characteristics of Aggregates

The procedures adopted for these experiments were in accordance with BS 1377: 1994; Methods of tests for Soils for civil engineering purposes and series of BS 812: 1975 – 1990; Methods for testing coarse aggregates, American Standards for Testing Materials (ASTM C 40-87; C 289-87; C 136-92; and C 127-93) and Nigerian Code of Practice (NCP).

3.3.1.1 Gradation and Size Distribution of Gravel (Sieve Analysis)

Sieve analysis helps to determine the particle size distribution of the coarse and fine aggregates. This was carried out by sieving the aggregates as per BS 812: Part 103.1: 1985 and ASTM C 136-92. Different sieve sizes as standardized by the code were used and the aggregates passed through them.

The cleaned and dried sieves were nested on a fitting receiver in order of increasing aperture size from bottom to top. The dried residue was placed on the top coarsest sieve and covered with a fitting lid. Using the mechanical sieve shaker, the sieves were shaken for a sufficient time to separate the test sample into the size fractions determined by the sieve apertures used.

The results were calculated and reported as: the cumulative percentage by weight of the total sample and the percentage by weight of the total sample passing through one sieve and retained on the next smaller sieve, to the nearest 0.1 percent. The results of the sieve analysis were recorded graphically on a semi-log graph with particle size as abscissa (log scale) and the percentage smaller than the specified diameter as ordinate. The uniformity coefficient Cu, coefficient of curvature Cz and fineness modulus FM were determine.

3.3.1.2 Moisture Content

This test was done to determine the water content in gravel by oven drying method as per BS 812: Part 109: 1990. The water content (w) of the sample was equal to the mass of water divided by the mass of solids.

The gravel specimen was representative of the mass. The quantity of the specimen taken depended upon the gradation and the maximum size of particles. The oven-drying method provides a measure of the total water present in a sample of aggregate and is the definitive procedure. The water content was expressed as;

$$w = \frac{M_2 - M_3}{M_3 - M_1} \times 100\% \quad \text{..........(Eq. 3.1)}$$

where:

M_1 is the mass of dry container and its lid in g;
M_2 is the mass of the container, lid, and wet test portion in g;
M_3 is the mass of the container, lid, and dry test portion in g.
An average of three determinations was taken.

3.3.1.3 Specific Gravity

The method used covered the determination of the specific gravity of soil particles in accordance with BS 1377: 1990 and ASTM C 127-93. It was not suitable for soils containing more than 10% of stones retained on a 37.5mm BS test sieve and such stones were broken down to less than this size.

A sample weighing 400g was obtained in accordance with the procedure for the preparation of disturbed soil samples for test. The weight of gas jar with plate was determined as m_1; gas jar, plate and 400g sample as m_2; 500ml of water, gas jar and sample as m_3; and gas jar filled to the brim as m_4.

The specific gravity, Gs, of the soil particles was calculated from the equation:

$$\mathbf{Gs} = \frac{\mathbf{m_2 - m_1}}{\mathbf{(m_4 - m_1) - (m_3 - m_2)}} \quad \text{...(Eq. 3.2)}$$

where;

m_1 is the mass of gas jar and ground glass plate (g);

m_2 is the mass of gas jar, plate and soil (g);

m_3 is the mass of gas jar, plate, soil and water (g);

m_4 is the mass of gas jar, plate and water (g).

The specific gravity of the sample was reported to the nearest 0.01g.

3.3.1.4 Water Absorption Capacity

This test was carried out to determine the water absorption of coarse aggregates as per BS 812: Part 2: 1995 and ASTM C 127-93. For this test a sample not less than 2000g was used. The thoroughly washed sample was placed in wire basket, immersed in distilled water for a period of 24 hrs. The sample was removed from the basket, properly dried to remove all surface water and weighed (weight A). The surface dried sample was oven dried and weighed (weight D).

$$\mathbf{WAC_{grav} = [(A - D)/D] \times 100\%.} \quad \text{...(Eq. 3.3)}$$

where; A - is the mass of the saturated surface-dry aggregate in air (in g);
D - is the mass of the oven-dried aggregate in air (in g).

Two such tests were done and the individual and mean results reported.

3.3.1.5 Particle Shape and Texture

In addition to the petrological characters of aggregate, its external characteristics are of importance, in particular the particle shape and surface texture. Due to the effects of shape and texture on both the fresh concrete such as consistency and hardened concrete such as strength and durability, all the gravel samples were visually examined and classified according to BS 812: Part 1: 1975.

3.3.2 Mechanical Characteristics of Gravels

The following mechanical characteristics of the gravels were carried out

3.3.2.1 Los Angeles Aggregate Abrasion Value

This test was carried out to determine the abrasion value of coarse aggregates as per BS 812: Part 113: 1990 (Draft). The details are also available in ASTM C131 – 89 and ASTM C535.

The test sample consisted of clean aggregates which had been dried in an oven at 105 to 110^{o}C to a substantially constant weight (weight A).

The test sample and the abrasive charge were placed in the Los Angles abrasion testing machine and the machine rotated at a speed of 28 to 30 revolutions/minute for 500 revolutions. At the completion of the test, the material was discharged and sieved through 1.70mm IS Sieve.

The material coarser than 1.70mm IS Sieve was washed, dried in an oven at a temperature of 100 to 110^{o}C to a constant weight and weighed (Weight 'B'). The proportion of loss between weight 'A' and weight 'B' of the test sample was expressed as a percentage of the original weight of the test sample. This value was reported as,

AAV =3(A-B)/d x 100%. …………………………………………………..(Eq. 3.4)

Where;

A is the mass of specimen before abrasion (in g);

B is the mass of specimen after abrasion (in g);

d is the particle density of the aggregate (on saturated surface dried basis in Mg/m^3) determined in accordance with clause **5** of BS 812-2:1995.

3.3.2.2 Aggregate Impact Value

This test was carried out as per BS 812: Part 112: 1990 to determine the aggregate impact value of coarse aggregates. The sample was oven-dried for 4hrs. at prescribed temperature.

A quantity of aggregates was measured and tamped. The net weight of the aggregates in the measure was determined to the nearest gram (Weight ‘A’). The sample was given 15 blows, removed and sieved through a 2.36mm BS Sieve. The fraction passing through was weighed (Weight ‘B’). The fraction retained on the sieve was also weighed (Weight ‘C’). The ratio of the weight of the fines formed to the total sample weight was expressed as a percentage.

AIV = (B/A) x 100% ……………………………………………………..…(Eq. 3.5)

Two such tests were carried out and the mean of the results reported.

3.3.2.3 Aggregate Crushing Value, (ACV)

The aggregate crushing value is a value which indicates the ability of an aggregate to resist crushing. The lower the figure the stronger the aggregate, i.e. the greater its ability to resist crushing. The standard used to determine the aggregate crushing value is; BS 812: Part 110: 1990. A sample of 14mm. size chippings of the aggregate to be tested was weighed (weight A), placed in a steel mould in three equal layers and each layer tamped and a steel plunger inserted into the mould on top of the chippings. The chippings were subjected to a force rising to 400kN. over a period of 10 minutes by placing in a concrete crushing apparatus. The fine material, (passing a 2.36mm. sieve, weight B), produced, expressed as a percentage of the original mass is the aggregate crushing value, (ACV);

ACV = B/A*100% …………………………………………...……………..(Eq. 3.6)

3.3.3 Chemical Characteristics of Gravels

3.3.3.1 pH Value

The following procedures as per BS 1377: 1994 were used to determine the pH. Other chemical components were tested as described in Standard Methods of Chemical Analysis.

The finely ground sample was dried overnight at 105 ± 4^0C. 20 grams of the sample was placed in a 50 milliliter beaker. 20 milliliters of distilled water was added to the sample and stirred at regular intervals for 1 hour. The mixture was stirred well just before placing the electrodes deep in it and the pH of the mixture was measured.

3.3.3.2 Carbonate Content

This procedure is designed to determine the percentage of insoluble residue in carbonate aggregates using Hydrochloric Acid (HCL) solution to dissolve the carbonates.

The aggregate used in the test sample passed the 1.18mm sieve and retained on the 600 μm sieve. An oven dry sample weighing a minimum of 200 grams was used for the test. Only one test sample is necessary for each aggregate sampled. A 200 gram sample was substituted for the size specified. Concentrated HCL was used, but the initial additions were confined to quantities which produce controlled effervescence. 1000ml of distilled water was readily available to control excessive effervescence and to wash the residue from the sides of the container. The contents were stirred periodically with a glass rod.

3.3.3.3 Sulphate Content

This procedure is designed to determine resistance to disintegration by saturated solution of sodium sulfate in the coarse aggregates. The test was carried out in accordance with BS 812: Part 118: 1988

An aggregate sample was extracted with twice its own mass of distilled or demineralized water to remove water-soluble sulphate ions. The water-soluble sulphate content was determined by either an ion-exchange method or a gravimetric method.

The sulphates were extracted from a crushed sample of aggregate by dilute hydrochloric acid. Barium chloride solution was added to the extract. The precipitate of barium sulphate was collected, dried and weighed and the total sulphate content was calculated.

The total sulphate content was calculated as a percentage by mass of the dry aggregate from the equation:

$$\textbf{Percentage of } SO_4 = \frac{m_2 \times 34.3}{m_1} \quad \text{(Eq. 3.7)}$$

where;

m_1 is the 3g of the test portion accurately weighed to the nearest 0.001g

m_2 is the mass of precipitate obtained from the increase in mass (to the nearest 0.001g) of the crucible. 34.3 is a constant.

3.3.3.4 Alkali – Aggregate Reactivity

Concrete test prisms were prepared from the aggregate combination under test, and stored for a period of 52 weeks in conditions which would promote any potential alkali-silica reaction (BS 812: Part 123: 1999). During this time measurements were made at intervals to determine whether any expansion had occurred. In order to promote the development of any expansive forces and to ensure that slowly reacting aggregates were detected in the 52-week period.

Calculation and expression of results

The increase in length of each prism for each period of measurement, from the difference between A_0, B_0, etc. and the appropriate values, A_n, B_n, etc was calculated. where n is 1, 2, 4, 13, etc. Hence;

$$h_{an} = \frac{A_n - Ao}{la} \times 100 \qquad \text{(Eq. 3.8)}$$

where:

A_n is the comparator measurement of the prism at 4 weeks age;

A_0 is the initial comparator measurement of the prism;

l_a is the initial length of the prism.

Record this length change to the nearest 0.01 %.

3.3.4 Engineering Tests on Concretes Made with Gravels

Mix of ratio 1:2:4 with water/cement ratio of 0.60 was adopted. The Lafarge Elephant Portland cement (grade 42.5) manufactured by WAPCO complying with BS 12 1991 was used. The sharp sand used was obtained from Ogun River at Majidun in Ikorodu, Lagos state. In order to obtain adequately consolidated concrete, the ratio of fine to coarse aggregate adopted was 45:55 (ACI 201, 1992; Krell and Wischers, 1988). All the aforementioned were used as constant parameters for all the samples. However, the characteristics of each sample such as grading of gravels and their specific gravities as determined in the laboratory were varied. The concrete constituent materials were calculated based on absolute volume method of mix design.

3.3.4.1 Compression Test

The compressive strength f_c was determined in accordance with BS 1881: Parts 108, 111, 116: 1983 using 150mm cubes. Fourty five (45) number of test cubes were cast in steel moulds of prescribed dimensions and planeness with narrow tolerances, with the mould and its base clamped together and oiled. The mould was filled in layers of approximately 50 mm compacted each layer with 35 strokes. Further treatment of the test cubes was carried out in accordance with BS 1881: Part 111: 1983. After the top surface had been finished by trowel and labeled, the cubes were demoulded after 24 hours and cured. Three cubes were cast from each gravel sample and tested using Unit Test Scientific (UTS) crushing machine at 28 days.

As specified by BS 1881: Part 116: 1983 the cube was placed with the cast faces in contact with the platens of the testing machine, i.e. the position of the cubes as tested was at right angles to the position as cast. The load was applied at a constant rate of stress of 0.2 $N/mm^2/s$, and the crushing strength was reported to the nearest 0.5 N/mm^2.

3.3.4.2 Flexural Tensile Test

Mix of 1:2:4 was used for casting beams. 30 number plain beam specimens of sizes 150mm x 150mm x 750mm were cast. In the flexural strength test, beams were cast, cured for 28 days and tested for flexure (modulus of rupture) by the third point loading method. At the end of curing period, the beams were tested using Universal Testing Machine (UTM) at a rate of increase in stress of 0.02 $N/mm^2/s$. The test was carried out immediately in moist condition conforming to BS 1881; Part 118: 1983.

The flexural strength of the specimen is expressed as the modulus of rupture f_b, which if 'a' equals the distance between the line of fracture and the nearer support, measured on the central line of the tensile side of the specimen is calculated as follows;

$$f_b = \frac{Pa}{bd^2} \quad \text{(Eq. 3.9a)}$$

If 'a' is greater than 200mm for 150mm width specimen, or greater than 133mm for 100mm width specimen, and;

$$f_b = \frac{3Pa}{bd^2} \quad \text{(Eq. 3.9b)}$$

If 'a' is less than 200mm but greater than 170mm for 150mm width specimen or less than 133mm but greater than 110mm for 100mm width specimen, where;

b = measured width of the specimen

d = measured depth of the specimen at the point of failure

a = length of the span between the line of fracture and the nearer support, and

P = maximum or breaking load applied to the specimen.

If 'a' is less than 170mm for a 150mm specimen, or less than 110mm for a 100mm specimen, the results of the tests are discarded.

3.3.4.3 Splitting Tensile Strength Test

There is little influence of the type of the aggregate on the direct and splitting tensile strengths, but the flexural strength of concrete is greater when angular crushed aggregate is used than with rounded natural gravel. The explanation is that the improved bond of crushed aggregate holds the material together but is ineffective in direct or indirect tension (Neville and Brooks, 2003).

In the splitting test, 45 concrete cubes of the type used in compressive strength testing, was cast, placed, with its axis horizontal, between platens of a testing machine, and the load was increased until failure took place by splitting in the plane containing the vertical diameter of the specimen. This is prescribed by BS 1881: Part 117: 1983; ASTM C 496 – 90 prescribes a similar test. To prevent very high local compressive stresses at the load lines, narrow strips of packing material, such as hardboard or plywood, were interposed between the specimen and the platen.

The load was applied at a constant rate of increase in tensile stress of 0.02 to 0.04 $N/mm^2/s$ according to BS 1881: Part 117: 1983, (0.011 to 0.023 $N/mm^2/s$ according to ASTM C 496 – 90). The tensile splitting strength (fspt) was then calculated, to the nearest 0.05 N/mm^2 from;

$$\mathbf{f_{spt} = 0.518P/a^2} \quad \text{………………………………………………...………..(Eq. 3.10)}$$

where;

P = maximum load,

a = the side of the cube.

3.3.4.3.1 Calculations of Mix Proportions

In the proportioning of the constituent materials in the preparation of concrete specimens, all the following parameters were held constant for all the selected gravels. The parameters are; type of cement which was Lafarge Elephant Portland cement obtained from WAPCO in Ogun state with specific gravity of 3.15, sharp sand obtained from Majidun river in Ikorodu Lagos state with specific gravity of 2.65, water/cement ratio of 0.6, mix ratio of 1 : 2 : 4, ratio of fine sand to gravel of 45% : 55% and curing period of 28 days. The only varied parameter was the specific gravities of various gravels obtained from the laboratory. The calculations are as follows; Using sample OG. 01 AB as example.

Gravel from Abule Sikiru (OG. 01 AB) – Specific gravity = 2.60, percentage fine = 45%

C : S : A = 1 : 2 : 4, w/c = 0.60. Total of aggregate = 6

Therefore, C : S : A = 1 : (0.45 x 6) : (0.55 x 6)

Required mix design = 1 : 2.7 : 3.3

Using Absolute Volume Method,

$$\frac{C}{3.15} + \frac{2.7C}{2.65} + \frac{3.3C}{2.60} + \frac{0.6C}{1} = 1000 \quad \text{.........................(Eq. 3.11)}$$

Therefore, 6.89C + 22.11C + 27.55C + 13.02C = 21703.5

69.57C = 21703.5; C = 311.97 kg/m^3

Weight of ingredients per m^3 of concrete is as follows;

Cement = 311.97 x 1 = 311.97 kg

Sand = 311.97 x 2.7 = 842.32 kg

Gravel = 311.97 x 3.3 = 1029 50 kg

Water = 311.97 x 0.6 = 187.18 kg

Wet density of concrete = 2370.97 kg/m^3

Therefore, weight of ingredients per cube cast was as follows;

0.15 x 0.15 x 0.15 = 0.003375m^3

Cement = 311.97 x 0.003375 = 1.05 kg

Sand = 842.32 x 0.003375 = 2.84 kg

Gravel = 1029.50 x 0.003375 = 3.48 kg

Water = 187.18 x 0.003375 = 0.63 kg

The calculation was repeated for all the gravel samples using their SG and the results tabulated in Table 3.1 below. These results were used to prepare concrete cubes and beams to be used in the determination of compressive, flexural and split strength tests, as well as other tests such as density of concrete, slump of concrete and absorption capacity of concrete.

Table 3.1. Weight of Ingredients per m^3 Concrete for Six Numbers $0.15m^3$ Concrete Cubes and Two Numbers 0.15m x 0.15 x 0.75m Plain Concrete Beams.

S/N	Samples Location	Cement (kg)		Sand (kg)		Gravel (kg)		Water (kg)	
		$1m^3$ Con.	6x $0.15m^3$ & 2 Beams	$1m^3$ Con.	6x $0.15m^3$ & 2 Beams	$1m^3$ Con.	6x $0.15m^3$ & 2 Beams	$1m^3$ Con.	6x $0.15m^3$ & 2 Beams
1	OG. 01 AB	311.97	16.85	842.32	45.49	1029.50	55.59	187.82	10.14
2	OG. 02 AG	315.20	17.02	851.04	45.96	1040.16	56.17	189.12	10.21
3	OG. 03 OB	283.17	15.29	764.56	41.29	934.46	50.46	169.90	9.18
4	OY. 01 IG	320.62	17.31	865.67	46.75	1058.05	57.14	192.37	10.39
5	OY. 02 IB	280.10	15.13	756.27	40.84	924.33	49.91	168.06	9.08
6	OY. 03 IS	319.73	17.27	863.27	46.62	1055.11	56.98	191.84	10.36
7	OS. 01 OS	281.96	16.92	761.29	41.11	930.47	50.25	169.18	9.14
8	OS. 02 IK	303.52	16.39	819.50	44.25	1001.62	54.09	182.11	9.83
9	OS. 03 MD	311.53	16.82	841.13	45.42	1028.05	55.52	186.92	10.09
10	OD. 01 OD	323.20	17.45	872.64	47.12	1066.56	57.59	193.92	10.47
11	OD. 02 IJ	325.20	17.56	878.04	47.41	1073.16	57.95	195.12	10.54
12	OD. 03 OK	327.70	17.70	884.79	47.78	1081.41	58.40	196.62	10.62
13	EK. 01 AD	300.93	16.25	812.51	43.88	993.07	53.63	160.56	8.67
14	EK. 02 IK	301.99	16.31	815.37	44.03	996.57	53.82	181.19	9.78
15	EK. 03 IG	313.83	16.95	847.34	45.76	1035.64	55.93	188.30	10.17

3.3.4.4 Water Absorption Capacity Test of Concrete

Most concrete is only partly saturated and the initial ingress of water and dissolved salt is dominated at least initially, by capillary absorption rather than either water permeability or ion diffusion (Bakker, 1985).

A wide variety of water absorption tests on concrete have been developed. These tests measure the weight gain of a sample, volume of water entering the sample, depth of penetration or a combination thereof, by either complete immersion of dry samples in water, exposing only one face to water, or spraying the specimen surface with water. Absorption is either measured at a single arbitrary time or by measuring the rate of absorption (by change in mass). Although in all these tests, the absorption process is proportional to the square root of time over a specified time period, the sorptivity varies a great deal between test methods.

The absorption test was carried out in accordance with ASTM: C 642-90: Test Method for Specific Gravity, Absorption, and voids in Hardened Concrete and BS 1881: Part 122: 1983. The specimen was dried at 100 to 110 ^{0}C and immersed in water at 21 ^{0}C.

The water absorbed by an oven dried specimen was measured after at least 48 hours immersion in water. The ratio of water absorbed to the dry weight was calculated as the absorption of the aggregate. Most good concretes have absorption well below 10 per cent by mass (Lea, 1970).

$$\mathbf{WAC_{conc.}(\%) = \frac{Wsat - Wdry}{Wdry} \times 100} \quad \text{...........................(Eq. 3.12)}$$

WAC_{con}. - water absorption, in percentage, Wsat - weight of the saturated sample, Wdry - weight of the dry sample.

3.4 Statistical Techniques

The results obtained from the laboratory were compared with permissible limits given in different standard codes and specifications using descriptive analysis method.

Further analysis was carried out using a SPSS version 16.0 to evaluate the data set. The coefficient of variation of physical/geotechnical properties of gravel and concrete made with it was calculated to measure and compare the dispersion of the data sets.

Correlation coefficient was used, with compressive strength of concrete as the dependent variable and each of other characteristics of the gravel and concrete as independent variables.

Linear regression equation was developed with water absorption capacity of concrete ($WAC_{conc.}$) as dependent variable and water absorption capacity of gravel aggregate (WAC_{grav}) as independent variable thus;

WACconc = A + BWACgrav……………………………………………(Eq. 3.13)

Where;

A is intercept and B is the slope of the equation line.

Multiple regression was also developed between each of concrete strengths [Compressive(f_c), Split-tensile(f_{spt}) and flexural strengths(f_b)] as dependent variable and mechanical properties of gravel [aggregate impact value (AIV), aggregate crushing value (ACV) and aggregate abrasion value (AAV)] as independent or predictor variables. The following equations were arrived at;

Compressive (f_c) = a + b_1*AIV + b_2*ACV + b_3*AAV …………….…….(Eq. 3.14)

Split-tensile (f_{spt}) = a + b_1*AIV + b_2*ACV + b_3*AAV……………………(Eq. 3.15)

Flexure (f_b) = a + b_1*AIV +b_2*ACV +b_3*AAV…………………….…….(Eq. 3.16)

Where 'a' is intercept and 'b_1, b_2 and b_3 are slopes of the equations.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

Having completed the administration of questionnaires, collection of gravel samples from selected locations in Southwestern Nigeria, and laboratory tests on physical, mechanical, chemical and engineering characteristics of gravels, the results are hereby analysed and discussed. The analyses and discussions are in relation or in comparison with standard values and ANOVA earlier mentioned in the literature review (Chapter Two) of this Thesis. The sieve analysis and graphical representations of the results are shown in appendix D.

4.1 Results and Discussions of Questionnaire

Tables B1 to B6 which illustrate the results generated from questionnaires administered to the respondents are as shown in Appendix B.

4.1.1 Technical Variables

Some of the pits available and cost of gravels in each state were as listed in Table 4.1. It should be noted that no single pit is available in Lagos state. 95% of the respondents said they got their supply from Ogun state while the remaining 5% came from Igboora in Oyo state. Therefore, the exorbitant cost of gravel in Lagos state was largely due to non availability and increased demand as a result of huge population and high rate of property development in the state.

The texture of the gravel as mined is shown in Table B1 Appendix B. The opinion of the respondents was almost 50-50 as 52% felt that the gravels were smooth while 48% agreed that they were rough. This is also a function of the parent rocks.

In terms of the state of gravel, 95% of the respondents said the aggregates were clean with 5% saying that they were dirty (Table B2). This might be as a result of method of mining which is crude and manual.

Table 4.1. Pits Identified in each State, Ranges of Depth of Gravel and Prices*

State	Pits Identified	Depth of Gravel (m)	Price Range/3.5 ton Truck (N . k)
Lagos**	None; 95% of supply in Lagos was from Ogun state while the remaining 5% came from Oyo state (Igboora).	-	25,000:00-27000:00
Ogun	Abeokuta North, Obete in Odeda, Opeji, Obafemi Owode, Sikiru Village, Awowo, Ikene, Ogbere, Ago-Iwoye, Ijebu-Igbo, Ijebu-Ijesha.	2.2 – 3.0	5,000:00-7,000:00
Oyo	Ibadan(Erunmu, Egbeda, Akanran, Omi Adio, Apata, Ojebode, Lalupon, Ejioku, Moniya, Ido, Ayede, Alugbo, Alabata, Kasumu, Temidire, Owobale, Jago, Ajia), Oyo, Ibarapa(Igboora), Ogbomoso, Iseyin, Oke-Ogun(Igboho, Saki, Oke-Iho, etc).	1.7 – 2.5	7,500 00-15,000:00
Osun	Ikire, Ile-Ife, Modakeke, Ede, Oshogbo, Ilesha, Ila Orangun, Ikirun.	2.0 – 2.8	8,000:00-15,000:00
Ondo	Oka, Opa Road Ore, Laje Road, Ondo Reserve Site, Iju-Itagbolu Oke-Igbo, Aratundin, Owo, Akure.	1.8 – 3.0	10,000:00-12,000:00
Ekiti	Okiti Pupa, Emure Ekiti, Ikole Ekiti, Ipoti Ekiti, Ikare Ekiti, Aramoko Ekiti, Igbara Odo, Ilawe Ekiti, Igede Ekiti, Efon Alaye Ekiti, Ijero Ekiti, Ijesa Isu Ekiti, Ado Ekiti, Iworoko Ekiti, Ilumoba Ekiti, Asado Ekiti, Omuo Ekiti, Ilumode Ekiti, Osun Ekiti, Oye Ekiti	1.5 – 3.2	10,00:00-13,000:00

*The price quoted above was given between July 2010 and January 2011

**In Lagos state, no commercial gravel pit was identified. In other five states the lists were not exhausted.

As per Table B3, 87% of the respondents didn't wash the gravel before selling, but 13% of them carried out washing as only means of gravel treatment. The washed gravel is always more expensive than the unwashed one.

In Table B4, 100% of the respondents confirmed that the gravels did not contain more sand, silt or clay. This confirms that the gravel was clean.

According to Table B5, 94% of the respondents said that the gravels did not contain shells and plant roots, but 6% of them indicated that some gravel actually contained these deleterious materials.

Table B6 shows that 84% of the respondents said that the strength of concrete produced was excellent while 16% judged the strength of the concrete as good. It must be noted however that their judgments were based on experience rather than empirical evidence.

4.2 Results and Discussions of Physical Characteristics of Gravel

4.2.1 Particle Size Distribution/Sieve Analysis of Gravel

The process of dividing a sample of aggregate into fractions of the same particle size is known as sieve analysis, and its purpose is to determine the grading or size distribution of the aggregate. The results of the sieve analysis are reported in Appendix D. Column (4) show the mass retained on each sieve, while column (5) is the same quantity expressed as a percentage of the total mass of the sample. Hence, working from the finest size upwards, the cumulative percentage (to the nearest one percent) passing each sieve is calculated from cumulative percentage retained (column 7) and it is this percentage that is used in the plotting of the grading curve. The curve is plotted on a grading chart, where the ordinates represent the cumulative percentage passing and the abscissae are the sieve apertures plotted to a logarithmic scale, which gives a constant spacing for the standard series of sieves. The curves are shown in Appendix D, Figures 4.1 to 4.15.

It is discovered that none of the aggregates is retained on sieve sizes 75mm, 63mm and 50mm indicating that the maximum size of all the aggregates is less than 50mm. . According to the results of sieve analysis, using of CT 382 (2003), only sample OG. 02

AG has maximum aggregate size of 19.0mm, samples OG. 01 AB, OS.02 IK and EK. 02 IK each has maximum aggregate size of 25.0mm while the rest samples have maximum aggregate size of 37.5mm each. These aggregates therefore fall within the limits of 20mm or 40mm specified for structural concrete.

Table 4.2.1 below shows the values of Finest Modulus (FM), percentage finer than 10%, 30% and 60% which are D_{10}, D_{30} and D_{60} respectively. Also shown in this table are Uniformity Coefficient (Cu), Coefficient of Concavity (Cz) and maximum size of gravel. These values are obtained from sieve analysis and Figures 4.1 to 4.15 shown in Appendix D.

The values of FM which is a measure of aggregate coarseness range between 6.52 and 7.83 with average value of 6.93 for all the aggregates obtained and tested in selected locations in Southwestern Nigeria. The higher the FM, the coarser the aggregate. FM can also be used to calculate concrete mix proportion. Further analysis of Table 4.2.1 reveals that only sample obtained from Igbara Odo (EK. 03 IG) fulfills the conditions

Table 4.2.1. Values of FM, D_{10}, D_{30}, D_{60}, Cu, Cz and Maximum Size of Gravels from Selected Locations in Southwestern Nigeria.

Gravel Location	Code Name/Sample Description	FM=Cum% Passing/100	D_{10} (mm)	D_{30} (mm)	D_{60} (mm)	Cu= D_{60}/D_{10}	Cz = $D_{30}^2/(D_{10})(D_{60})$	Minimum Size of Gravel (mm)	Maximum Size of Gravel (mm)
Abule Sikiru	OG.01 AB	6.64	5.5	8.0	14.0	2.6	0.8	3.0	25.0
Ago Iwoye	OG.02 AG	6.65	8.0	12.0	14.0	1.8	1.3	3.35	19.0
Obafemi Owode	OG.03 OB	6.87	4.9	8.5	16	3.3	0.9	2.68	37.5
Igboora	OY.01 IG	6.97	8.0	10	16.5	2.1	0.8	2.0	37.5
Erunmu Ibadan	OY.02 IB	6.75	5.5	7.0	14.5	2.6	0.6	2.65	37.5
Dugbe Iseyin	OY.03 IS	7.83	16.0	23.0	27.0	1.7	1.2	4.75	37.5
Oko Awo Osogbo	OS. 01 OS	6.75	5.5	8.0	16.0	2.9	0.7	3.35	37.5
Ikire	OS. 02 IK	6.52	5.8	7.5	9.5	1.6	1.0	2.60	25.0
Toro Road Modakeke	OS.03 MD	6.92	5.8	10.0	18.0	3.1	1.0	3.35	37.5
Laje Road Ondo	OD.01 OD	6.52	5.9	8.5	10.0	1.7	1.2	2.35	37.5
Iju Itagbolu	OD. 02 IJ	6.55	8.0	9.0	13.0	1.6	0.8	3.0	37.5
Oke Igbo	OD.03 OK	6.84	7.0	9.0	16.0	2.3	0.7	4.75	37.5
Ado Ekiti	EK.01 AD	7.51	10.5	18.0	28.0	2.7	1.1	4.75	37.5
Ikole Ekiti	EK.02 IK	7.69	17.0	28.0	32.0	1.9	1.4	3.35	25.0
Igbara Odo	EK. 03 IG	6.92	4.1	10.0	24.0	5.9	1.0	2.60	37.5

for a well graded sample having Cu = 5.9 and Cz = 1.0. It should be noted that for a sample to be well graded, it must satisfy these conditions: Cu > 5 and $1 \leq Cz \leq 3$. Other samples partially fulfill these conditions. Furthermore, for a sample to be poorly or uniformly graded, the following conditions must be met: Cu < 5 and $Cz \leq 0.5$. None of the samples actually fulfill these conditions. The only samples close to meeting the conditions are OY. 02 IB, OS. 01 OS and OD. 03 OK

4.2.2 Moisture Content

Table 4.2.2 shows the values of moisture content of gravel. The mean value is 1.95 per cent with lowest value of 1.09 per cent for gravel sample (EK. 03 IG) collected from Igbara Odo in Ekiti state and the highest value of 2.95 per cent for sample (OY. 01 IG), Igboora gravel in Oyo State. According to Neville (1995), coarse aggregate rarely contains more than 1 percent of surface moisture but fine aggregate can contain in excess of 10 percent. The surface moisture is expressed as a percentage of the mass of the saturated and surface-dry aggregate, and is termed moisture content. Since absorption represents the water contained in a saturated and surface-dry condition, and the moisture content is the water in excess of that state, the total water content of a moist aggregate is equal to the sum of absorption and moisture content. The moisture content of aggregate depends on weather, so it needs to be frequently taken to determine its effects on concrete workability. ASTM C566 specifies moisture content of coarse aggregate to fall between 0.5% and 2%.

Table 4.2.2. Moisture Content (MC) of Gravels from Selected Locations in Southwestern Nigeria.

State	Sample Code	Moisture Content (%)			Mean Value (%)
		1	2	3	
Ogun	OG. 01 AB	2.76	2.42	2.30	2.49
	OG. 02 AG	1.95	1.62	1.97	1.85
	OG. 03 OB	1.38	1.61	1.44	1.48
Oyo	OY. 01 IG	3.0	3.14	2.70	2.95
	OY. 02 IB	1.91	1.91	1.85	1.89
	OY. 03 IS	1.44	1.04	1.48	1.32
Osun	OS. 01 OS	1.61	1.38	1.44	1.48
	OS. 02 IK	1.52	1.44	1.55	1.50
	OS. 03 MD	2.02	2.09	1.79	1.97
Ondo	OD. 01 OD	2.22	2.34	2.19	2.25
	OD. 02 IJ	2.45	2.20	2.32	2.32
	OD. 03 OK	2.41	2.43	2.42	2.42
Ekiti	EK. 01 AD	1.66	1.77	1.63	1.69
	EK. 02 IK	2.47	2.37	2.60	2.48
	EK. 03 IG	1.11	1.17	1.00	1.09

4.2.3 Water Absorption Capacity

All aggregates are porous, but some are more porous than others. How porous an aggregate is determines how much liquid may be absorbed when soaked in water. **AASHTO T85-10** defines absorption as the increase in the weight of aggregate because of water in the pores of the material, but not including water adhering to the outside surface of the particles. Absorption is expressed as a percentage of the dry weight. Absorption requirements are of concern only regarding aggregates used in hot mix asphalt and Portland cement concrete. The intent is to avoid using highly porous, absorptive aggregates because extra water and cement or asphalt is needed to make a good mix. However, some aggregates, such as blast furnace slag, may be used despite their high absorptive capacity because of other characteristics that make them desirable, including skid resistance, economics, etc.

The water absorption capacity being a measure of aggregates' porosity could be used to determine the rate of absorption of mixing water during concrete mixing. According to Table 2.21, chapter two of this thesis, ASTM C128/C127 specifies a maximum value of 2% water absorption for coarse aggregate.

A vivid examination of Table 4.2.3 reveals that the average values of water absorption vary from minimum of 0.48% for Ago Iwoye gravel in Ogun State to maximum of 1.40% for Igboora gravel in Oyo State. This shows clearly, therefore, that all the selected gravel samples from Southwestern Nigeria fall within stipulated specification of 2% maximum specified by ASTM C128/C127 standards.
It can therefore be inferred that these gravels are non-porous, durable and hard to the extent that the mixing water will not be absorbed during concrete mixing, hence, concrete strength will not be adversely affected as a result of mixing water.

4.2.4 Specific Gravity

It is rarely possible to use specific gravity as an index for soils classification. But knowledge of the specific gravity is essential in relation to some other soil tests, especially for calculating porosity and void ratio and is particularly important when compaction and consolidation properties are to be considered. The specific gravity must also be known for the computation of particle size for analysis from a sedimentation readings. It should also be noted that values of specific gravity of aggregates are used in

Table 4.2.3. Water Absorption Capacity (WAC) of Gravels from Selected Locations in Southwestern Nigeria.

State	Sample Code	Water Absorption Capacity (%)		Mean Value (%)
		1	2	
Ogun	OG. 01 AB	1.11	1.01	1.06
	OG. 02 AG	0.49	0.47	0.48
	OG. 03 OB	0.46	0.53	0.49
Oyo	OY. 01 IG	1.44	1.35	1.40
	OY. 02 IB	0.48	0.46	0.47
	OY. 03 IS	0.48	0.59	0.54
Osun	OS. 01 OS	0.54	0.58	0.56
	OS. 02 IK	0.51	0.48	0.50
	OS. 03 MD	0.51	0.61	0.56
Ondo	OD. 01 OD	0.56	0.52	0.54
	OD. 02 IJ	0.61	0.53	0.57
	OD. 03 OK	1.20	1.45	1.33
Ekiti	EK. 01 AD	0.55	0.49	0.52
	EK. 02 IK	1.24	1.10	1.17
	EK. 03 IG	0.56	0.57	0.57

calculation or design of mix ratios of concrete when translating from weight to volume proportions.

Particles such as diatomaceous earth may have specific gravity values below 2.0, while soils containing heavy substances, such as iron, may have specific gravity values above 3.0 (Head, 1980). In addition, ASTM C128/127 specifies minimum specific gravity value of 2.6 for coarse aggregate.

Analysis of Tables 4.2.4 shows that gravels from Abule Sikiru (OG. 01 AB), Ago Iwoye (OG. 02 AG), Igboora (OY. 01 IG), Dugbe (OY. 03 IS), Laje Road (OD. 01 OD), Iju Itagbolu (OD. 02 IJ, Oke Igbo (OD. 03 OK) and Igbara Odo (EK. 03 IG) all conform with the specification, having their specific gravity values greater or equal to 2.60. Low specific gravity values of 2.07, 2.02 and 2.05 for gravels from OG. 03 OB, OY. 02 IB and OS. 01 OS respectively might be due to presence of air content and or diatomaceous earth in the gravels (www.globalsecurity.org). Others have their values lying between normal weight and light-weight aggregates.

4.2.5 Particle Shape and Texture

The shape of aggregates, from whatever source, plays a crucial role in determining the properties of the composite material in which they are embedded. On the other hand surface texture of the aggregate affects its bond to the cement paste and also influences the water demand of the mix, workability and coarse aggregate-mortar bond strength.

Table 4.2.5 below reveals the results of visual examination of the shape and texture of gravel samples. A scrutiny of the table indicates that the shape of 11 gravel samples is irregular. Three samples combine irregular and angular shape while one exhibits fairly rounded shape. In terms of texture, all the samples but one have rough texture. The only one with smooth texture is sample OY. 02 IB which is also the only sample with almost rounded shape.

The implication of this result is that there is tendency for these aggregates to bond perfectly with cement paste thereby leading to very high strength concretes.

Table 4.2.4. Specific Gravity (Gs) of Gravels from Selected Locations in Southwestern Nigeria.

State	Sample Code	Specific Gravity			Mean Value
		1	2	3	
Ogun	OG. 01 AB	2.60	2.61	2.60	2.60
	OG. 02 AG	2.67	2.67	2.67	2.67
	OG. 03 OB	2.07	2.07	2.06	2.07
Oyo	OY. 01 IG	2.78	2.80	2.78	2.79
	OY. 02 IB	2.02	2.01	2.02	2.02
	OY. 03 IS	2.78	2.76	2.76	2.77
Osun	OS. 01 OS	2.04	2.06	2.04	2.05
	OS. 02 IK	2.42	2.44	2.44	2.43
	OS. 03 MD	2.58	2.61	2.58	2.59
Ondo	OD. 01 OD	2.86	2.84	2.84	2.85
	OD. 02 IJ	2.90	2.92	2.88	2.90
	OD. 03 OK	2.96	3.00	2.96	2.97
Ekiti	EK. 01 AD	2.38	2.40	2.37	2.38
	EK. 02 IK	2.40	2.40	2.40	2.40
	EK. 03 IG	2.63	2.65	2.65	2.64

Table 4.2.5. Visual Examination of Particle Shape and Texture of Gravel.

Sample Code	Shape	Texture
OG. 01 AB	Irregular	Rough
OG. 02 AG	Irregular/Angular	Rough
OG. 03 OB	Irregular/few elongated	Rough
OY. 01 IG	Irregular/Angular	Rough/dull
OY. 02 IB	Irregular/few Rounded	Smooth
OY. 03 IS	Irregular	Rough
OS. 01 OS	Irregular/Angular	Rough
OS. 02 IK	Irregular	Rough/vitreous tiny material
OS. 03 MD	Irregular	Rough
OD. 01 OD	Irregular	Rough
OD. 02 IJ	Irregular	Rough
OD 03 OK	Irregular/few elongated	Rough
EK. 01 AD	Irregular	Rough
EK. 02 IK	Irregular	Rough
EK. 03 IG	Irregular	Rough

4.3 Results and Discussions of Mechanical Characteristics of Gravel

The results of laboratory tests on Aggregate Impact Values (AIV), Aggregate Crushing Values (ACV) and Los Angeles Abrasion Values (AAV) of gravel aggregate are shown in Tables 4.3.1, 4.3.2 and 4.3.3 respectively.

4.3.1 Aggregate Impact Value (AIV)

The results of aggregate impact value tests are as shown in Tables 4.3.1. The average values of aggregate impact value vary from 28% for Ikire gravel in Osun State to maximum of 50% for gravel obtained from Igbara – Odo in Ekiti State. Referring to Table 2.18 in chapter two, it is observed that none of the gravel samples from all the Southwestern states meet the specification of 25% maximum specified for heavy duty concrete floor finishes.

However, the aggregate impact value of 30% is specified for pavement wearing surfaces. Only two samples; OS. 02 IK and OY. 03 IS with aggregate impact values of 28% and 30% respectively fall within this specification.

For other concretes maximum aggregate impact value of 45% is specified. Samples OG. 02 AG, OG. 03 OB, OY. 02 IB, OS. 01 OS, OS. 03 MD, OD. 01 OD, OD. 02 IJ, OD. 03 OK, EK. 01 AD and EK. 02 IK all satisfy this condition. However, samples OG. 01 AB, OY. 01 IG and EK.03 IG fail to meet any of the specifications as their values of 49%, 49% and 50% respectively are not within the limiting values.

4.3.2 Aggregate Crushing Value (ACV)

Table 4.3.2 below shows the average ACV of gravels from different locations in Southwestern Nigeria. According to (Shetty, 2001), the aggregate crushing value should not be more than 45 per cent for aggregate used for concrete other than for wearing surfaces, and 30 per cent for concrete used for wearing surfaces such as runways, roads and air field pavements. Based on these assertions, it can therefore be inferred from the Table that samples OG. 03 OB and OS. 03 MD from Obafemi Owode and Modakeke which have aggregate crushing values of 25 and 30 per cent respectively can be used for concrete in runways, roads and air field pavements. The remaining thirteen samples also fall within the permissible values of 45 per cent for other purposes; therefore, they can also be used for concrete other than for wearing surfaces.

Table 4.3.1. Aggregate Impact Value (AIV) of Gravels from Selected Locations in Southwestern Nigeria.

State	Sample Code	Aggregate Impact Value (%)		Average Value (%)
		1	2	
Ogun	OG. 01 AB	50	48	49
	OG. 02 AG	38	37	38
	OG. 03 OB	33	33	33
Oyo	OY. 01 IG	48	50	49
	OY. 02 IB	43	45	44
	OY. 03 IS	29	31	30
Osun	OS. 01 OS	34	34	34
	OS. 02 IK	29	26	28
	OS. 03 MD	31	30	31
Ondo	OD. 01 OD	43	43	43
	OD. 02 IJ	40	40	40
	OD. 03 OK	43	40	42
Ekiti	EK. 01 AD	40	43	42
	EK. 02 IK	37	38	38
	EK. 03 IG	51	49	50

Table 4.3.2. Aggregate Crushing Values (ACV) of Gravels Obtained from Selected Locations in Southwestern Nigeria.

State	Sample Code	First Trial Wt. Tested (g)	First Trial Wt. of fine (g)	First Trial ACV (%)	Second Trial Wt. Tested (g)	Second Trial Wt. of fine (g)	Second Trial ACV (%)	Average ACV (%)
Ogun	OG. 01 AB	2636	805	31	2640	845	32	32
	OG. 02 AG	2225	716	32	2227	690	31	32
	OG. 03 OB	2278	538	24	2290	595	26	25
Oyo	OY. 01 IG	2437	824	34	2441	830	34	34
	OY. 02 IB	2044	807	40	2043	797	39	40
	OY. 03 IS	2267	738	33	2274	682	30	32
Osun	OS. 01 OS	2356	745	32	2357	707	30	31
	OS. 02 IK	2431	936	39	2437	926	38	39
	OS. 03 MD	2018	620	31	2023	587	29	30
Ondo	OD. 01 OD	2284	809	35	2280	798	35	35
	OD. 02 IJ	2615	805	31	2630	789	30	31
	OD. 03 OK	2520	795	32	2519	806	32	32
Ekiti	EK. 01 AD	2281	719	32	2288	778	34	33
	EK. 02 IK	2460	800	33	2455	786	32	33
	EK. 03 IG	2420	840	35	2425	800	33	34

4.3.3 Los Angles Abrasion Value (AAV)

The results of Los Angeles Abrasion Value (AAV) are reported in Table 4.3.3 below. The values range from the lowest value of 40.7 per cent for gravel sample OS. 03 MD to the highest value of 44.98 per cent for sample OY. 01 IG. According to permissible limits for physical, chemical and mechanical properties of aggregates for concrete shown in Table 2.21, ASTM C131 specifies maximum value of 30 per cent for AAV of aggregate. In line with this requirement, it is discovered that none of the gravel aggregates satisfies this condition. This in essence means that these gravels cannot be used in applications where abrasion is a major requirement for construction purposes. However, ASTM C33 'concrete aggregate' specifies a maximum mass loss of 50 per cent for gravel, crushed gravel or crushed stone. In accordance with this, all the gravel samples are suitable as concrete aggregate. Also, ASTM C535 specifies maximum AAV value of 45 per cent for materials for stone pitching. Base on this latter specification it is discovered that the AAV values of all gravel samples fall within this specification as well. The gravel aggregates from the selected locations in South-Western Nigeria are therefore useful in applications such as stone pitching.

4.4 Chemical Characteristics of Gravels

Table 4.4.1 below shows the results of various chemical tests performed on the gravels. These tests include pH values, carbonate content, chloride content, sulphate content, organic content and alkali reactivity of the gravels. The results are as analysed in the following sections.

4.4.1 pH Values

The pH of a solution is a measure of the molar concentration of hydrogen ions in the solution and as such is a measure of the acidity or basicity of the solution. The letters pH stands for "power of hydrogen" and numerical value for pH is just the negative of the power of 10 of the molar concentration of H+ ions.

The usual range of pH values encountered is between 0 and 14, with 0 being the value for concentrated hydrochloric acid (1 M HCl), 7 is the value for pure water (neutral pH), and 14 being the value for concentrated sodium hydroxide (1 M NaOH). It is possible to get a pH of -1 with 10 M HCl, but that is about a practical limit of acidity. At the other extreme, a 10 M solution of NaOH would have a pH of 15 (Shipman *et al* 1993).

Table 4.3.3. Los Angeles Abrasion Values (AAV) of Gravels obtained from Selected Locations in South Western Nigeria.

State	Sample Description.	Trial	Total Wt. Tested (kg)	No. of Spheres used.	Wt of fines retained (kg)	AAV Value (%)	Average AAV value (%)
Ogun	OG.01 AB	1	2500	6	1090	43.60	43.56
		2	2500	6	1088	43.52	
	OG. 02 AG	1	2600	6	1100	42.31	42.6
		2	2600	6	1115	42.89	
	OG. 03 OB	1	2500	6	1112	44.48	44.48
		2	2500	6	1112	44.48	
Oyo	OY. 01 IG	1	2450	6	1103	45.02	44.98
		2	2450	6	1101	44.94	
	OY. 02 IB	1	2450	6	1110	45.31	45.27
		2	2450	6	1108	45.23	
	OY. 03 IS	1	2500	6	1030	41.20	41.20
		2	2500	6	1030	41.20	
Osun	OS. 01 OS	1	2500	6	1110	44.40	44.46
		2	2500	6	1113	44.52	
	OS. 02 IK	1	2500	6	1120	44.80	44.74
		2	2500	6	1117	44.68	
	OS. 03 MD	1	2500	6	1020	40.80	40.70
		2	2500	6	1015	40.60	
Ondo	OD. 01 OD	1	2500	6	1090	43.60	43.40
		2	2500	6	1080	43.20	
	OD. 02 IJ	1	2500	6	1111	44.44	44.44
		2	2500	6	1111	44.44	
	OD. 03 OK	1	2500	6	1125	45.00	44.86
		2	2500	6	1118	44.72	
Ekiti	EK. 01 AD	1	2500	6	1040	41.60	41.68
		2	2500	6	1044	41.76	
	EK. 02 IK	1	2500	6	1096	43.84	43.72
		2	2500	6	1090	43.60	
	EK. 03 IG	1	2500	6	1115	44.60	44.58
		2	2500	6	1114	44.56	

The strongly alkaline nature of $Ca(OH)_2$ (pH of about 13) prevents the corrosion of the steel reinforcement by the formation of a thin protective film of iron oxide on the metal surface; this protection is known as passivity. However, if the concrete is permeable to the extent that carbonation reaches the concrete in contact with the steel or soluble chlorides can penetrate right up to the reinforcement, and water and oxygen are present, then corrosion of reinforcement will take place (Neville and Brooks, 2003).

No Portland cement is resistant to attack by acids. In damp conditions, sulphur dioxide (SO_2) and carbon dioxide (CO_2), as well as some other fumes present in the atmosphere, form acids which attack concrete by dissolving and removing a part, of the hydrated cement paste and leave a soft and very weak mass. This form of attack is encountered in various industrial conditions, such as chimneys, and in some agricultural conditions, such as floors of dairies (Neville, 1983).

In practice, the degree of attack increases as acidity increases; attack occurs at values of pH below about 6.5, a pH of less than 4.5 leading to severe attack. The rate of attack also depends on the ability of hydrogen ions to be diffused through the cement gel (C-S-H) after $Ca(OH)_2$ has been dissolved and leached out (C. L. Page, 1985).

The essence of carrying out this test is to know the level of acidity in the aggregates to avoid corrosion of reinforcement in concrete produced with these aggregates. Corrosion of iron rods is an undesirable effect in concrete and effort should be made especially at planning stage while selecting the materials to guide against it.

Examination of Table 4.4.1 above shows the range of pH values from 6.36 for sample OG 03 OB to a maximum value of 8.69 for sample OG 02 AG. It is observed that the pH values of all the samples revolve around 7 which is the neutral point. Hence, apart from samples OG. 03 OB; OY. 03 IS; OD. 02 IJ; OD. 03 OK and EK. 01 AD which are liable to acid attack, because their pH values are less than 6.5, all other samples are safe and free from acid attack.

Table 4.4.1. Chemical Characteristics of Gravels from Selected Locations in Southwestern Nigeria.

State	Sample Code Name	pH	CO_3^{2-} %	Cl^- %	SO_4^{2-} %	Organic Content %	Alkali Reactivity ppm (%)
Ogun	OG. 01 AB	7.75	3.5	0.72	1.81	0.40	28 (0.003)
	OG. 02 AG	8.69	11.0	1.12	1.53	0.30	88 (0.009)
	OG. 03 OB	6.36	4.0	0.68	1.11	0.26	32 (0.003)
Oyo	OY. 01 IG	7.43	3.0	1.20	2.70	1.02	24 (0.002)
	OY. 02 IB	6.56	6.0	1.08	0.76	0.07	48 (0.005)
	OY. 03 IS	6.43	5.0	0.72	1.63	0.35	40 (0.004)
Osun	OS. 01 OS	7.54	3.5	1.12	1.40	0.62	28 (0.003)
	OS. 02 IK	7.01	4.5	0.68	1.65	1.25	36 (0.004)
	OS. 03 MD	6.64	4.5	0.92	0.93	0.39	36 (0.004)
Ondo	OD. 01 OD	7.75	7.5	1.44	1.48	0.87	60 (0.006)
	OD. 02 IJ	6.49	6.0	1.04	1.07	0.08	48 (0.005)
	OD. 03 OK	6.38	3.5	0.30	0.88	0.30	28 (0.003)
Ekiti	EK. 01 AD	6.43	4.0	0.80	1.48	1.76	32 (0.003)
	EK. 02 IK	7.97	7.5	1.12	3.80	1.49	60 (0.006)
	EK. 03 IG	7.82	4.5	0.84	1.46	0.09	36 (0.004)

4.4.2 Carbonate Content

The percentage of carbonate content of gravels is as shown in Table 4.4.1. The values range from the lowest value of 3.5 per cent for OG. 01 AB sample to the highest value of 11.0 per cent for OG. 02 AG. Incidentally, the two samples are from Ogun state, but different locations in the state.

The effects of carbonate in aggregate have been described as undesirable. This is because the carbonate will absorb the water from the wet mix. Hence the water which the cement would have used for hydration will be inadequate leading to lesser concrete strength. Another problem is inadequate compaction especially in mass concrete which may result in structural failure.

MnDOT has set a criterium for carbonate content in aggregate to be ≤ 30 per cent for the aggregate to be accepted as concrete aggregate. Base on this, the values of carbonate content for gravels from selected locations of Southwestern Nigeria are well within this limit and can therefore be said to be all acceptable as concrete aggregate.

4.4.3 Chloride Content

The levels of soluble sulphate and chloride contaminants in the aggregates need to be monitored in order to ensure the durability of the concrete. Whatever the source of such contamination – cement, water, sand, coarse aggregate (gravel) or admixture – the total soluble sulphate and chloride ion in the concrete contributed by all the sources should not exceed the limits given in Table 2.19 of chapter two.

However, Table 2.21 gives specific permissible limits in accordance with BS 812; Part 117 Apen. C for acid soluble chlorides content in coarse aggregate as; Permissible values for reinforced concretes, made with SRPC and OPC/MSRPC cements are max. 0.01% and 0.02% respectively. Mass concrete made with SRPC and OPC/MSRPC cements are max. 0.02% and 0.04% respectively, while prestressed concrete and steam cured structural concrete should be maximum value of 0.01%.

Chloride ions present in the cement paste surrounding the reinforcement react at anodic sites to form hydrochloric acid which destroys the passive protective film on the steel. The surface of the steel then becomes activated locally to form anode, with the passive surface forming the cathodes (Neville and Brooks, 2003).

Analysis of Table 4.4.1 indicates an average value of 0.92%. The highest value of 1.44% is for sample OD. 01 OD (Laje Road Ondo) and the lowest value of 0.30% is for OD. 03 OK (Oke Igbo also in Ondo State). These values are far greater than the permissible values given by standards. On the basis of these findings, preliminary cautions must be taken in the usage of these samples to avoid the corrosion of reinforcements in concrete. Such cautions may include proper washing and use of special cements and admixtures that will neutralize the effects of chloride without compromising on the strength, durability and other properties of concrete. However, these gravels are suitable for mass concrete.

4.4.4 Sulphate Content

Due to adverse effects of soluble sulphate in concrete, Table 2.19 in chapter two also specifies the limit for total sulphate content from all sources (cement, water, sand, coarse aggregate and admixtures) not to exceed 4.0% for plain, reinforced and prestressed concretes. Table 2.21 in accordance with BS 812; Part 118 gives maximum value of 0.3% as permissible limit from only acid soluble sulphates.

The results from laboratory as shown in Table 4.4.1 gives average value of 1.54%. The maximum value of 3.80% is obtained from sample EK. 02 IK (Ikole Ekiti in Ekiti state) while the lowest value of 0.76% is got from sample OY. 02 IB (Erunmu, Ibadan, Oyo state). The values of all the samples selected from southwestern Nigeria do not fall within the permissible limit of 0.3%. This again calls for extra cautions such as washing of aggregate and use of special cement like sulphate resisting Portland cement (SRPC) as long term effects of these high values on concrete will be disastrous.

4.4.5 Organic Content

This test is used for an approximate determination of the presence of injurious organic compounds in aggregates that are to be used in cement mortar or concrete (ASTM C40, 1987). The test is normally conducted when there is strong suspicion that organic material may be present in the aggregate. ASTM C40 (1987) indicates that this test is significance in making a preliminary determination of the acceptability of aggregates with respect to the requirement of ASTM C33 specifications.

According to BS 1377 Part 3, Method 3, the permissible limit of organic content is 0.2% maximum. Table 4.4.1 reveals that sample EK. 01 AD has maximum value of 1.76% while sample OY. 02 IB has minimum value of 0.07%. Samples OY. 02 IB, OD.

02 IJ and EK. 03 IG with organic content values of 0.07%, 0.08% and 0.09% respectively fall within the permissible value of 0.2% maximum recommended by the standard. The values of other twelve selected samples do not conform to the standard.

4.4.6 Alkali-Aggregate Reactivity

Alkali-aggregate reaction is a chemical reaction between certain types of aggregates and hydroxyl ions (OH-) associated with alkalis in the cement. Usually, the alkalis come from the Portland cement but they may also come from other ingredients in the concrete or from the environment. Under some conditions, the reaction may result in damaging expansion and cracking of the concrete. Concrete deterioration caused by alkali-aggregate reaction is generally slow, but progressive.

Harmful alkali-aggregate reaction will occur when: (a) the concrete aggregate is reactive and (b) the alkali content of the concrete is high enough to sustain the reaction and (c) enough moisture (greater than ~85% RH) is present to sustain the reaction. Usually, the alkali content must be less than 3 kg/m^3 to prevent adverse reaction, but in mass structures where the moisture content of the concrete remains high (dams, for example), harmful reactions have been recorded with alkali contents as low as 2 kg/m^3. Most of the alkalis originate from the Portland cement (Grattan-Bellew and Lyndon, 2002).

As stated in the literature, in case the avoidance of suspicious reactive aggregate is not possible due to economic reasons, the possibility of alkali-aggregate reaction can be avoided by the use of low alkali cement. Restricting the alkali content in cement to less than 0.6 per cent or possibly less than 0.4 per cent, is another good step (ASTM C 227 – 90). Table 4.4.1 reveals that sample OG. 02 AG has the highest alkali reactivity of 0.009 per cent with other samples having lesser values. These values are negligible, if compared with maximum of 0.6 percent recommendation in Portland cement and permissible limit of 3 kg/m^3 content in concrete.

4.5 Engineering Characteristics of Concrete made with Gravel

Some of the engineering characteristics of fresh and hardened concrete measured are density, slump, water absorption capacity of concrete, compression, flexural and split tensile strengths of concrete. All the concrete specimens were made with gravel as coarse aggregate. Some of these characteristics of the concrete measured in the laboratory are shown in Table 4.5.1.

4.5.1 Slump Test of Fresh Concrete

Table 4.5.1, third column shows the values of the slump. Relating these values and comparing to Table 2.22 after Bartos' proposal in chapter two, it can be analysed that mixes of OS. 01 OS sample with zero slump and OG. 03 OB, OD. 03 OK as well as EK. 01 AD having slump values of 3mm, 2mm and 4mm respectively fall under 'no slump or stiff consistency'.

Samples OS. 02 IK and OD. 02 IJ each has slump of 5mm. The two are grouped under 'very low consistency'. Similarly, OG. 01 AB, OG. 02 AG, OY. 01 IG, OY. 02 IB and EK. 02 IK with slumps of 30mm, 25mm, 26mm, 17mm and 26mm respectively are classified 'low consistency'. Other samples such as OS. 03 MD, OD. 01 OD and EK. 03 IG measuring 70mm, 65mm, and 55mm slumps respectively show 'medium consistency'. The only mix that exhibits collapsed slump which is an indication of too much water is OY. 03 IS.

4.5.2 Density

It is common to determine the density of compacted fresh concrete when measuring workability or the air content. Density is easily obtained by weighing the compacted fresh concrete in a standard container of known volume and mass.

The density of concrete of normal weight or dense concrete is between 2240 to 2400 kg/m^3. The density of lightweight concrete is between 160 to 1920 kg/m^3. The concrete density varies depending on the amount and density of the aggregate, how much air is entrapped or purposely entrained, the cement concentration, and the maximum size of aggregate used.

Table 4.5.1, column 7 reports the average density of concrete produced using the selected gravels as coarse aggregate. The values of the densities range from 2123.5 kg/m^3 for OS. 02 IK concrete specimen to 2429.6 kg/m^3 for EK. 02. IK concrete specimen. All the densities of concrete specimens therefore fall within the range of normal weight or dense concrete and by extension all the gravels can be used to produce normal weight concrete.

Table 4.5.1. Engineering Characteristics (Slump, Density and Compressive Strength) of Gravel Concrete.

Gravel Sample 1	No of Cubes 2	Slump (mm) 3	Weight (kg) 4	Ave. Wt. (kg) 5	Density (kg/m^3) 6	Ave. Density (kg/m^3) 7	Load (kN) 8	Ave. Load (kN) 9	Compr. Str (N/mm^2) 10	Ave. Compr. Str. (N/mm^2) 11
OG. 01 AB	1		8.0		2370.4		335		14.89	
	2	30	7.8	7.93	2311.1	2350.6	325	326.7	14.44	14.52
	3		8.0		2370.4		320		14.22	
OG. 02 AG	1		8.0		2370.4		330		14.67	
	2	25	8.0	7.98	2370.4	2365.5	330	325.0	14.67	14.45
	3		7.95		2355.6		315		14.0	
OG. 03 OB	1		7.5		2222.2		345		15.33	
	2	3	7.5	7.6	2222.2	2251.8	395	365.0	17.56	16.22
	3		7.8		2311.1		355		15.78	
OY. 01 IG	1		8.0		2370.4		425		18.89	
	2	26	8.05	8.05	2385.2	2385.2	400	418.3	17.78	18.59
	3		8.1		2400		430		19.11	
OY. 02 IB	1		8.0		2370.4		250		11.11	
	2	17	8.0	7.97	2370.4	2360.5	250	255.0	11.11	11.33
	3		7.90		2340.7		265		11.78	
OY. 03 IS	1		8.0		2370.4		450		20.0	
	2	Col.	8.0	7.98	2370.4	2365.5	455	445.0	20.22	19.78
	3		7.95		2355.6		430		19.11	
OS. 01 OS	1		7.5		2222.2		205		9.11	
	2	0	8.0	7.78	2370.4	2306.2	205	206.7	9.11	9.63
	3		7.85		2325.9		240		10.67	
OS. 02 IK	1		7.0		2074.1		270		12.0	
	2	5	7.0	7.17	2074.1	2123.5	285	276.7	12.67	12.3
	3		7.5		2222.2		275		12.22	
OS. 03 MD	1		8.0		2370.4		450		20.0	
	2	70	7.5	7.83	2222.2	2321.0	455	451.7	20.22	20.07
	3		8.0		2370.4		450		20.0	
OD. 01 OD	1		8.0		2370.4		435		19.33	
	2	65	8.0	7.97	2370.4	2360.4	430	426.7	19.11	18.96
	3		7.9		2340.7		415		18.44	
OD. 02 IJ	1		8.0		2370.4		455		20.22	
	2	5	8.0	7.93	2370.4	2350.6	455	453.3	20.22	20.15
	3		7.8		2311.1		450		20.0	
OD. 03 OK	1		8.0		2370.4		360		16.0	
	2	2	8.0	7.92	2370.4	2345.7	345	350.0	15.33	15.55
	3		7.75		2296.3		345		15.33	
EK. 01 AD	1		8.0		2370.4		575		25.56	
	2	4	7.9	7.97	2340.7	2360.5	550	558.3	24.44	24.81
	3		8.0		2370.4		550		24.44	
EK. 02 IK	1		8.0		2370.4		540		24.0	
	2	26	8.5	8.2	2518.5	2429.6	500	521.7	22.22	23.18
	3		8.1		2400		525		23.33	
EK 03 IG	1		8.0		2370.4		445		19.78	
	2	55	8.0	7.97	2370.4	2360.5	360	401.7	16.0	17.85
	3		7.9		2340.7		400		17.78	

4.5.3 Compressive Strength

Table 4.5.1 gives results of compressive strength tests. The values of cube strength at 28 day curing age range from 9.63 N/mm^2 for OS. 01 OS to 24.81 N/mm^2 for EK. 01 AD concrete specimens. It should be noted that the same mix ratio of 1:2:4 and water/cement ratio of 0.6 were used in the preparation of the concrete.

Referring to Table 2.23, BS 8110 – 2: 1985, different grades of concrete and characteristic strength, the cube strengths at different ages from 7 days to one year are given. By interpolation, the cube strength of grade 20 concrete (C20) at 28 days is 16.87 N/mm^2 while grade 25 concrete (C25) also at 28 days gives cube strength of 20.86 N/mm^2.

Based on these interpolated values, it is found out that specimens EK. 01 AD, EK. 02 IK, OS. 03 MD and OD. 02 IJ having concrete cube strengths of 24.81, 23.18, 20.07, and 20.15 N/mm^2 respectively are all grade 25 concretes. Other specimens expect OY. 02 IB, OS. 01 OS and OS. 02 IK are in the category of grade 20 concretes. The low values of these specimens might be due to one or more of the following factors;

- The variation in moisture content.
- The grading of the aggregates.
- The human or mechanical errors or inaccuracies in weighing and batching.
- The manner in which the cubes are made, etc.

4.5.4 Flexural Strength

The tensile strength of concrete otherwise known as modulus of rupture is much smaller than the compressive strength and is in any case usually effectively eliminated by cracking, whether this cracking is visible or not. Consequently, the tensile strength of concrete is not usually taken into account for design purposes, though it can be important inasmuch as it influences and contributes to the flexural strength of concrete paving (Blake, 1951).

A study of Table 4.5.2 shows a range of flexural strengths from lowest value of 2.17 N/mm^2 for specimen OS. 01 OS to highest value of 3.49 N/mm^2 for specimen EK. 01 AD. Comparison of these results with Tables 2.24 and 2.25 reveals that the values of flexural strength got in the laboratory is well within the permissible values given by BS 8110 : Part 1 : 1985 and BS EN 1992 1-1.

Table 4.5.2. Flexural Strength of Gravel Concrete.

Beam Specimen	Trial	Weight (kg)	Density (kg/m^3)	Ave. Den. (kg/m^3)	Load (kN)	Point of fracture (mm)	Flexural Strength (f_b) (N/mm^2)	Average Flexural Strength (f_b) (N/mm^2)
OG. 01 AB	1	40.08	2375.2	2366	28	318	2.64	2.65
	2	39.77	2356.8		29	310	2.66	
OG.02 AG	1	39.83	2360.5	2362.8	30	300	2.67	2.65
	2	39.91	2365.0		30	295	2.62	
OG. 03 OB	1	37.97	2250.0	2362.8	30	315	2.80	2.73
	2	38.81	2300.1		31	290	2.66	
OY. 01 IG	1	40.50	2400	2391.3	32	320	3.03	3.04
	2	40.21	2382.6		33	312	3.05	
OY. 02 IB	1	40.0	2370.0	2365.35	26	305	2.35	2.35
	2	39.84	2360.7		25	316	2.34	
OY. 03 IS	1	39.91	2365.3	2367.9	33	318	3.11	3.11
	2	40.0	2370.		35	300	3.11	
OS. 01 OS	1	37.68	2232.9	2288.7	27	270	2.16	2.18
	2	39.57	2345.0		29	255	2.19	
OS. 02 IK	1	34.95	2070.9	2145.5	26	319	2.46	2.49
	2	37.48	2220.8		28	302	2.51	
OS. 03 MD	1	40.50	2400	2390.1	33	320	3.13	3.12
	2	40.16	2380.1		34	309	3.11	
OD. 01 OD	1	40.14	2378.6	2367.75	35	295	3.06	3.08
	2	39.77	2356.9		33	317	3.10	
OD. 02 IJ	1	40.0	2370.6	2365.3	35	300	3.11	3.11
	2	39.83	2360.0		33	318	3.11	
OD. 03 OK	1	39.58	2345.8	2359.1	32	295	2.80	2.79
	2	40.03	2372.3		30	312	2.77	
EK. 01 AD	1	39.84	2360.7	2365.35	37	322	3.53	3.50
	2	40.0	2370		39	300	3.47	
EK. 02 IK	1	41.0	2430	2415.3	36	315	3.36	3.38
	2	40.5	2400		36	318	3.39	
EK. 03 IG	1	40.12	2377.5	2363.85	35	285	2.96	2.97
	2	39.66	2350.2		32	314	2.98	

4.5.5 Splitting Tensile Strength

Splitting tensile strength is used in the design of structural lightweight concrete members to evaluate the shear resistance provided by concrete and to determine the development length of reinforcement (ASTM C496/C496M – 11).

Table 4.5.3 shows the results of splitting tensile strength of concrete. The values range from minimum of 1.72N/mm^2 for sample OS. 01 OS to maximum value of 2.80N/mm^2 for specimen EK. 02 IK. These results conform with Table 2.24: Values of tensile strength in relation to strength class derived from BS EN 1992 1-1 in chapter two. The values range from 1.7N/mm^2 to 2.8N/mm^2 for strength class C12/16 and C25/30 respectively. Critical examination of Table 2.24 also confirms an assertion that splitting tensile strength is generally greater than direct tensile strength and lower than flexural strength - modulus of rupture (Hannant, 1972).

Table 4.5.3. Splitting Tensile Strength of Gravel Concrete

Cube Specimen	**Trial No.**	**Wt. (Kg)**	**Density (Kg/m^3)**	**Ave Density (Kg/m^3)**	**Load (kN)**	**Split Strength f_{spt} (N/mm^2)**	**Ave. Split Strength f_{spt} (N/mm^2)**
OG. 01 AB	1	8.0	2370.4	2350.6	75.4	2.13	2.13
	2	7.8	2311.1		76	2.15	
	3	8.0	2370.4		75	2.12	
OG. 02 AG	1	8.0	2370.4	2370.4	75.0	2.12	2.13
	2	8.0	2370.4		75.2	2.13	
	3	7.9	2370.4		75.2	2.13	
OG. 03 OB	1	7.5	2222.2	2288.9	79.7	2.26	2.23
	2	7.8	2311.1		78.0	2.21	
	3	7.8	2311.1		78.1	2.21	
OY. 01 IG	1	8.0	2370.4	2380.3	85.0	2.41	2.43
	2	8.1	2400.0		85.7	2.43	
	3	7.9	2370.4		86.2	2.44	
OY. 02 IB	1	8.1	2400.0	2390.1	65.0	1.84	1.88
	2	8.0	2370.4		67.0	1.90	
	3	8.1	2400.0		67.0	1.90	
OY. 03 IS	1	8.0	2370.4	2370.4	88.0	2.49	2.48
	2	8.0	2370.4		87.0	2.46	
	3	8.0	2370.4		88.0	2.49	
OS. 01 OS	1	7.5	2222.2	2301.2	60.0	1.70	1.71
	2	8.0	2370.4		61.5	1.74	
	3	7.8	2311.1		60.0	1.70	
OS. 02 IK	1	7.0	2074.1	2074.1	70.0	1.98	1.97
	2	7.0	2074.1		69.4	1.96	
	3	7.0	2074.1		70.0	1.98	
OS. 03 MD	1	8.0	2370.4	2321.0	89.0	2.52	2.53
	2	7.5	2222.2		88.7	2.51	
	3	7.9	2370.4		90.0	2.55	
OD. 01 OD	1	8.0	2370.4	2370.4	86.2	2.44	2.45
	2	8.0	2370.4		87.1	2.46	
	3	8.0	2370.4		87.0	2.46	
OD. 02 IJ	1	8.0	2370.4	2380.3	90.0	2.55	2.52
	2	8.0	2370.4		88.0	2.49	
	3	8.1	2400.0		88.7	2.51	
OD. 03 OK	1	8.0	2370.4	2370.4	78.0	2.21	2.21
	2	8.0	2370.4		78.1	2.21	
	3	7.9	2370.4		78.0	2.21	
EK. 01 AD	1	8.0	2370.4	2370.4	99.1	2.80	2.80
	2	7.9	2370.4		98.5	2.79	
	3	8.0	2370.4		99.0	2.80	
EK. 02 IK	1	8.0	2370.4	2429.6	95.3	2.70	2.69
	2	8.5	2518.5		94.9	2.69	
	3	8.1	2400.0		95.0	2.69	
EK. 03 IG	1	8.0	2370.4	2370.4	83.6	2.37	2.38
	2	8.0	2370.4		84.0	2.38	
	3	8.0	2370.4		84.0	2.38	

4.5.6 Water Absorption Capacity

Table 4.5.4 shows the results of the water absorption capacity of concrete. Lea, (1970) states that absorption tests are not used frequently except for routine quality control of precast products. He further states that most good concretes have absorption well below 10 per cent by mass.

Vivid examination of the results reveals that specimen OS. 02 IK has the highest value of absorption capacity of 6.80 per cent, while specimen OS. 03 MD has the lowest water absorption capacity of 4.32 per cent. From this finding, it can be inferred that specimen OS. 02 IK is the most porous of all the samples, while specimen OS. 03 MD is the least porous. Interestingly, the two samples are from Osun state.

However, going by the assertion that most good concretes have absorption well below 10 per cent (Lea, 1970), it can be inferred that all the selected gravel aggregate samples from Southwestern Nigeria produce good quality concrete in terms of water absorption characteristic of concrete products.

4.6 Statistical Analysis

4.6.1 Coefficient of Variation (CV)

The CV for a single variable aims to describe the dispersion of the variable in a way that does not depend on the variable's measurement unit. They are arranged in descending order in Table 4.6.1. The higher the CV, the greater the dispersion in the variable. A critical examination of Table 4.6.1 reveals that properties such as aggregate crushing value (ACV), pH, fineness modulus (FM) and aggregate abrasion value (AAV) with coefficients of variation of 10%, 10%, 6% and 3% ($CV \leq 10\%$) indicate uniformity in the values of their parameters. The other parameters with coefficients of variation above 10% ($CV > 10\%$) showed variation in values of the parameters.

Table 4.5.4. Water Absorption Capacity of Concrete

Concrete Sample	No of cubes	Weight of Saturated Specimen (kg)	Weight of Oven dried Specimen (kg)	Water Absorption Capacity (%)	Ave. Value of Water Absorption Capacity (%)
OG. 01 AB	1	7.75	7.30	6.16	
	2	7.70	7.30	5.48	5.44
	3	7.85	7.50	4.67	
OG. 02 AG	1	8.00	7.65	4.58	
	2	7.95	7.56	5.16	5.02
	3	7.90	7.50	5.33	
OG. 03 OB	1	7.45	7.07	5.38	
	2	7.40	7.05	4.97	5.05
	3	7.65	7.30	4.80	
OY. 01 IG	1	7.95	7.60	4.61	
	2	7.80	7.45	4.70	5.30
	3	8.10	7.60	6.58	
OY. 02 IB	1	7.90	7.50	5.33	
	2	7.95	7.55	5.30	5.09
	3	7.88	7.53	4.65	
OY. 03 IS	1	7.90	7.60	3.95	
	2	7.98	7.63	4.59	4.52
	3	7.95	7.57	5.02	
OS. 01 OS	1	7.50	7.18	4.46	
	2	7.80	7.40	5.41	5.08
	3	7.83	7.43	5.38	
OS. 02 IK	1	7.00	6.60	6.06	
	2	6.98	6.52	7.06	6.80
	3	7.08	6.60	7.27	
OS. 03 MD	1	7.80	7.50	4.00	
	2	7.43	7.12	4.35	4.32
	3	7.95	7.60	4.61	
OD. 01 OD	1	7.85	7.40	6.08	
	2	7.90	7.52	5.05	5.27
	3	7.85	7.50	4.67	
OD. 02 IJ	1	7.75	7.35	5.44	
	2	7.80	7.50	4.00	4.46
	3	7.90	7.60	3.95	
OD. 03 OK	1	7.80	7.35	6.12	
	2	7.75	7.45	4.03	4.97
	3	7.70	7.35	4.76	
EK. 01 AD	1	7.85	7.45	5.37	
	2	7.85	7.54	4.11	4.48
	3	7.90	7.60	3.95	
EK. 02 IK	1	8.10	7.70	5.20	
	2	8.00	7.65	4.58	5.01
	3	8.00	7.60	5.26	
EK. 03 IG	1	8.00	7.63	4.85	
	2	7.95	7.60	4.61	4.70
	3	7.90	7.55	4.64	

Table 4.6.1. Coefficient of Variation of Physical/Geotechnical Properties of Gravels and Gravel made Concrete.

Physical/Geotechnical Properties	**Coefficient of Variation (%)**
Organic Content of Gravel	87.3
Sulphate Content of Gravel (SO_4)	49.0
Water Absorption Capacity of gravel (WAC_{agg})	46.8
Carbonate Content of Gravel (CO_3)	40.9
Alkali Reactivity of Gravel	40.9
Chloride Content of Gravel (Cl^-)	30.6
Moisture Content of Gravel (MC)	27.1
Compressive Strength of Concrete	25.0
Maximum Aggregate Size	18.8
Aggregate Impact Value of Gravel (AIV)	18.0
Specific Gravity of Gravel (Gs)	13.1
Flexural Strength of Concrete	12.9
Split Tensile Strength of Concrete	12.7
Water Absorption Capacity of Concrete (WAC_{conc})	11.8
Aggregate Crushing Value Gravel (ACV)	10.8
pH Value of Gravel	10.4
Fineness Modulus of Gravel	6.0
Los Angeles Abrasion Value of Gravel ((AAV)	3.3

4.6.2 Correlation Coefficient

Correlation coefficient is a vital aspect used to calculate how strong the correlation of two quantities is. The dependence between two measures is obtained by dividing the covariance of the two variables by the multiplication of their standard deviations and is represented mathematically by corr(x, y).

The correlation coefficient between compressive strength of concrete and other physical and geotechnical properties is computed as given in Table 4.6.2. Flexural and split strengths of concrete with r = 0.99 are very highly correlated or 98% correlated with the compressive strength. Fineness modulus of gravel with r = 0.62 is moderately correlated or 38% related. Organic content of gravel has r of 0.44 indicating low correlation with 19 percent variance. Other parameters are linearly correlated having correlation coefficient values of less than 0.3

4.6.3 Linear Regression

A linear regression equation is developed from the analysis of research data, which enables the prediction of water absorption capacity of concrete (WACconc) as dependent variable against water absorption capacity of aggregate (WACgrav) as explanatory or independent variable. Water absorption capacity is the only tested parameter that is common to both concrete and gravel aggregate. The regression formula is stated as;

Y = A + BX …………………………………..……………………(Eq. 4.1)

where Y = dependent variable (WACconc), X = independent variable (WACgrav)

A = intercept and, B = slope of linear regression line

The estimated equation of the regression using SPSS 16.0 version and coefficient "r" is;

WACconc=WACconc=4.9109+0.1715WACgrav …………………….…..(Eq. 4.2)

r = 0.096

This is an indication of very weak but positive correlation. The linear regression line intercepts the water absorption capacity of concrete axis (Y-axis) at 4.9109 with slope of 0.1715. The water absorption capacity of the concrete can therefore be evaluated using the above equation by simply determining the water absorption capacity of gravel or vice visa. The cross plots of this and that of AIV and ACV against SG and WAC of gravel respectively are shown in Figure 4.6.1(a – e) Appendix E.

Table 4.6.2. Correlation Coefficient of Physical/Geotechnical Parameters with Compressive Strength as Dependent Variable.

Physical/Geotechnical Parameters	**Correlation Coefficient (r)**	**Coefficient of Determination or Variance (r^2)**	**Percentage of Variation (%)**
Flexural Strength of Concrete	0.99	0.98	98
Split tensile Strength of Concrete	0.99	0.98	98
Fineness Modulus (FM)	0.62	0.38	38
Organic Content of Gravel	0.44	0.19	19
Specific Gravity (Gs)	0.39	0.15	15
Sulphate Content (SO_4)	0.39	0.15	15
Slump Value	0.28	0.08	8
Moisture Content (MC)	0.21	0.04	4
Maximum Aggregate Size	0.17	0.03	3
Water Absorption Cap (WAC_{agg})	0.15	0.02	2
Aggregate Impact Value (AIV)	0.10	0.01	1
Chloride Content (Cl^-)	0.08	0.01	1
Carbonate Content (CO_3)	0.07	0.01	1
Alkali Reactivity	0.07	0.01	1
pH Value	-0.15	0.02	2
Aggregate Crushing Value (ACV)	-0.25	0.06	6
Aggregate Abrasion Value(AAV)	-0.52	0.27	27
Water Absorption Cap (WAC_{con})	-0.54	0.29	29

4.6.4 Multiple Regression

The multiple regression using SPSS 16.0 version with each of concrete strengths as dependent variable and mechanical properties of gravel as independent variables are

$\mathbf{Y = a + b_1*X_1 + b_2*X_2 + \ldots\ldots b_p*X_P + \varepsilon}$ ……………………………………(Eq. 4.3)

where; Y is dependent variable f_c, f_{spt} and f_b

a is coefficient of constant

b_1, b_2 and b_3 are regression coefficients of the predictor variables

ε is error component in the model

X_1, X_2 and X_3 are predictors or independent variables which are AIV, ACV and AAV.

Gives the estimated equation of the models as;

$\mathbf{f_c = 91.661 + 0.219AIV - 0.176ACV - 1.773AAV}$ ……………...…………….(Eq. 4.4)

$\mathbf{f_{spt} = 7.667 + 0.016AIV - 0.012ACV - 0.129AAV}$ …………………...……..(Eq. 4.5)

$\mathbf{f_b = 9.361 + 0.020AIV - 0.010ACV - 0.159AAV}$ ……………...………….. (Eq. 4.6)

The model, which is the equation of best regression, is the equation for predicting the dependent variable, fc, given quantitative values for the predictor variables. Aggregate impact value of gravel is a predictor variable for fc, from the multiple regression analysis of the research data. The unstandardized regression coefficient of the predictor variable is 0.219 which indicates that a one hundred percent change in it will exert 21.9% change in the dependent variable, holding the effect of the other variables in the model constant. Thus, the compressive strength of concrete will improve significantly with an increase in the quality of aggregate impact value. In the same vein, a hundred percent change in the value of aggregate crushing value will exert 17.6% change in compressive strength in opposite direction, controlling the effect of the other predictors in the model. Thus, the compressive strength of concrete will improve with reduction in the percentage of aggregate crushing value. The same explanation goes for the other two dependent variables

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study has established the following:

i. Gravels are found to be available in all the states in the zone except Lagos state that does not have a single gravel pit being operated on commercial basis. The superficial deposits in Lagos are mainly of sandy and clayey minerals (Jones and Hockey, 1964; Omatsola and Adegoke, 1981). This results in imbalance between demand and supply of gravel in Lagos, hence, very high cost of gravel per 3.5 ton truck load in the state.

ii. The physical/geotechnical characteristics of gravels are within the permissible limits specified by standard codes and specifications. Exceptions are chloride and sulphate contents of some samples that might need further treatment such as washing, use of special cements and/or addition of admixtures to avoid corrosion of reinforcement.

iii. The properties of concrete (compressive, flexural and split-tensile strengths, consistency measured with slump, density, and absorption capacity of concrete) made with the gravel as coarse aggregate varied from location to location.

iv. The coefficient of variation computed for properties such as Aggregate Crushing Value (ACV), molar concentration of hydrogen (pH), Fineness Modulus (FM) and Aggregate Abrasion Value (AAV) indicate uniformity in values of these parameters, having values of 10% and less. The values of other properties point out variation in values of their parameters.

v. The correlation of flexural and split-tensile strengths of concrete with compressive strength ($r = 0.99$; $r^2 = 0.98$). Other parameters show various degree of correlation.

vi. The linear regression equation computed between water absorption capacity of concrete (WACconc) as dependent variable and water absorption capacity of gravel (WACgrav) as independent or explanatory variable yield;

$$\mathbf{WAC_{conc} = 4.9109 + 0.1715WAC} \quad \text{.......................................(See Eq. 4.2)}$$

Based on the equation, water absorption capacity of concrete could be predicted by simply determining the water absorption capacity of gravel.

vii. The multiple regression equations established between concrete strengths (fc, fspt and fb) as dependent variables and mechanical properties of gravels (AIV, ACV and AAV) as independent variables developed could also be used in analysing the parameters.

Based on these findings, it can be concluded that properties of concretes produced from gravel sourced from different locations in southwestern Nigeria varied (CV of 3.3% for AAV of gravels to 87.3% for Organic Content of gravel). Other parameters of gravels and concretes are within these limits as shown in Table 4.6.1.

Gravelly concretes with high strengths could be used in construction of low rise buildings and rural roads while those with low strengths could be employed in applications (walkways) where high strengths are not required. Therefore the results provide data bank for technical and economical infrastructural developments in southwestern Nigeria.

5.2 Recommendations

In line with the above conclusions these gravels are recommended for use especially in ordinary concrete for buildings and rural roads.

Going by this recommendation, further investigations required to complement and extend some of the findings of the present research work include;

- Inventory, preliminary and major laboratory investigations of concretes produced from gravels obtainable from other climatic and geographical locations of Nigeria so as to have data that will cover the whole country.

- Measurement of long term effects of chemical contents for example, alkali-aggregate reaction on concrete produced with these gravels, to determine the extent of expansion as a result of the use of these gravels if any.

However, it should be noted that the tests on gravels for this research were carried out after the samples had been treated; i.e., sieving of fine particles that can affect mix ratio and washing of coating materials that can affect proper bonding between cement paste and aggregates.

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APPENDICES

APPENDIX A

Table A1.0. Reported Cases of Collapsed Buildings in Nigeria between 2013 and 2014.

S/N	Building Location	Type/Nature of Building	Date	Result of Preliminary Investigation	No. of Casualities
1.	Idi-Ose, Akinyele LGA, Oyo State	A church building under construction	28th February, 2013	Use of inferior materials	5 killed, 2 Injured
2.	Mararaba, Baisa, Donga LGA, Taraba State.	N/A	24th April, 2013	N/A	5 killed, Several Injured
3.	19, Bashiru Street, Ojodu, Berger Lagos State	3-storey building under constrution	6th May, 2013	Sharp practice of the developer	2 killed
4.	8, Round about Lokoja, Kogi State	3- storey building under construction	7th May, 2013	N/A	3 Injured
5.	19, Shoghawon Str, Bariga, Lagos State	Fence of a building	7th May, 2013	N/A	1 killed
6.	Ikorodu, Lagos State	3-Storey buildg under construction	7th May, 2013	Defective bldg, after heavy downpour	2 Injured
7.	Agbama Area of Umuahia, Abia State.	3-storey building/ under construction	15th May, 2013		7 killed, 3 Injured
8.	353, Challenge Rd, Off Amu Street, Mushin Lagos	Old 3- Storey Building	12th June, 2013	Old and Lack of maintenance	1 killed, 3 injured
9.	29b Oloto Street, Ebute Meta, Lagos	3-Storey Building	11th July, 2013	Foundation on marshy ground and Poor Construction	7 killed, Several injured
10.	26 Onasanya street off Ishaga Road, Surulere Lagos.	2-storey Building/Under Construction	21st July, 2013	Poor construction	5 killed, scores injured
11.	Okofia-Umuenem, Otolo Nnewi, Nnewi North Local Govt Area, Anambrar State	3-storey building/ under construction	27th August 2013	Foundation not adequate, sizeable rods not used for columns	3 killed, 6 seriously injured
12.	24, Obanye Street Odoakpu near Onisha General Post Office, Anambra State	4-storey building/ under construction	4th September 2013	Settlement, inferior materials	3 feared killed
13.	15, Alli Street,	3-storey Bldg	25th		3 died and

	Lagos Island.	collapsed on a bungalow next to it.	September, 2013		10 injured.
14.	9, Dosa Road, Angwan Dosa, Kaduna North Council, Kaduna	During demolition of formerly St. Faith Catholic church	30th November 2013	Crude method of demolition.	5 killed, several injured
15.	8, Muri Okunola Street V/I Lagos	4-storey building under construction	4th November 2013	Yet to be determined	7 killed
16.	Enugu Rd. Nsukka, Nsukka LGA, Enugu State	Three (3) storey building under construction	1st March 2014	Yet to be determined	7 killed
17.	Ologuneru, in Ido LGA, Ibadan, Oyo State.	Two (2) storey building.	2nd March 2014	-	1 person feared dead
18.	11, Sand Beach Lanes off Alonge street, Oworonsoki, Kosofe LGA, Lagos State.	Two (2) storey building under construction	24th April 2014	Bungalow converted to storey building	10 people injured
19.	Akure, Ondo State	Boarding house under construction	9th May 2014	Built inswampy area, poor quality work & no approvals	2 killed, 2 injured
20.	Agbama Housing Estate, Umuahia, Abia State	Three (3) storey building	14th May 2014	-	4 killed, 4 injured
21.	St. Christopher Anglican Church, Odo-Akpu, Onisha, Anambra State	Four (4) Storey Buildings – Under Construction	1st June 2014	Yet to be determined	4 killed
22.	Pedro Police Barrack, Shomolu Lagos.	Two (2) storey with 27 units of flats	30th June 2014	Under investigation	No casualty
23.	Urora community, Benin City, Edo State	Very old building	July 19th 2014	Persistent rainfall	3 killed
24.	Synagogue Church of all Nations, Ikotun Lagos	Six (6) storey building under construction	12th September 2014	Failure due to inappropriate design.	116 killed, several injured
25.	Liberty Power Bible Church, a k a Power Palace, Benin, Edo State	Bungalow with high walls	28th September 2014	-	No casualty
26.	Udude Street, Ntezi Aba, Abakaliki, Ebonyi State	Three (3) Storey building just completed	7th October 2014	-	1 injured

Source: NBRRI (2014b)

APPENDIX B

ANALYSIS OF QUESTIONNAIRES

Table B.1. Reaction of Customers in Terms of Gravel Texture.

State	Alternative	Response	Percentage
Lagos	Rough	50	42
	Smooth	70	48
	Total	**120**	100
Ogun	Rough	75	45
	Smooth	90	55
	Total	**165**	100
Oyo	Rough	98	54
	Smooth	84	46
	Total	**182**	100
Osun	Rough	60	54
	Smooth	51	46
	Total	**111**	100
Ondo	Rough	132	85
	Smooth	23	15
	Total	**155**	100
Ekiti	Rough	77	63
	Smooth	46	37
	Total	**123**	100

Considering the texture of the gravel, 52% felt that the gravels were smooth while 48% said they were rough.

Table B.2. State of Gravel as Mined.

State	Alternative	Response	Percentage
Lagos	Clean	118	98
	Dirty	2	2
	Total	**120**	100
Ogun	Clean	155	94
	Dirty	11	6
	Total	**165**	100
Oyo	Clean	172	95
	Dirty	10	5
	Total	**182**	100
Osun	Clean	103	93
	Dirty	8	7
	Total	**111**	100
Ondo	Clean	147	95
	Dirty	8	5
	Total	**155**	100
Ekiti	Clean	118	96
	Dirty	5	4
	Total	**123**	100

95% of the respondents said the gravels were clean as against 5% who chose dirty

Table B.3. Treatment Carried out Before Sale.

State	Alternative	Response	Percentage
Lagos	Washed	15	13
	Unwashed	105	87
	Sieved	0	0
	Others	0	0
	Total	**120**	100
Ogun	Washed	28	17
	Unwashed	135	82
	Sieved	2	1
	Others	0	0
	Total	**165**	100
Oyo	Washed	38	21
	Unwashed	144	79
	Sieved	0	0
	Others	0	0
	Total	**182**	100
Osun	Washed	19	17
	Unwashed	92	83
	Sieved	0	0
	Others	0	0
	Total	**111**	100
Ondo	Washed	0	0
	Unwashed	155	100
	Sieved	0	0
	Others	0	0
	Total	**155**	100
Ekiti	Washed	6	5
	Unwashed	117	95
	Sieved	0	0
	Others	0	0
	Total	**123**	100

87% of the respondents sold their gravels unwashed while 13% washed before selling.

Table B.4. Whether the Gravels Contain more Sand, Silt and Clay**.**

State	**Alternative**	**Response**	**Percentage**
Lagos	Yes	0	0
	No	135	100
	Total	**135**	100
Ogun	Yes	0	0
	No	160	100
	Total	**160**	100
Oyo	Yes	0	0
	No	145	100
	Total	**145**	100
Osun	Yes	0	0
	No	170	100
	Total	**170**	100
Ondo	Yes	0	0
	No	125	100
	Total	**125**	100
Ekiti	Yes	0	0
	No	136	100
	Total	**136**	100

In all the states, 100% of the respondents said the gravel contained no sand, silt or clay

Table B.5. Whether the Gravels Contain Shells and Plant Roots.

State	Alternative	Response	Percentage
Lagos	Yes	5	4
	No	130	96
	Total	**135**	100
Ogun	Yes	8	5
	No	152	95
	Total	**160**	100
Oyo	Yes	12	8
	No	133	92
	Total	**145**	100
Osun	Yes	10	6
	No	160	94
	Total	**170**	100
Ondo	Yes	6	5
	No	119	95
	Total	**125**	100
Ekiti	Yes	15	11
	No	121	89
	Total	**136**	100

94% of the respondents said that the gravel did not contain shells and plant roots, but 6% agreed that there were trace of shells and plant roots.

Table B.6. Performance of Gravel in Relation to Strength of Concrete**.**

State	Alternative	Response	Percentage
Lagos	Excellent	115	85
	Good	20	15
	Fair	0	0
	Poor	0	0
	Total	**135**	100
Ogun	Excellent	139	87
	Good	21	13
	Fair	0	0
	Poor	0	0
	Total	**160**	100
Oyo	Excellent	94	65
	Good	51	35
	Fair	0	0
	Poor	0	0
	Total	**145**	100
Osun	Excellent	160	94
	Good	10	6
	Fair	0	0
	Poor	0	0
	Total	**170**	100
Ondo	Excellent	113	90
	Good	12	10
	Fair	0	0
	Poor	0	0
	Total	**125**	100
Ekiti	Excellent	116	85
	Good	20	15
	Fair	0	0
	Poor	0	0
	Total	**136**	100

84% of the respondents agreed that the strength of concrete produced with the gravel is excellent, while 16% said that strength wise, the concrete was good.

APPENDIX C
MINING PROFILES FROM DIFFERENT PITS IN SOUTHWESTERN NIGERIA


(a) Abule Sikiru, Abeokuta, Ogun State

(b) Gravel Depot- Ago Iwoye, Ogun State


(c) Erunmu Egbeda, Ibadan Oyo State


(d) Igbo-Ora, Oyo State


(e) Ikire, Osun State


(f) Toro Road, Modakeke, Osun State

Plate 3. Mining Pits and Operations in different Locations

(g) A Pit at Oke-Igbo, Ondo State

(h) Laje Road, Ondo, Ondo State

(i) Ikole-Ekiti, Ekiti State

(j) Ado-Ekiti, Ekiti State

(k) Tipper Garage at Lafenwa, Ayetoro-Itele, Ogun State

Plate 3. (contd.). Mining Pits and Operations in different Locations

APPENDIX D

PARTICLE SIZE DISTRIBUTION CURVES

Sieve Analysis: Abule Sikiru, Abeokuta Sample(OG. 01 AB)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wn (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	600	600	0	0	0	100
37.5	500	500	50	0	0	100
25.0	550	850	200	10.0	10.0	90
19.0	500	700	200	6.7	16.7	83.3
13.2	500	1000	500	16.7	33.4	66.6
9.5	500	1100	300	20.0	53.5	46.6
6.3	500	1350	600	28.3	81.7	18.2
4.75	550	900	1050	11.7	93.4	3.2
3.35	500	650	50	5.0	98.4	1.5
Recceiver	300	350	50	1.7		
TotalTested			3000			

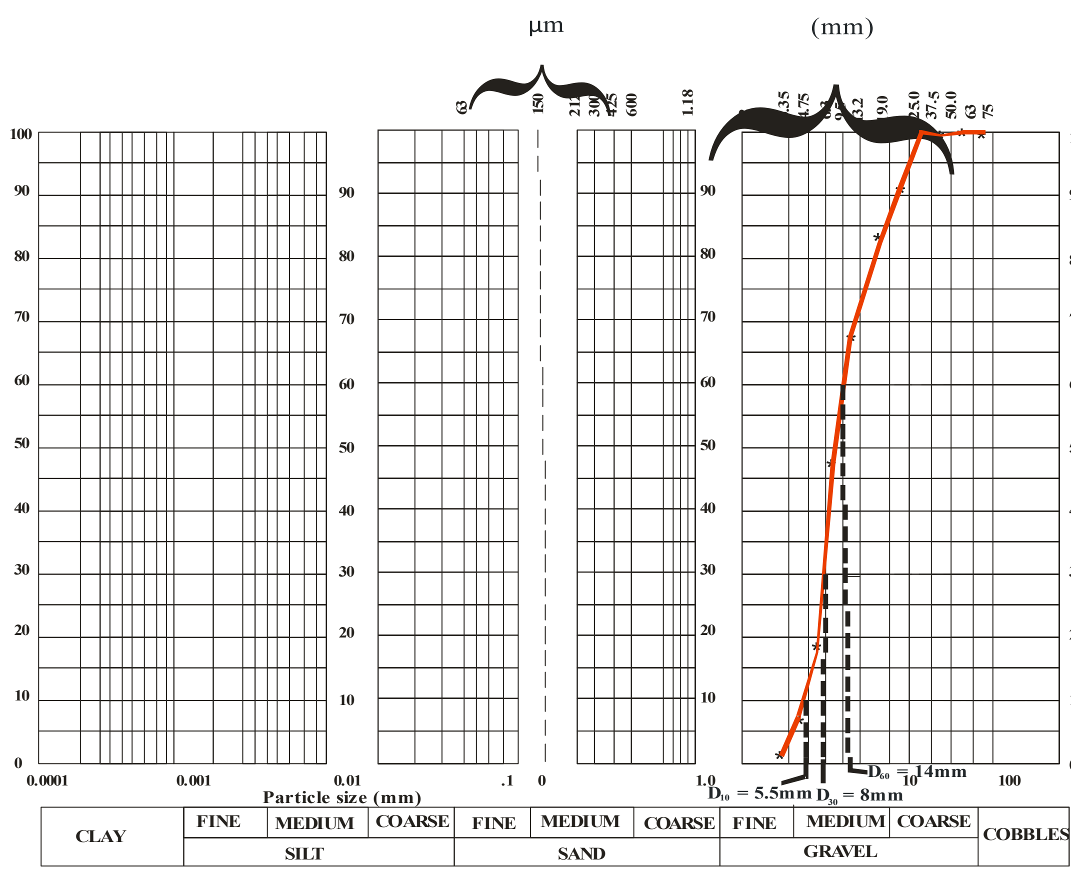


Figure 4.1: Particle Size Distribution Curve - Abule Sikiru Gravel, Abeokuta, Ogun Stat

Sieve Analysis: Ago-Iwoye Sample(OG. 02 AG).

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wh (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	600	600	0	0	0	100
37.5	500	500	0	0	0	100
25.0	550	550	0	0	0	100
19.0	500	600	100	3.3	3.3	96.7
13.2	500	1200	700	23.3	26.6	73.4
9.5	500	1650	1150	38.3	64.9	35.1
6.3	500	1300	800	26.7	91.6	8.4
4.75	550	700	150	5.0	96.6	3.4
3.35	500	550	50	1.7	98.3	1.7
Recceiver	300	350	50	1.7		
TotalTested			3000			

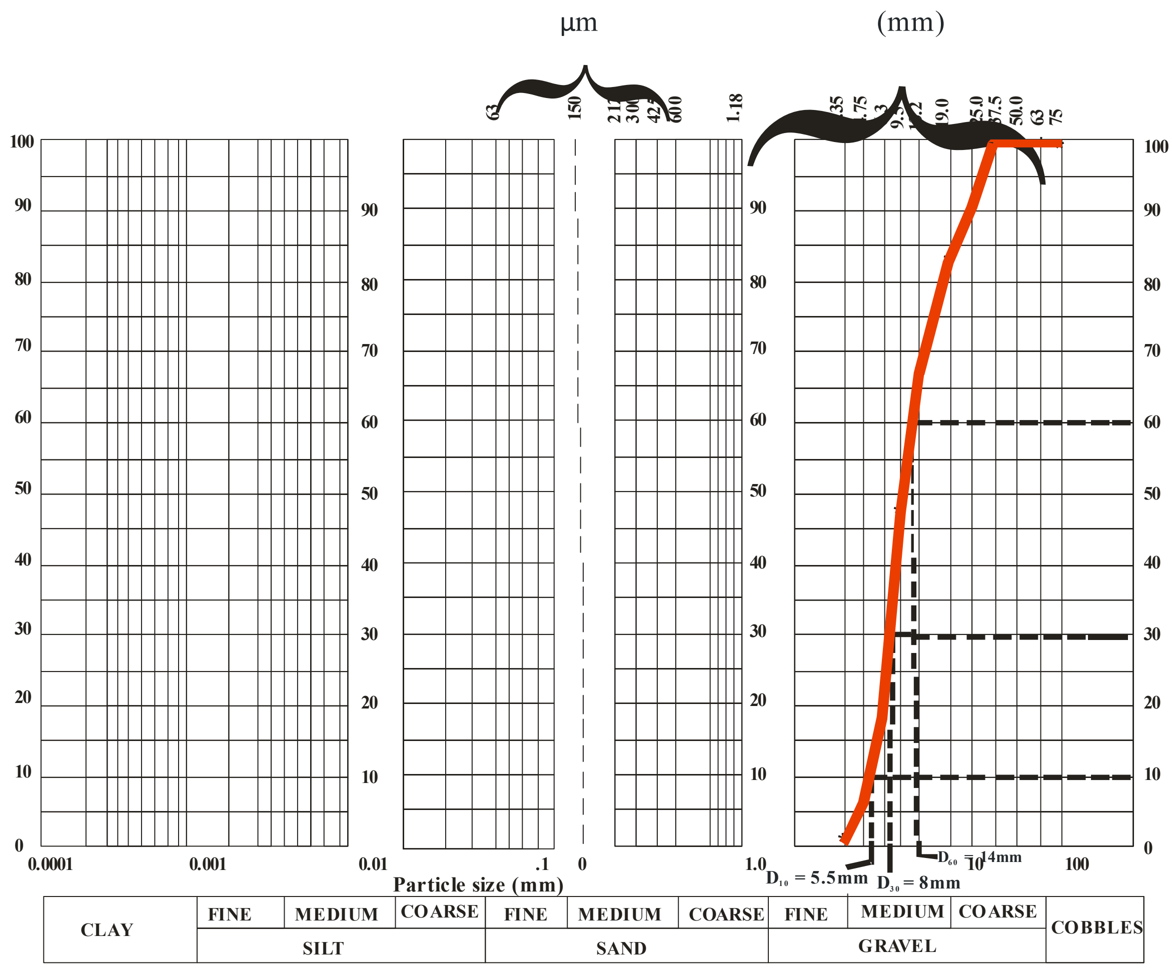


Figure 4.2: Particle Size Distribution Curve - Ago Iwoye Gravel, Ogun State

Sieve Analysis: Obafemi Owode Sample(OG. 03 OB

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wh (g)	Percentage of Mass Retained on each Sieve, Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	600	600	0	0	0	100
37.5	500	850	350	11.7	11.7	88.3
25.0	550	800	250	8.3	20.0	80.0
19.0	500	700	200	6.7	26.7	73.3
13.2	500	1000	500	16.7	43.4	56.6
9.5	500	900	400	13.3	56.7	43.3
6.3	500	900	400	13.3	70.0	30.0
4.75	550	1200	650	21.7	91.7	8.3
3.35	500	650	150	5.0	96.7	3.3
Recceiver	300	400	100	3.3		
Total Tested			3000			

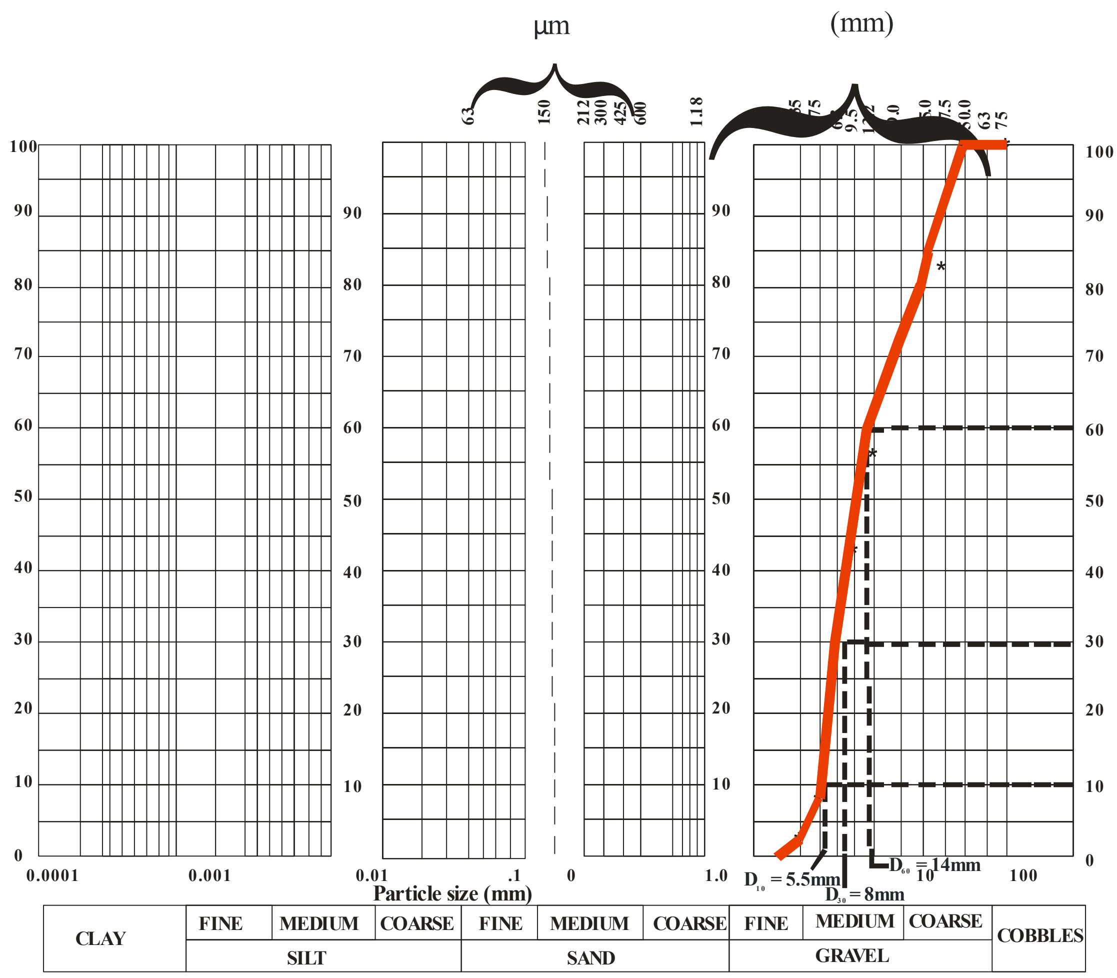


Figure 4.3: Particle Size Distribution Curve - Obafemi Owode, Ogun State

Sieve Analysis: Igbo-ora Sample(OY. 01 IG)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wn (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	600	600	0	0	0	100
37.5	500	600	100	3.3	3.3	96.7
25.0	550	900	350	11.7	15.0	85.0
19.0	500	800	300	10.0	25.0	75.0
13.2	500	1200	700	23.3	48.3	51.7
9.5	500	1150	650	21.7	70.0	30.0
6.3	500	1150	650	21.7	91.7	8.3
4.75	550	750	200	6.7	98.4	1.6
3.35	500	550	50	1.7	100	0
Recceiver	300	300	0	0		
TotalTested			3000			

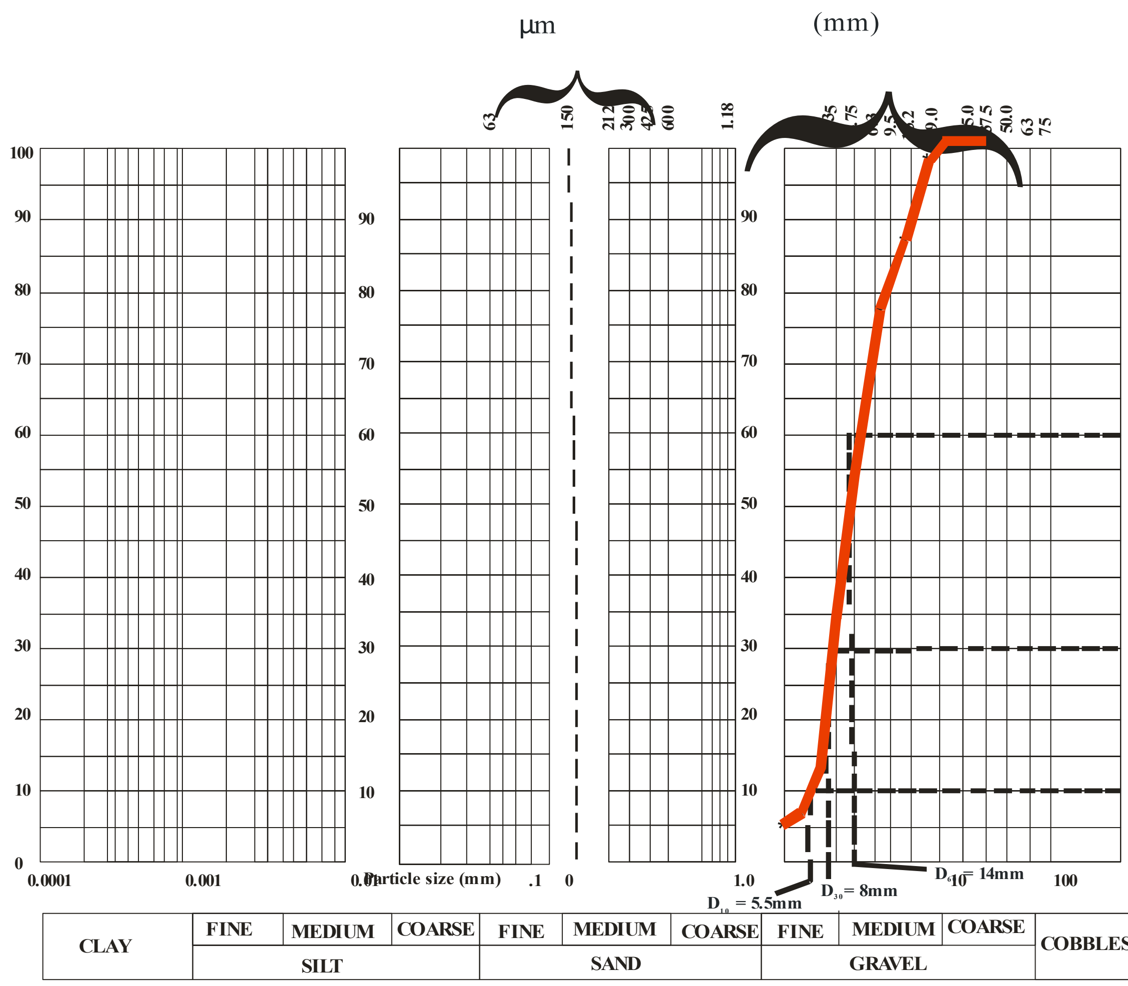


Figure 4.4: Particle Size Distribution Curve - Igboora Gravel, Oyo State

Sieve Analysis: Erunmu, Ibadan Sample(OY. 02 IB)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wn (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	600	600	0	0	0	100
37.5	500	700	200	6.7	6.7	93.3
25.0	550	850	300	10.0	16.7	83.3
19.0	500	750	250	8.3	25.0	75.0
13.2	500	1000	500	16.7	41.7	58.3
9.5	500	700	200	6.7	48.4	51.6
6.3	500	1050	550	18.3	66.7	33.3
4.75	550	1400	850	28.3	95.0	5.0
3.35	500	550	50	1.7	96.7	3.3
Recceiver	300	400	100	3.3		
TotalTested			3000			

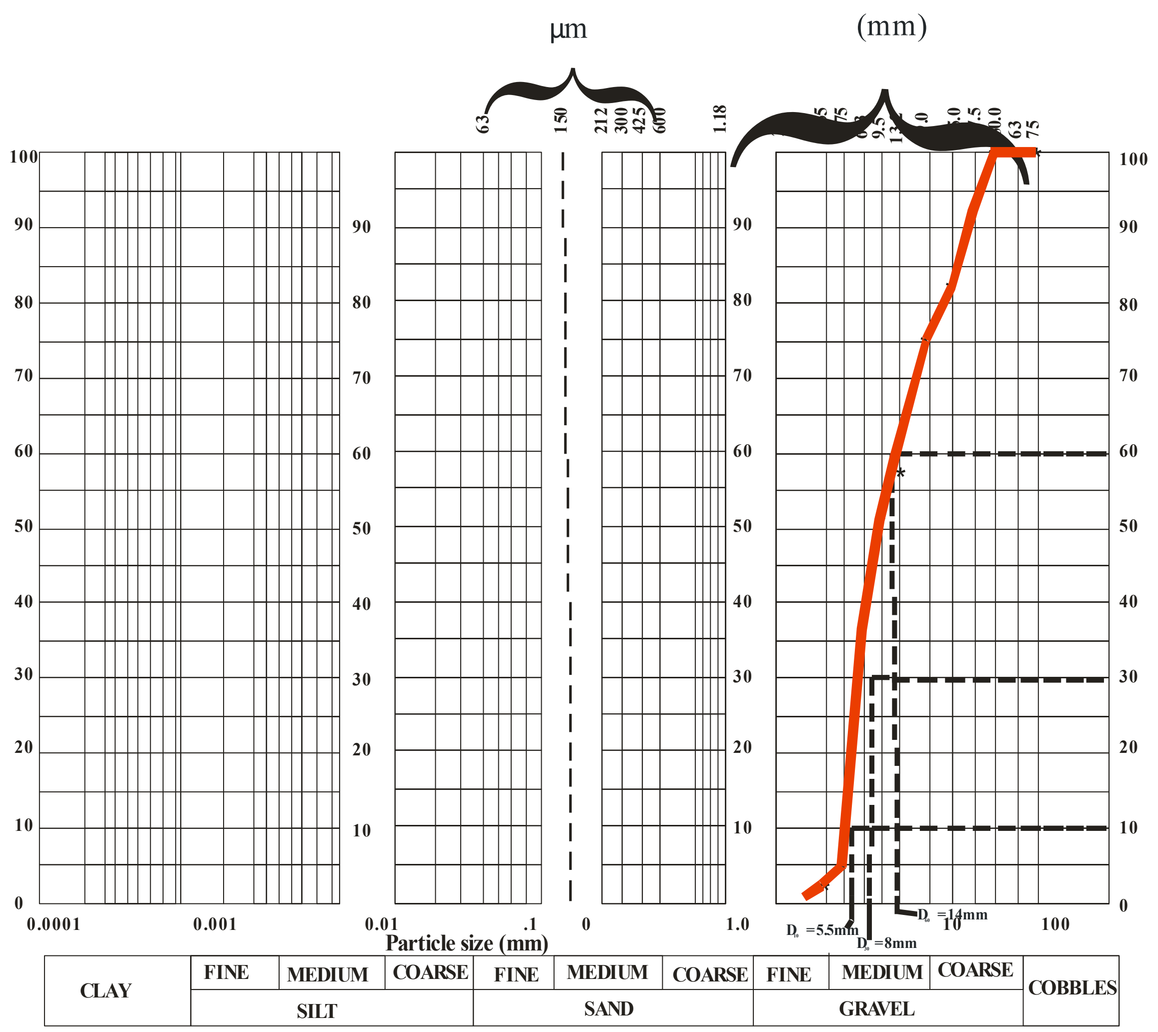


Figure 4.5: Particle Size Distribution Curve - Erunmu Ibadan Gravel, Oyo State

Sieve Aanalysis: Dugbe Iseyin Sample(OY. 03 IS)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wn (g)	Percentage of Mass Retained on each Sieve, Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - Srn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	600	600	0	0	0	100
37.5	500	550	50	1.7	1.7	98.3
25.0	550	1400	850	28.3	30.0	70.0
19.0	500	900	400	13.3	43.3	56.7
13.2	500	950	450	15.0	58.3	41.7
9.5	500	700	200	6.7	65.0	35.0
6.3	500	750	250	8.3	73.3	26.7
4.75	550	800	250	8.3	81.6	18.4
3.35	500	800	300	10.0	91.6	8.4
Recceiver	300	550	250	8.3		
Total Tested			3000			

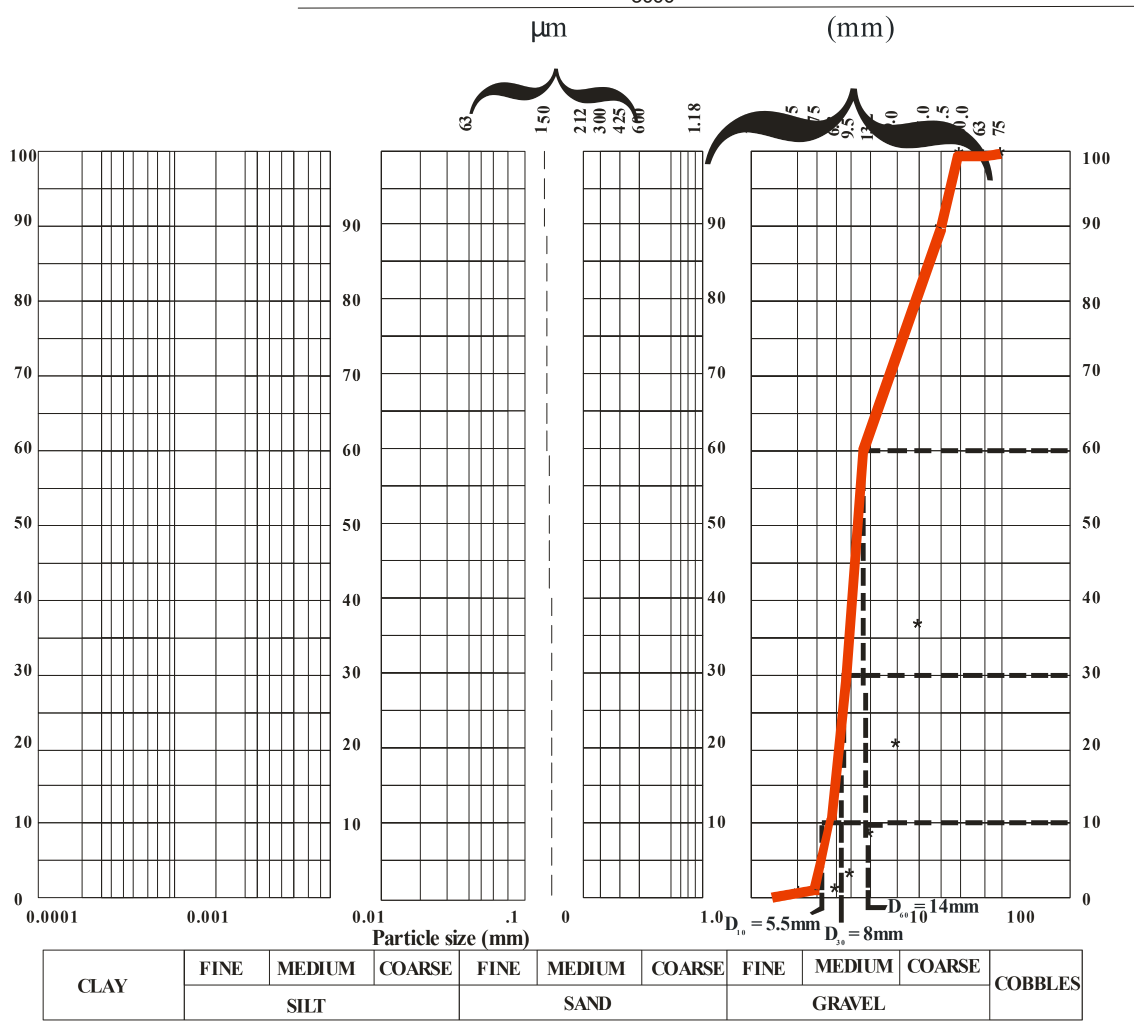


Figure 4.6: Particle Size Distribution Curve - Dugbe Iseyin Gravel, Oyo State

Sieve Analysis: Oko Awo, Oshogbo Sample (OS. 01 OS)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wh (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	500	600	0	0	0	100
37.5	550	600	100	3.3	3.3	96.7
25.0	500	850	300	10.0	13.3	86.7
19.0	500	850	350	11.7	25.0	75.0
13.2	500	1050	550	18.3	43.3	56.7
9.5	500	850	350	11.7	55.0	45.0
6.3	500	1150	650	21.7	76.7	23.3
4.75	550	1000	450	15.0	91.7	8.3
3.35	500	700	200	6.7	98.4	1.6
Recceiver	300	350	50	1.7		
TotalTested			3000			

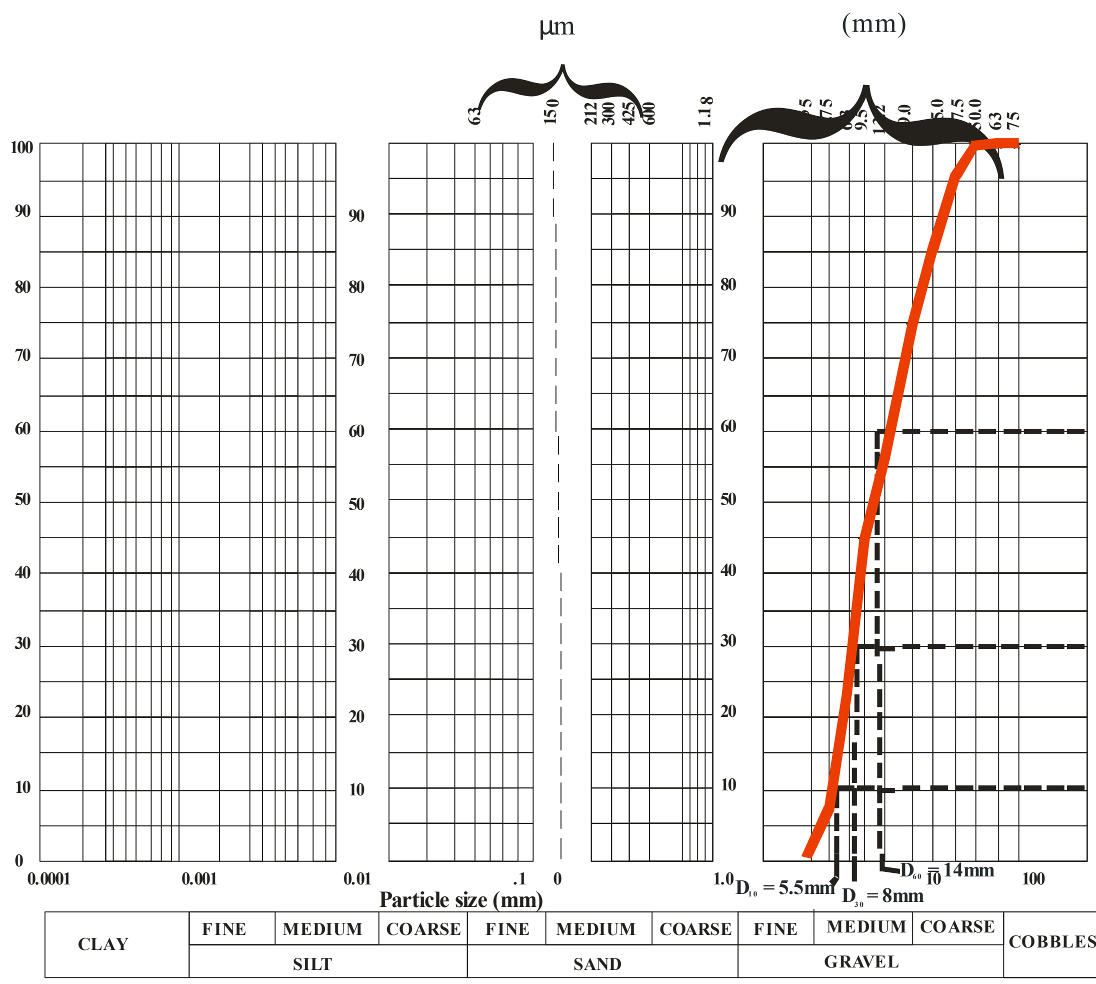


Figure 4.7: Particle Size Distribution Curve - Oko Awo, Oshogbo Gravel, Osun State

Sieve Analysis: Ikire Sample(OS. 02 IK)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wn (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	500	600	0	0	0	100
37.5	550	500	0	0	3.3	100
25.0	500	650	100	3.3	3.3	96.7
19.0	500	700	200	6.7	10	90.0
13.2	500	900	400	13.3	23.3	76.6
9.5	500	1200	700	23.3	46.6	53.4
6.3	500	1100	600	20.0	66.6	33.4
4.75	550	1400	850	28.3	94.9	5.1
3.35	500	650	50	1.7	96.6	3.4
Recceiver	300	400	100	3.3		
TotalTested			3000			

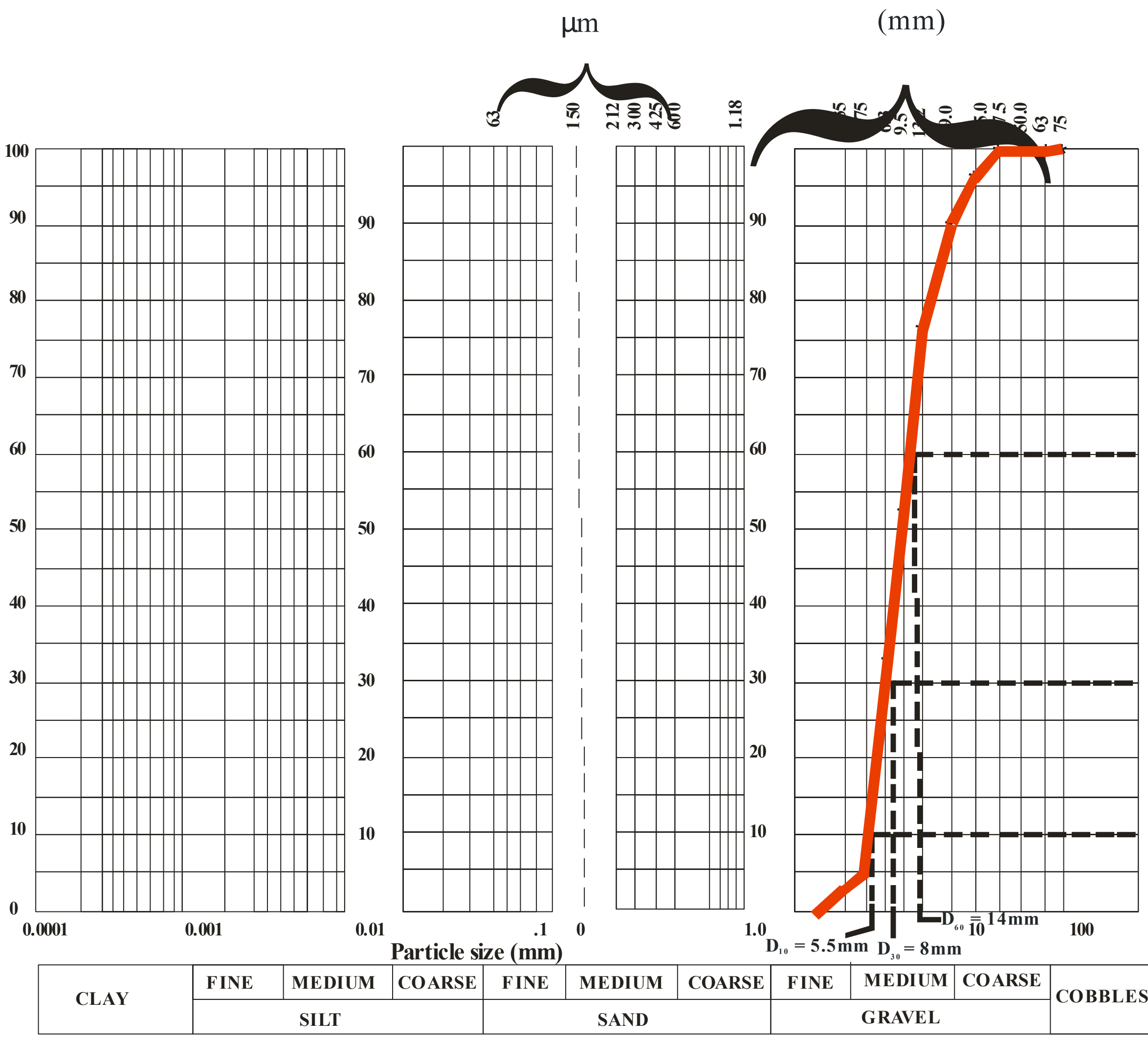


Figure 4.8: Particle Size Distribution Curve - Ikire Gravel, Osun State

Sieve Analysis: Toro Road, Modakeke Sample(OS. 03 MD)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wh (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	500	600	0	0	0	100
37.5	550	600	100	3.3	3.3	96.7
25.0	500	1000	450	15.0	18.3	81.7
19.0	500	850	350	11.7	30.0	70.0
13.2	500	1150	650	21.7	51.7	48.3
9.5	500	900	400	13.3	65.0	35.0
6.3	500	1000	500	16.7	81.7	18.3
4.75	550	900	350	11.7	93.4	6.6
3.35	500	650	150	5.0	98.4	1.6
Recceiver	300	350	50	1.7		
TotalTested			3000			

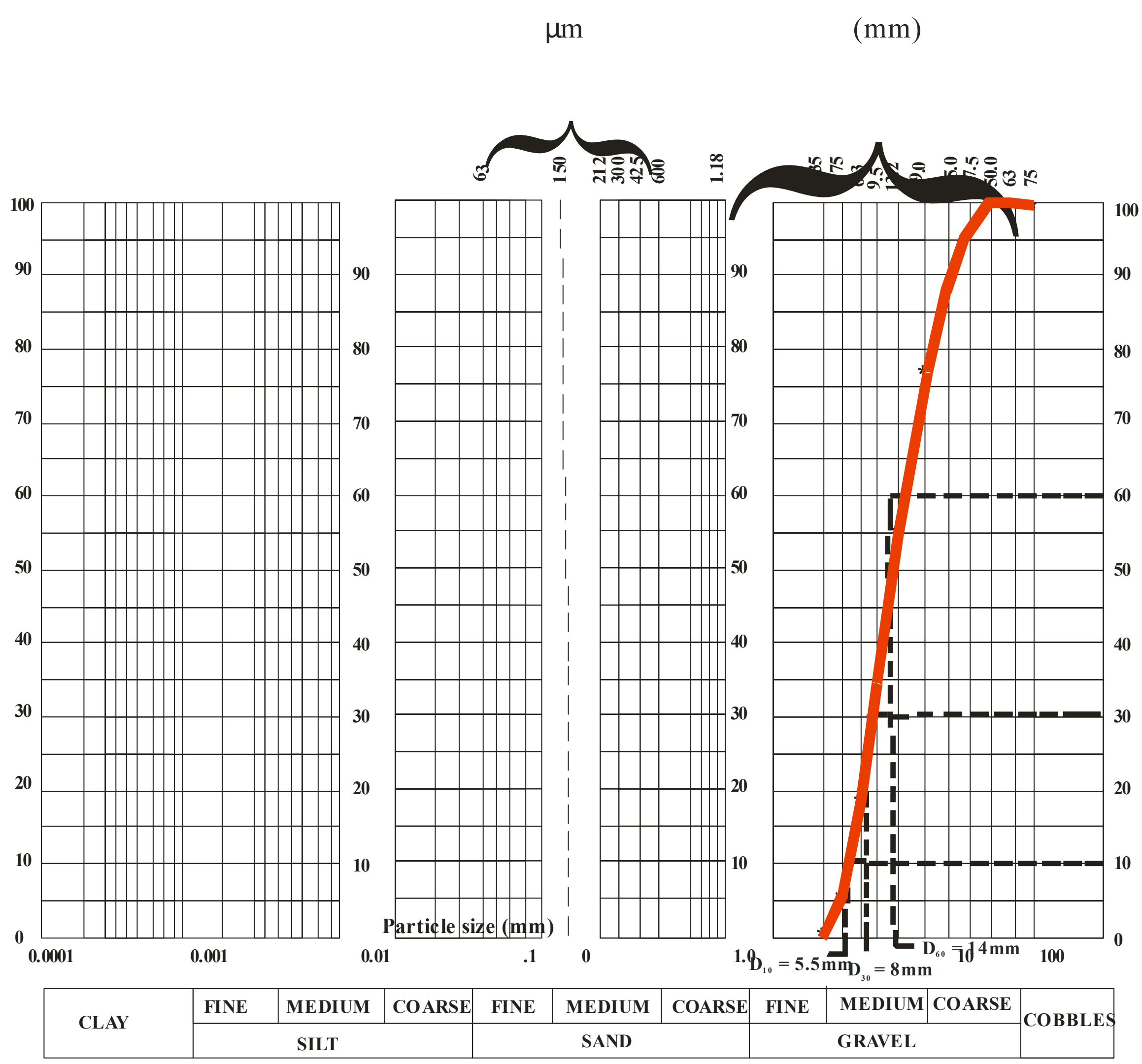


Figure 4.9: Particle Size Distribution Curve - Toro Road, Modakeke Gravel, Osun Stat

Sieve Analysis: Laje Road, Ondo Sample(OD. 01 OD)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wn (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	500	600	0	0	0	100
37.5	550	650	150	5.0	5.0	95.0
25.0	500	750	200	6.7	11.7	88.3
19.0	500	600	100	3.3	15	85.0
13.2	500	700	200	6.7	21.7	78.3
9.5	500	950	450	15.0	36.7	63.0
6.3	500	1250	750	25.0	61.7	38.3
4.75	550	1550	1000	33.3	95.0	5.0
3.35	500	550	50	1.7	96.7	3.3
Recceiver	300	400	100	3.3		
TotalTested			3000			

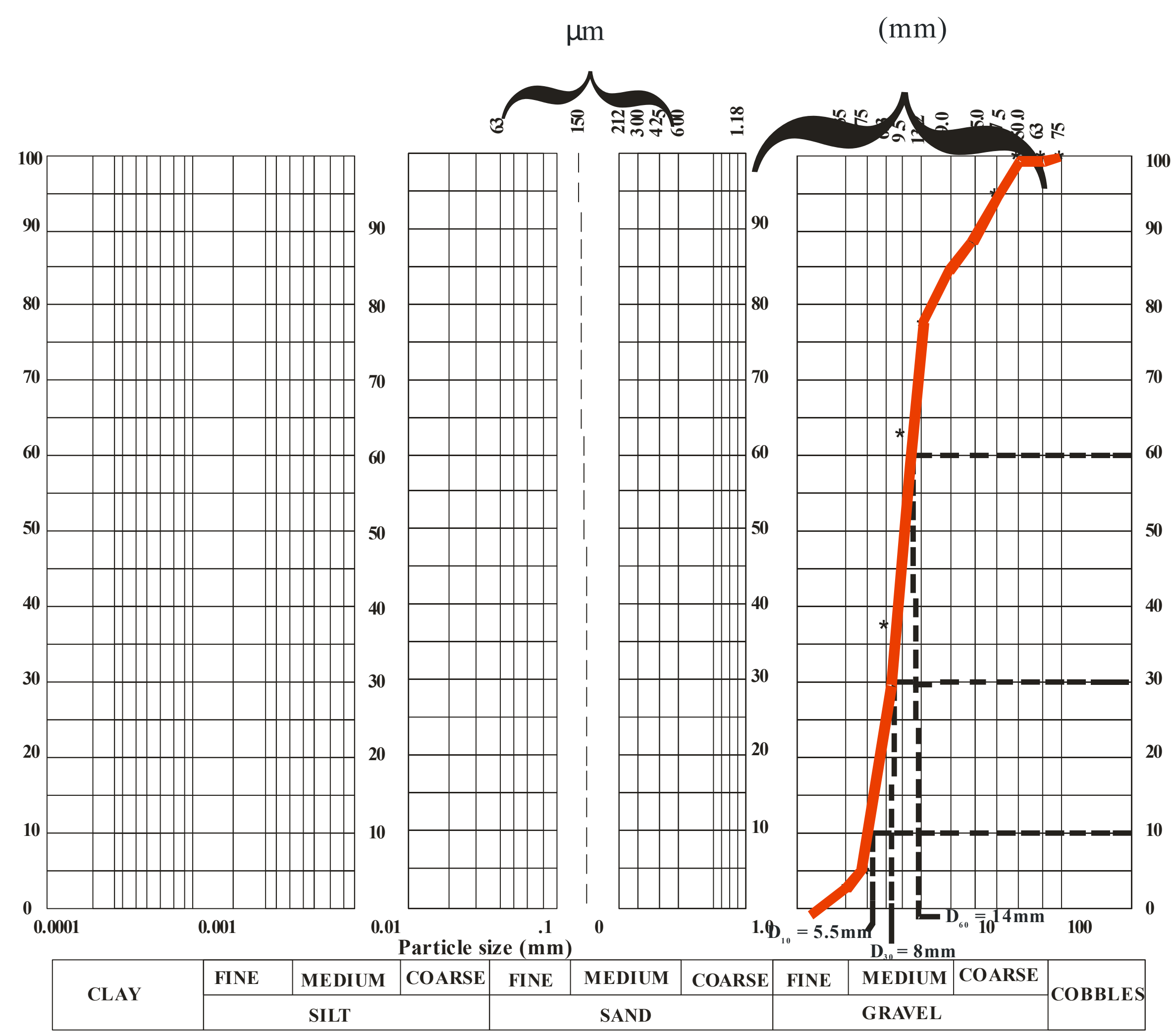


Figure 4.10: Particle Size Distribution Curve - Laje Road, Ondo Gravel, Ondo State

Sieve Analysis: Iju Itagbolu Sample(OD. 02 IJ)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wh (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	600	600	0	0	0	100
37.5	500	550	50	1.7	1.7	98.3
25.0	550	750	200	6.7	8.4	91.6
19.0	500	700	200	6.7	15.1	84.9
13.2	500	1000	500	16.7	31.8	68.3
9.5	500	800	300	10.0	41.8	58.2
6.3	500	1100	600	20.0	61.8	38.2
4.75	550	1650	1050	35.0	96.8	3.2
3.35	500	550	50	1.7	98.5	1.5
Recceiver	300	350	50	1.7		
TotalTested			3000			

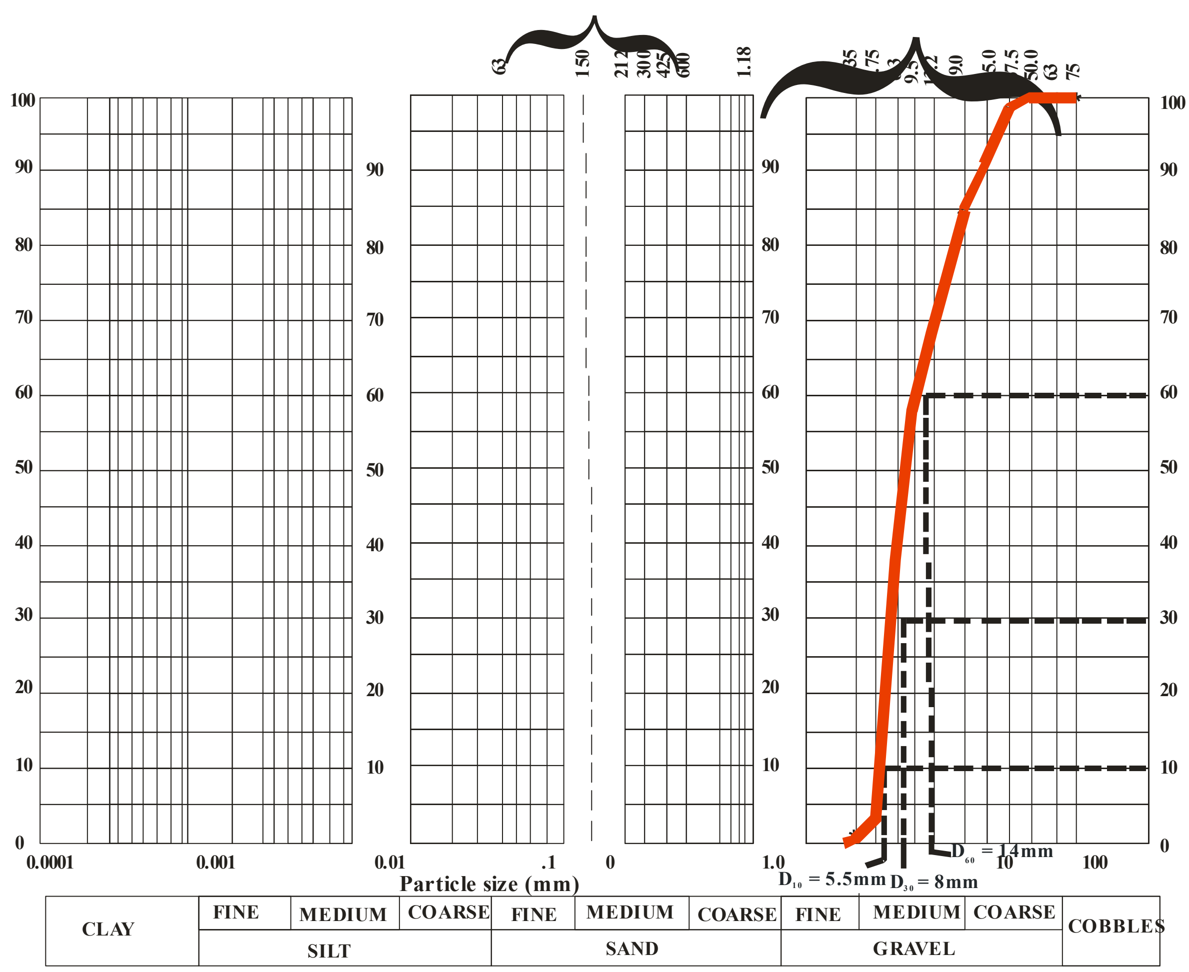


Figure 4.11: Particle Size Distribution Curve - Iju Itagbolu Gravel, Ondo Stat

Sieve Analysis: Oke Igbo Sample(OD. 03 OK)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wn (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	600	600	0	0	0	100
37.5	500	700	200	6.7	6.7	93.3
25.0	550	850	300	10.0	16.7	83.3
19.0	500	800	300	10.0	26.7	73.3
13.2	500	950	450	15.0	41.7	58.3
9.5	500	850	350	11.7	53.4	46.6
6.3	500	1050	650	21.7	75.1	24.9
4.75	550	1200	650	21.7	96.8	3.2
3.35	500	500	0	0	96.8	3.2
Recceiver	300	400	100	3.3		
TotalTested			3000			

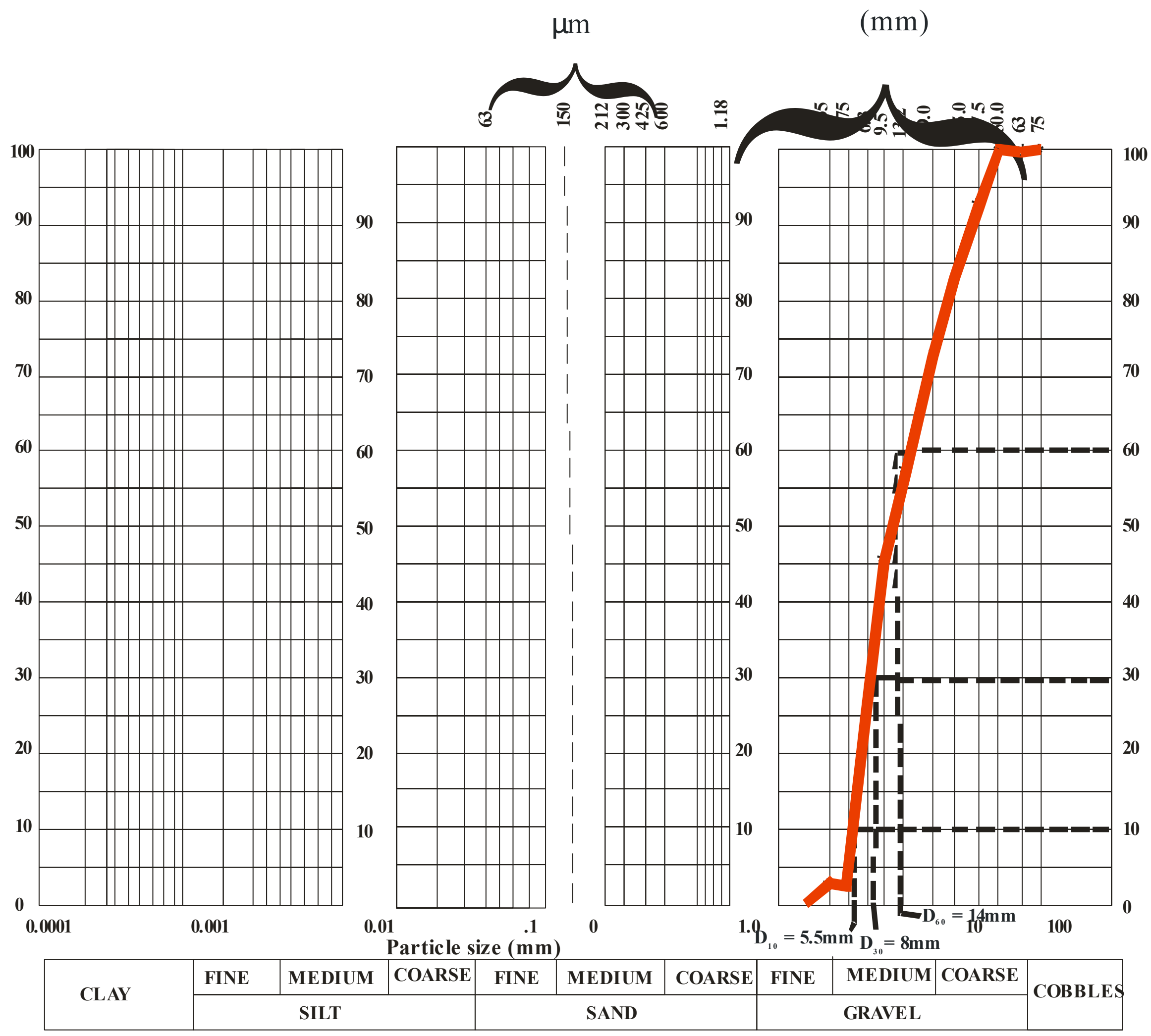


Figure 4.12: Particle Size Distribution Curve - Oke Igbo Gravel, Ondo State

Sieve Analysis: Ado-Ekiti Sample(EK. 01 AD)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wn (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	600	600	0	0	0	100
37.5	500	650	200	5.0	5.0	95.0
25.0	550	1300	300	25.0	30.0	70.0
19.0	500	1350	300	28.3	58.3	41.7
13.2	500	1200	450	23.3	81.6	18.4
9.5	500	750	250	8.3	89.9	10.1
6.3	500	650	150	5.0	94.9	5.1
4.75	550	650	100	3.3	98.2	1.8
3.35	500	500	0	0	98.2	1.8
Recceiver	300	350	50	1.7		
TotalTested			3000			

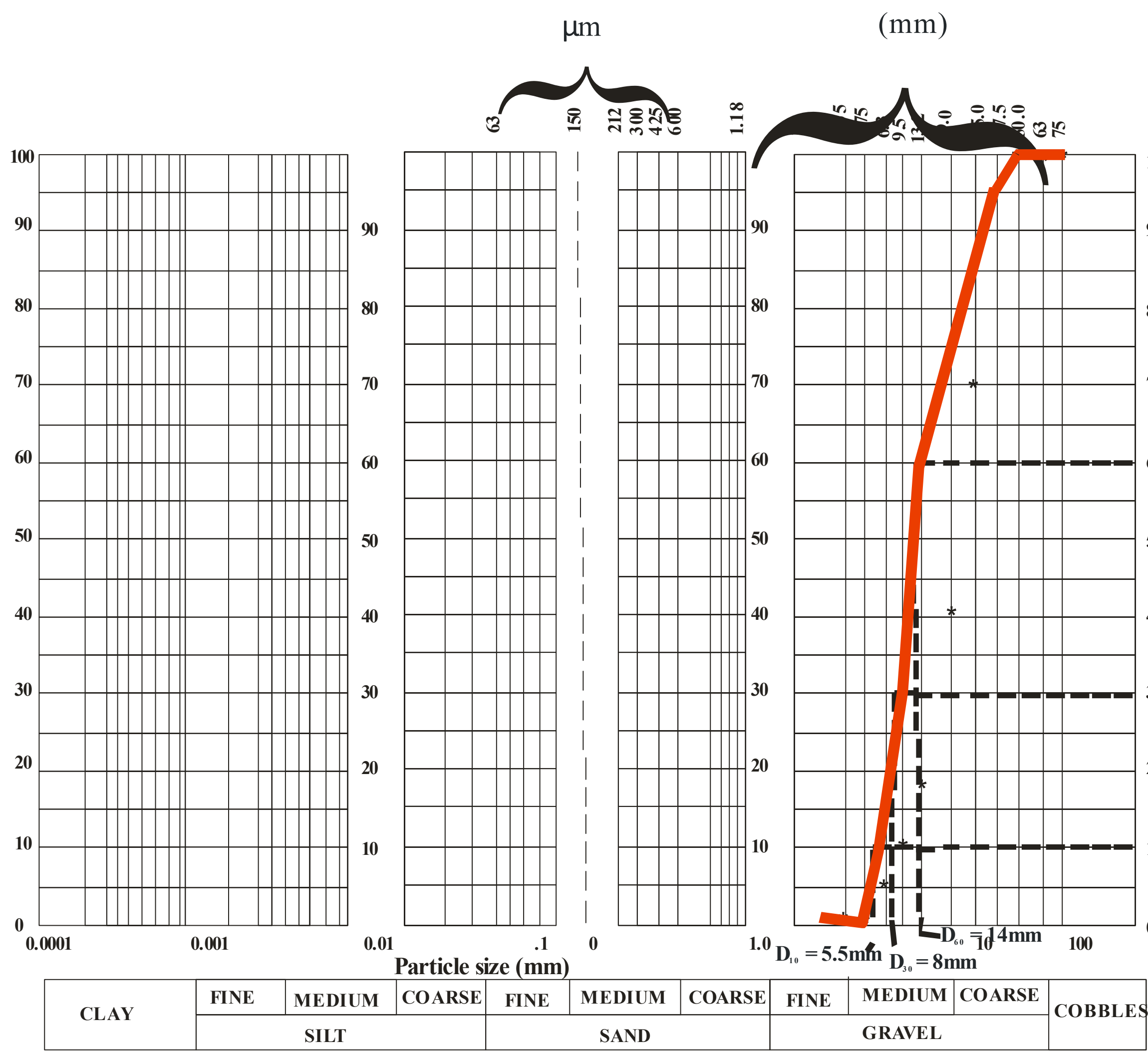


Figure 4.13: Particle Size Distribution Curve - Ado Ekiti Gravel, Ekiti State

Sieve Analysis: Ikole-Ekiti Sample(EK. 02 IK)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wn (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	600	600	0	0	0	100
37.5	500	500	0	0	0	100
25.0	550	2250	1700	56.7	56.7	43.3
19.0	500	1000	500	16.7	73.4	26.6
13.2	500	1050	550	18.3	91.7	8.3
9.5	500	650	150	5.0	96.7	3.3
6.3	500	550	50	1.7	98.4	1.6
4.75	550	550	0	0	98.4	1.6
3.35	500	500	0	0	98.4	1.6
Recceiver	300	300	50	1.7		
TotalTested			3000			

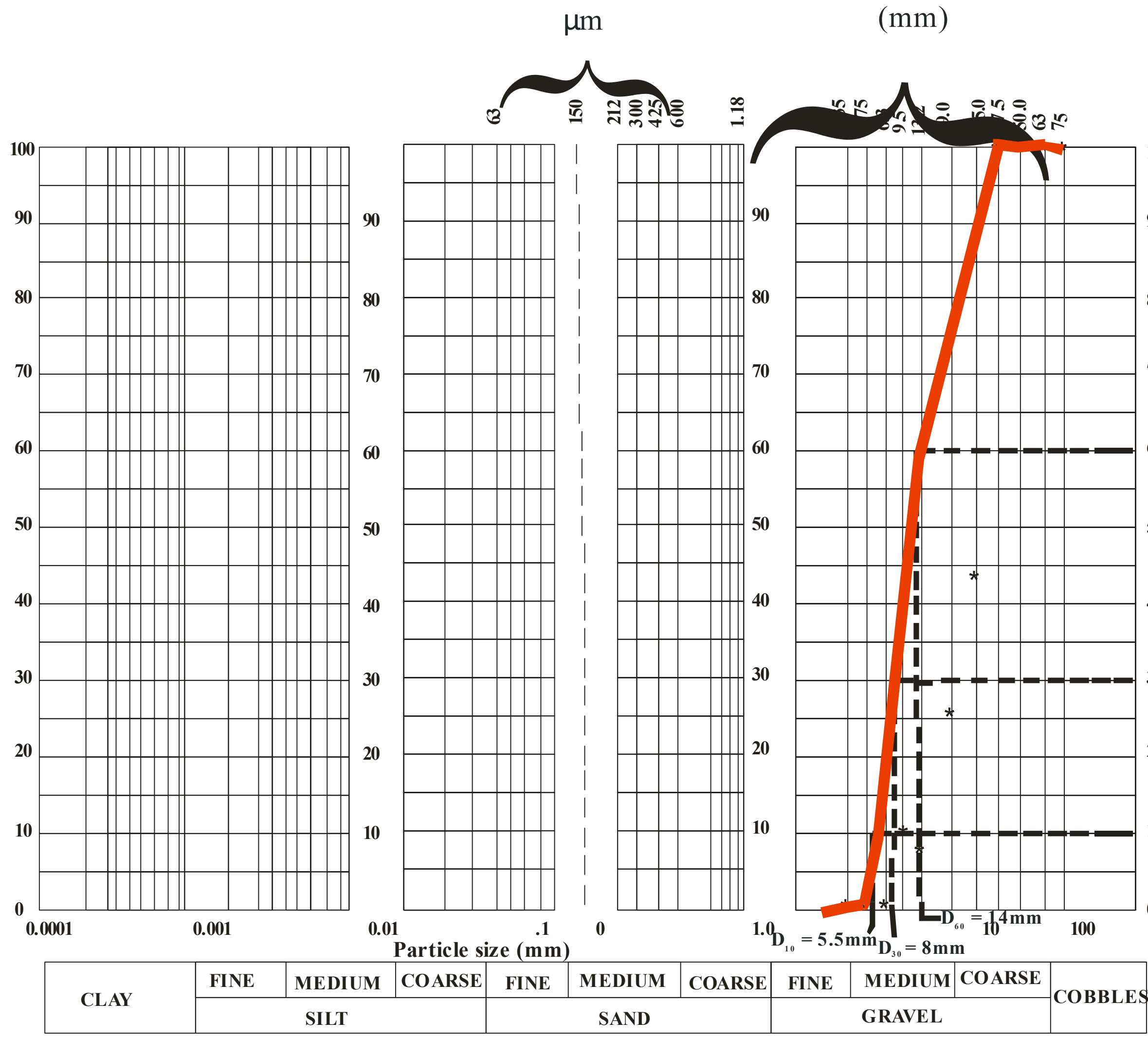


Figure 4.14: Particle Size Distribution Curve - Ikole Ekiti Gravel, Ekiti State

Sieve Analysis-Igbara-Odo Sample (EK. 03 IG)

Sieve Opening (mm)	Mass of Sieve (g)	Mass of Sieve + Aggregate (g)	Mass of Aggregate Retained on each Sieve, Wn (g)	Percentage of Mass Retained on each Sieve,Rn	Cumulatve Percent Retained, SRn	Percent Finer 100 - SRn
75	700	700	0	0	0	100
63	750	750	0	0	0	100
50	600	600	0	0	0	100
37.5	500	550	50	1.7	1.7	98.3
25.0	550	1400	850	28.3	30.0	70.0
19.0	500	900	400	13.3	43.3	56.7
13.2	500	950	450	15.0	58.3	41.7
9.5	500	700	200	6.7	65.0	35.0
6.3	500	750	250	8.3	73.3	26.7
4.75	550	800	250	8.3	81.6	18.4
3.35	500	800	300	10.0	91.6	8.4
Recceiver	300	550	250	8.3		
TotalTested			3000			

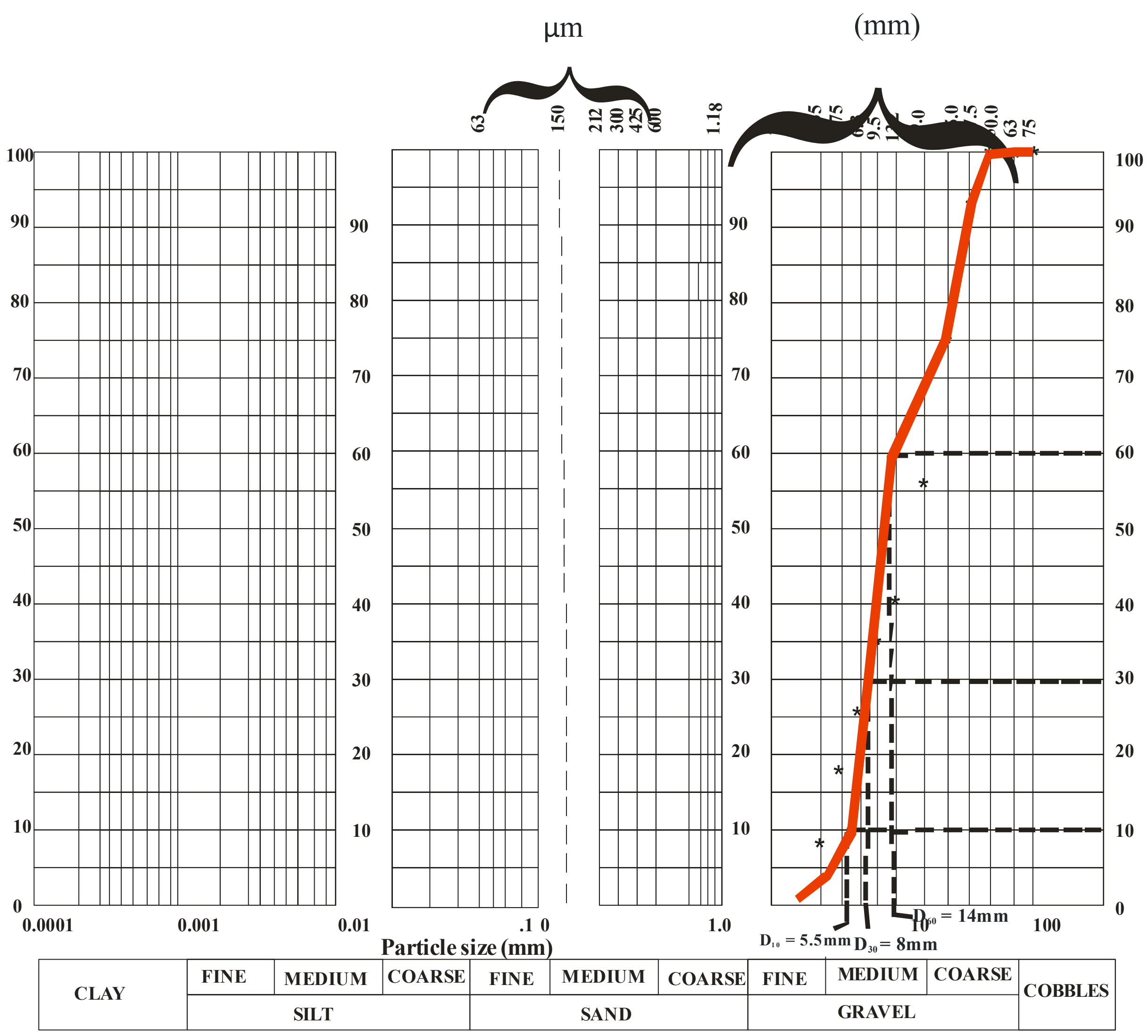
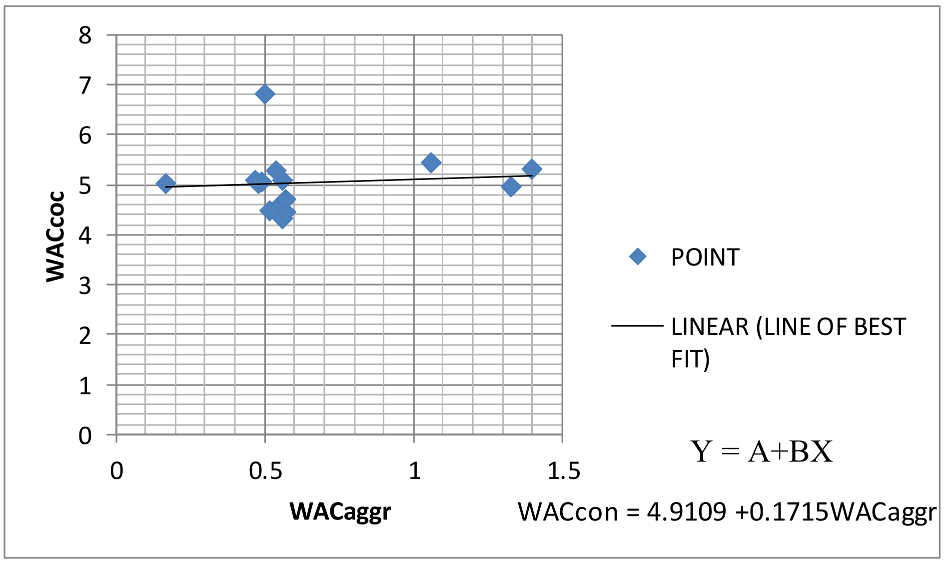


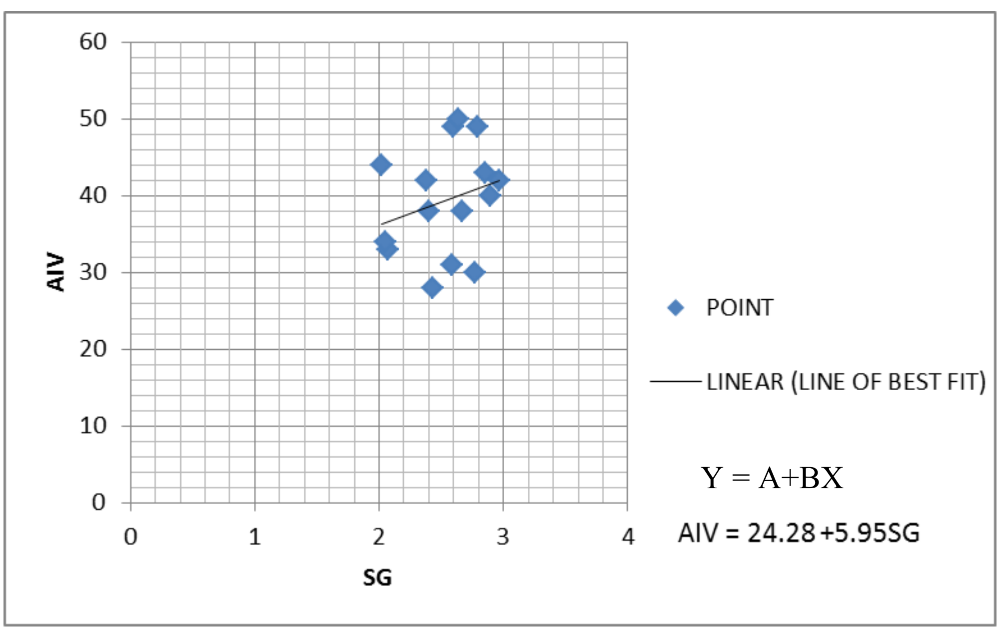
Figure 4.15: Particle Size Distribution Curve - Igbara Odo Gravel, Ekiti State

APPENDIX E

CROSSPLTTING OF SOME PARAMETERS

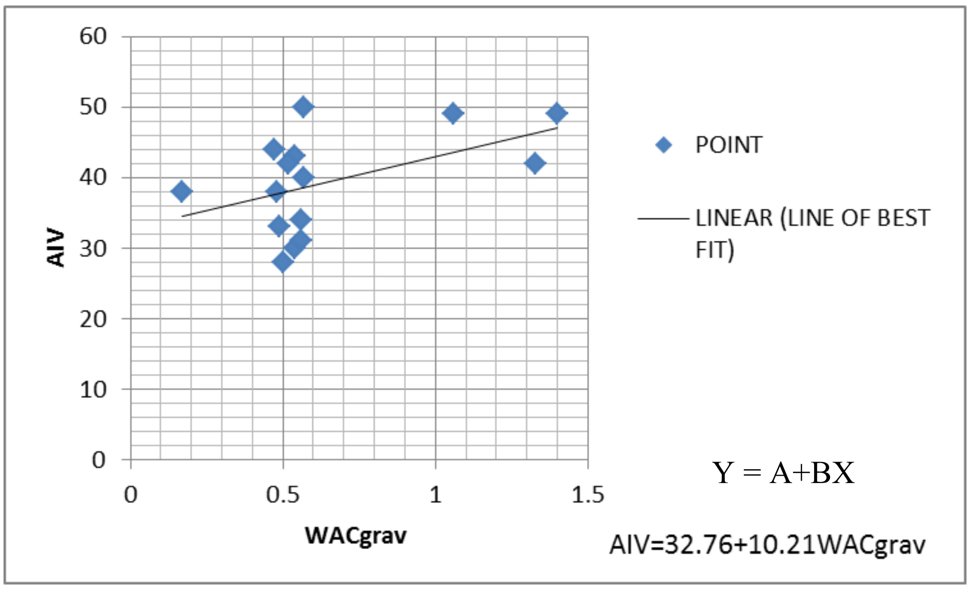


a) Graph showing Water Absorption Capacity of Concrete against that of Gravel.

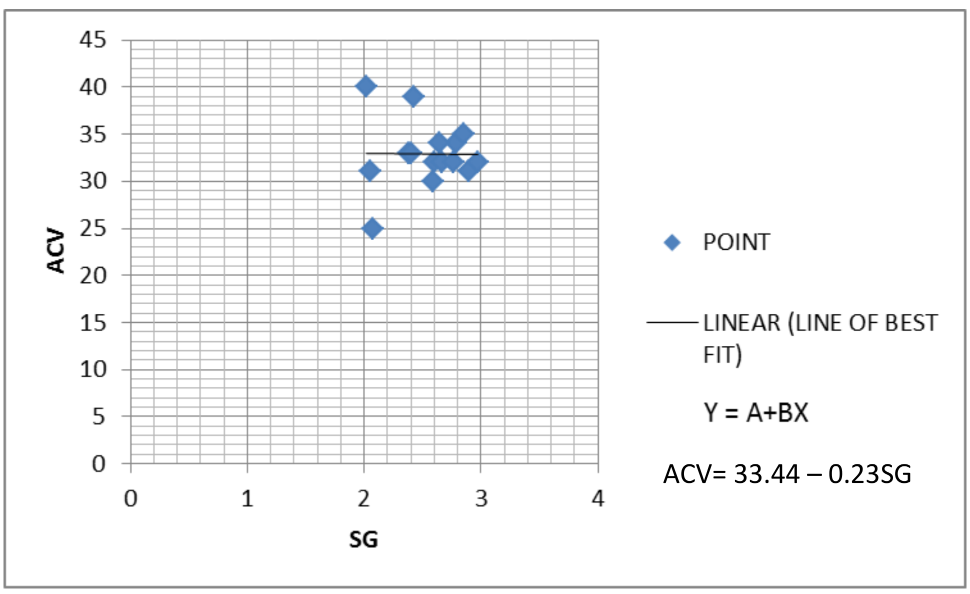


b) Graph of Aggregate Impact Value against Specific Gravity of Gravel.

Figure 4.6.1. Cross - plotting of some Gravel Parameters

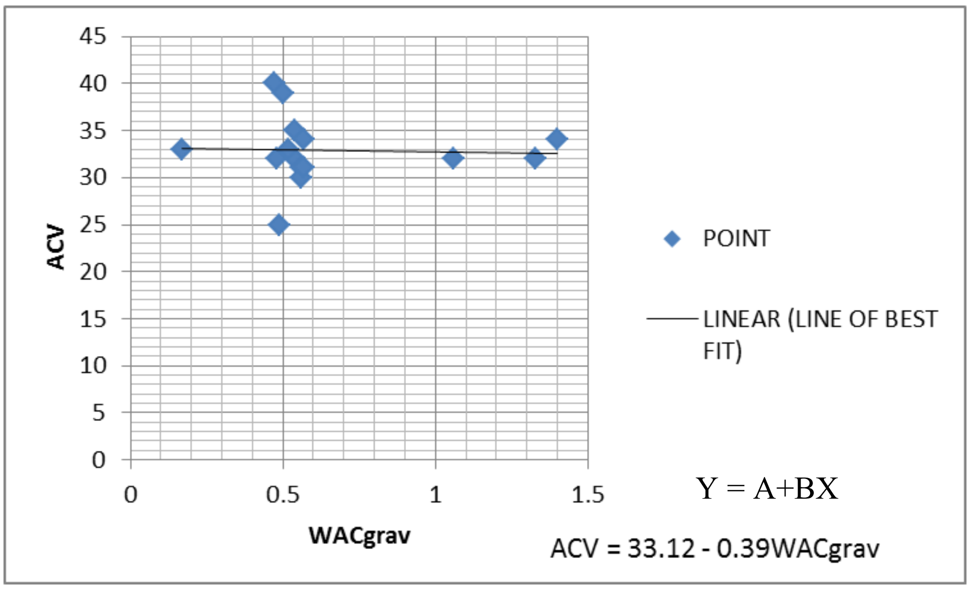


c) Graph of Aggregate Impact Value against Water Absorption Capacity of Gravel.



d) Graph of Aggregate Crushing Value against Specific Gravity of Gravel.

Figure 4.6.1. (Contd.). Cross - plotting of some Gravel Parameters



e) Graph of Aggregate Crushing Value against Water Absorption Capacity of Gravel.

Figure 4.6.1. (Contd.). Cross - plotting of some Gravel Parameters