EFFECTS OF QUARRY ROCK DUST AS A PARTIAL REPLACEMENT FOR RIVER SAND ON THE COMPRESSIVE STRENGTH OF CONCRETE

BY

NAME : EJEZIE GOODNESS KOSISOCHUKWU

REG NO: 2017224019

DEPARTMENT OF CIVIL ENGINEERING

FACULTY OF ENGINEERING

NNAMDI AZIKIWE UNIVERSITY, AWKA

MAY, 2023

CERTIFICATION

This is to certify that I Ejezie Goodness Kosisochukwu with registration number 2017224019 personally carried out this project till completion and was undertaken and submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering Degree (B. Eng) in the Department of Civil Engineering, Nnamdi Azikiwe University, Awka.

…………………… ……………………..

EJEZIE GOODNESS KOSISOCHUKWU DATE

APPROVAL

This research work has been confirmed complete on assessment and approved by the Department of Civil Engineering of Faculty of Engineering, Nnamdi Azikiwe University, Awka.

………………………… ………………….

Engr. Ezenwamma A.A Date

Supervisor

………………………… ………………….

Engr. Prof Ezeagu A. C Date

………………………… ………………….

External Supervisor Date

DEDICATION

With a grateful heart, I dedicate the success of this work to God Almighty for His divine inspirations and protection through the course of this research work.

Secondly to my parents Mr. and Mrs. EJEZIE CHRISTIAN, who showed me love through finance, prayers and advice.

ACKNOWLEDGEMENT

My deepest gratitude goes to God who has provided all that was needed to complete this work and the program for which it was undertaken for.

I will not forget to acknowledge and extend my gratitude to my project supervisor, Engr. Ezenwamma A.A without his guidance and advice, this work would not have been a success and also my HOD Engr. Prof. Ezeagu A . C. Not forgetting my lecturers who saw me through the starting and completion of my academic program: Engr. Prof Aginam Chukwura H, Engr. Prof. Nwaiwu Charles Okechukwu, Engr. Dr Onoduagu P. O, Engr. Prof. (Mrs) Nwaiwu, Engr. Nwajuaku Afemefuna I, Engr. Odinaka Victor , Engr. (Mrs) Nwajuaku Ijeoma,

Also the contribution of the lab technologists in civil engineering lab to the success of my research works. My course mates, and friends, may God bless you all.

ABSTRACT

Concrete is the most widely used infrastructure development throughout the world. The widely used raw materials in a concrete are cement, fine aggregate, coarse aggregate and water and in which river sand is used as fine aggregate and it is of prime importance in mix design. Due to increasing demand of river sand, river erosion and other environmental issues have led to scarcity of river sand. Concrete plays a very important role in the construction industry and environmental transportation and consistent use has made the availability and use of river sand less attractive, river sand which is one of the essential materials used in concrete has become expensive and also a scarce material. This study presents the feasibility of the usage of quarry dust as partial replacement for natural sand in concrete. Tests were carried out on cubes of dimension 150mm x 150mm x 150mm using various replacement percentages ranging from 10% to 70% of quarry dust to compare the strength properties of concrete on replacement to that of natural sand concrete. This research work covers several practical tests which includes, Sieve analysis, specific gravity, slump test, and the compressive strength test of concrete.

TABLE OF CONTENT

CHAPTER ONE

INTRODUCTION

1.1.0 Background of Study

Concrete is an assemblage of cement, aggregates (fine and coarse) and water. The most commonly used fine aggregate is sand derived from river banks. The global consumption of natural sand is too high due to its extensive use in concrete. The demand for natural sand is quite high in developing countries owing to rapid infrastructural growth which results supply scarcity. Therefore, construction industries of developing countries are in stress to identify alternative materials to replace the demand for natural sand. On the other hand, the advantages of utilization of byproducts or aggregates obtained as waste materials are pronounced in the aspects of reduction in environmental load and waste management cost, reduction of production cost as well as augmenting the quality of concrete. In this context, fine aggregate has been replaced by quarry dust a byproduct of stone crushing unit and few admixtures to find a comparative analysis for different parameters which are tested in the laboratories to find the suitability of the replacement adhered to the Indian Standard specifications for its strength. Quarry dust has been used for different activities in the construction industry such as road construction and manufacture of building materials such as light weight aggregates, bricks, and tiles. Crushed rock aggregates are more suitable for production of high strength concrete.

River sand which is one of the main constituents used in the production of concrete has become highly expensive and also scarce. In order to conserve river sand and to reduce the cost in concrete production, quarry dust may be used as an alternative partial replacement for river sand. Quarry dust is a kind of waste material that is generated from stone crushing industry and it is available to the extent of 200 million tons per annum which has landfill disposal problems. In highway department the quarry dust is used as binding material between bitumen and coarse aggregate. In this study, attempt has been made to experimentally find whether quarry dust can partially replace river sand in concrete.

1.1.1 Statement of Problem

This study serves to evaluate the feasibility of using quarry rock dust as a replacement for river sand as fine aggregate in concrete. This is in order to alleviate the scarcity and high cost of river sand due to increased rate of demand in the construction industries.

1.1.2 Objective of Study

The aim of this study is to ascertain the compressive strength of concrete with quarry rock dust as a partial replacement for river sand. It tends to also determine the

1. The density of the quarry dust and river sand
2. The specific gravity of quarry dust and river sand
3. Particle size distribution of quarry dust and river sand through sieve analysis

1.1.3 Justification

This work focuses its purpose on the determining the compressive strength of concrete in which the river sand (fine aggregate) has been partially replaced with quarry dust. It also serves to determine the workability of quarry dust as a replacement for river sand in concrete. There have been a continual increase in the demand and consumption of river sand calls the need for economical and workable alternative constituents concrete.

By replacement of quarry dust, the requirement of land fill area can be reduced and can also solve the problem of sand scarcity.

1.1.4 Significance of study

As the level of construction in Nigeria keeps increasing rapidly, for instance the construction of buildings in estate environments for development as was not before, construction of highway pavements as was not before, construction of Dams as were not before etc. there have been an observable decline in the availability and supply of river sand for construction which has consequently reflected in price hike on purchase of river sand for construction. The use of quarry dust to partially replace river sand has also been shown to improve the splits tensile strength (Jamale, and Kawade, 2015).

1.1.5 Study Area

This study is to be carried out at the concrete lab workshop unit and at the geotechnical engineering laboratory unit of Civil Engineering department, Nnamdi Azikiwe University, Awka, Anambra state.

1.1.6 Scope of Study

This work covers the replacement of river sand (sharp sand) with quarry dust and also accommodating several tests which includes slump test, compressive strength test, sieve analysis, specific gravity test.

1.1.7 Limitation of Study

The biggest challenge during the course of this study, borders on financial challenges in purchasing and transporting the materials to the concrete lab workshop, also unavailability of necessary equipment that would aid a speedy completion of the study at the laboratory level.

1.1.8 Research Questions

In proposing for the use of quarry rock dust as a partial replacement for river sand, some questions form the need to carry out this study which may include

1. How available in proportion can quarry dust readily be, to meet up as a replacement for river sand in concrete?
2. In terms of workability, can the concrete produced from quarry dust be compared to that of a standard concrete with sand as fine aggregate
3. In terms of density can a concrete produced from quarry dust be comparable to a standard concrete with sand as fine aggregate.
4. In terms of compressive strength, can concrete produced from quarry rock dust meet the standard specifications using river sand concrete?

1.1.9 Hypothesis

Density of concrete produced from quarry dust is comparable to the standard

Water absorption percent of concrete produced from quarry dust is comparable to the standard.

The workability of concrete produced from quarry dust meets the standard specifications

Quarry dust can be used in concrete production

The compressive strength of concrete produced with quarry dust can meet the specifications.

CHAPTER TWO

LITERATURE REVIEW

2.1.1 Review of Concrete

Concrete is an artificial composite material, comprising a matrix of cementitious binder (typically Portland cement paste or asphalt) and a dispersed phase or "filler" of aggregate (typically a rocky material, loose stones, and sand). The binder "glues" the filler together to form a synthetic conglomerate.

Concrete is a composite material composed of coarse granular materials (the aggregate or filler) embedded in a hard matrix of material (the cement binder) that fills the space among the aggregate particles and glues them together (Naresh Kumar, et al., 2017)

Many types of concrete are available, determined by the formulations of binders and the types of aggregate used to suit the application of the engineered material. These variables determine strength and density, as well as chemical and thermal resistance of the finished product.

Aggregates consist of large chunks of material in a concrete mix, generally a coarse gravel or crushed rocks such as limestone, or granite, along with finer materials such as sand.

Cement paste, most commonly made of Portland cement, is the most prevalent kind of concrete binder. For cementitious binders, water is mixed with the dry cement powder and aggregate, which produces a semi-liquid slurry (paste) that can be shaped, typically by pouring it into a form. The concrete solidifies and hardens through a chemical process called hydration. The water reacts with the cement, which bonds the other components together, creating a robust, stone-like material. Other cementitious materials, such as fly ash and slag cement, are sometimes added either pre-blended with the cement or directly as a concrete component and become a part of the binder for the aggregate. Fly ash and slag can enhance some properties of concrete such as fresh properties and durability. Alternatively, other materials can also be used as a concrete binder: the most prevalent substitute is asphalt, which is used as the binder in asphalt concrete.

Admixtures are added to modify the cure rate or properties of the material. Mineral admixtures use recycled materials as concrete ingredients. Conspicuous materials include fly ash, a by-product of coal-fired power plants; ground granulated blast furnace slag, a by-product of steelmaking; and silica fume, a by-product of industrial electric arc furnaces.

Structures employing Portland cement concrete usually include steel reinforcement because this type of concrete can be formulated with high compressive strength, but always has lower tensile strength. Therefore, it is usually reinforced with materials that are strong in tension, typically steel rebar.

The mix design depends on the type of structure being built, how the concrete is mixed and delivered, and how it is placed to form the structure. When aggregate is mixed with dry Portland cement and water, the mixture forms a fluid slurry that is easily poured and molded into shape. The cement reacts with the water through a process called concrete hydration that hardens over several hours to form a hard matrix that binds the materials together into a durable stone-like material that has many uses. This time allows concrete to not only be cast in forms, but also to have a variety of tooled processes preformed.

2.1.2 Review on properties of concrete

Strength

The strength of concrete is of the following types:

a. Compressive strength
b. Tensile strength
c. Flexural strength
d. Shear strength

a. Compressive Strength

Two types of test specimens are used in Bangladesh -(1) Cube and (2) Cylinder.

The cube specimens of concrete of the desired proportion are cast in steel or cast iron molds, normally 6-inch cube. The standard cylinder specimen of concrete is 6 inch in diameter and 12 inches in height and cast in a mold generally made of cast iron;

Standard cubes and cylinders are tested at prescribed ages, generally, 28 days, with additional tests often made at 1, 3, and 7 days. The specimens are tested for crushing strength under a testing machine**.** The cube tests give much greater values of crushing strength, usually 20 to 30 % more than those given by cylinders.

According to British standard, the strength of a cylinder specimen is equal to three-quarters of the strength of the cube specimen

Effect of age on concrete strength:

Concrete attains strength with time. Ordinary cement concrete gains above 70 to 75% of its final strength within 28 days and about 90 to 95 % in the course of one year. It is often desirable to check the suitability of a concrete long before the results of the 28-day test are available. When no specific data on the materials used in making concrete are available, the 28-day strength may be assumed to be 1.5 times of the 7 days' strength. Tests have shown that for concrete made with ordinary Portland cement the ratio of the 28 days to 7 days' strength generally lies between 1.3 to 1.7, and the majority of the results fall above 1.5.

b. Tensile strength

Concrete is very weak in tension. The tensile strength of ordinary concrete ranges from about 7 to 10 percent of the compressive strength.

c. Flexural strength

The flexural strength of plain concrete is almost wholly dependent upon the tensile strength. However, experiments show that the modulus of rupture is considerably greater than the strength in tension.

d. Shear strength

It is the real determining factor in the compressive strength of short columns. The average strength of concrete in direct shear varies from about half of the compressive strength for rich mixtures to about 0.8 of the compressive strength for lean mixtures.

Workability

The strength of concrete of a given mix proportion is very seriously affected by the degree of its compaction. It is therefore vital that the consistency of the mix be such that the concrete can be transported, placed and finished sufficiently easily and without segregation. A concrete satisfying these conditions is said to be workable. Usually, Slump test is done to indirectly determine the workability of a concrete mix.

Factors affecting the workability of concrete are:

i. Water Content
ii. Mix Proportions
iii. Size of Aggregates
iv. Shape of Aggregates
v. Grading of Aggregates
vi. Surface Texture of Aggregates
vii. Use of Admixtures
viii. Use of Supplementary Cementitious Materials
ix. Time
x. Temperature

Elastic Properties

Concrete is not perfectly elastic for any range of loading, an appreciable permanent setting taking place for even low loads. The deformation is not proportional to the stress at any stage of loading. The elastic properties of concrete vary with the richness of the mixture and with the intensity of the stress. They also vary with the age of concrete.

Durability

Durability is the property of concrete to withstand the condition for which it has been designed, without deterioration over a period of years. Lack of durability can be caused by external agents arising from the environment or by internal agents within the concrete.

Causes can be categorized as physical, mechanical and chemical.

Physical cause arises from the action of frost and from differences between the thermal properties of aggregate and of the cement paste, while mechanical causes are associated mainly with abortion.

Impermeability

Penetration of concrete by materials in solution may adversely affect its durability, for instance, when $Ca(OH)_2$ is being leached out or an attack by aggressive liquids (acids) takes place. Permeability has an important bearing on the vulnerability of concrete to water and frost. In the case of reinforced cement concrete, the penetration of moisture and air will result in the corrosion of steel. This leads to an increase in the volume of the steel, resulting in cracking and spalling of the concrete. Permeability of concrete is also of importance for liquid retaining and hydraulic structures;

Segregation

The tendency of separation of coarse aggregate grains from the concrete mass is called segregation. It increases when the concrete mixture is lean and too wet. It also increases when rather large and rough-textured aggregate is used. The phenomenon of segregation can be avoided as follows.

i. Addition of little air-entraining agents in the mix.
ii. Restricting the amount of water to the smallest possible amount.
iii. All the operations like handling, placing and consolidation must be carefully conducted.
iv. Concrete should not be allowed to fall from large heights.

Bleeding

The tendency of water to rise to the surface of freshly laid concrete is known as bleeding. The water rising to the surface carries with it, particles of sand and cement, which on hardening form a scum layer is popularly known as laitance.

Concrete bleeding can be checked by adopting the following measures.

i. By adding more cement
ii. By using more finely ground cement
iii. By properly designing the mix and using the minimum quantity of water
iv. By using little air entraining agent
v. By increasing the finer part of fine aggregate

Fatigue

Plain concrete when subjected to flexure, exhibits fatigue. The flexure resisting ability of concrete of a given quality is indicated by an endurance limit whose value depends upon the number of repetitions of stress. In concrete pavement design, the allowable flexural working stress is limited to 55% of the modulus of rupture.

Advantages of concrete

Advantages of Concrete

i. Ingredients of concrete are readily available in most places.
ii. Unlike natural stones, concrete is free from defects and flaws.
iii. Concrete can be manufactured to the desired strength with an economy.
iv. The durability of concrete is very high.
v. It can be cast to any desired shape.
vi. The casting of concrete can be done on the working site which makes it economical.
vii. The maintenance cost of concrete is almost negligible.
viii. The deterioration of concrete is not appreciable with age.
ix. Concrete makes a building fire-safe due to its non-combustible nature.
x. Concrete can withstand high temperatures.
xi. Concrete is resistant to wind and water. Therefore, it is very useful in storm shelters.
xii. As a soundproofing material cinder concrete could be used.

Disadvantages of Concrete

i. Compared to other binding materials, the tensile strength of concrete is relatively low.
ii. Concrete is less ductile.
iii. The weight of concrete is high compared to its strength.
iv. Concrete may contain soluble salts. Soluble salts cause efflorescence.

2.1.3 Review on Historical Development of concrete

Concrete is a versatile composite **man-made** material, widely used as building /construction material in the world. Concrete is a composite material composed of coarse granular materials (the aggregate or filler) embedded in a hard matrix of material (the cement binder) that fills the space among the aggregate particles and glues them together (Naresh Kumar, et al., 2017). We can't imagine any structure without the use of concrete whether it is any kind of building, high-rise structures, dams, bridges, or roads.

The use of concrete started way back in the ancient time when people used clay, gypsum, and limestone as the binding material to form a concrete-like composite. Over many years people used these materials and with every passing time, it transformed into the modern world of concrete.

But finally, in the year 1824, an English man named Joseph Aspdin patented Portland Cement. It was named by the resemblance to the Portland Stone found in England and was regarded as the most prestigious building stone at that time.

2.1.4 Review on components of Concrete

Components of concrete are cement, sand, aggregates and water. Mixture of Portland cement and water is called as paste. So, concrete can be called as a mixture of paste, sand and aggregates. Sometimes rocks are used instead of aggregates.

The cement paste coats the surface of the fine and coarse aggregates when mixed thoroughly and binds them. Soon after mixing the components, hydration reaction starts which provides strength and a rock solid concrete is obtained.

2.1.5 Review on grades of concrete

Grade of concrete denotes its strength required for construction. For example, M30 grade signifies that compressive strength required for construction is 30MPa. The first letter in grade "M" is the mix and 30 is the required strength in MPa.

Based on various lab tests, grade of concrete is presented in Mix Proportions. For example, for M30 grade, the mix proportion can be 1:1:2, where 1 is the ratio of cement, 1 is the ratio of sand and 2 is the ratio of coarse aggregate based on volume or weight of materials.

The strength is measured with concrete cube or cylinders by civil engineers at construction site. Cube or cylinders are made during casting of structural member and after hardening it is cured for 28 days. Then compressive strength test is conducted to find the strength.

Regular grades of concrete are M15, M20, M25 etc. For plain cement concrete works, generally M15 is used. For reinforced concrete construction minimum M20 grade of concrete are used.

2.1.6 Review on types of Cement

1. Ordinary Portland Cement

This cement is also called basic Portland cement and is best suited for use in general concrete construction where there is no exposure to sulphates in the soil or in groundwater.

This cement is obviously produced in the maximum quantity than other cements. It is produced by grinding Portland clinker with the possible addition of a small quantity of gypsum, water or both and not more than 1 % of air-entraining agents. This very useful types of cement.

The clinker of Portland consists of calcium silicate and is obtained by heating to incipient fusion a predetermined and homogeneous mixture of materials mainly containing 59% – 64% lime (CaO) and 19% – 24% silica (SiO_2) with 3% – 6% of alumina (Al_2O_3) and 1% – 4% iron oxide (Fe_2O_3).

The setting and hardening of cement after the addition of water to it is due to the dissolution and reaction of the constituents.

The calcium aluminate is the first to set and harden, then comes calcium trisilicate ($3CaO.2SiO_2.3H_2O$) which is responsible for the early gain in strength during the first 48 hours.

Calcium disilicate reacts slowly and contributes to the strength at a later stage usually from 14 to 28 days.

Typical chemical reactions are as follows:

$3CaO.Al_2O_3 + 6H_20 \rightarrow 3CaO.Al_2O_3.6H_2O$

$(3CaO.SiO_2) + 6H_2O \rightarrow 3\ CaO.2SiO_2.3H_2O + 3Ca(OH)_2$

$3\ (2CaO.SiO_2) + 6\ H_2O \rightarrow 3CaO.2SiO_2.3H_2O + 3\ Ca(OH)_2$

Types of Ordinary Portland cement

- 33 grade ordinary Portland cement,
- 43-grade ordinary portland cement,
- 53 grade ordinary Portland cement,

2. Portland Pozzolana cement

Portland pozzolana cement is prepared either by grinding clinker and pozzolana or by blending Portland cement and fine pozzolana. The proportion of pozzolana may vary between 10% to 25% by weight of cement. This type of cement is suitable for waterfront structure or for marine structure as in dams, bridge piers and thick foundation where mass concrete is used, also used for sanitation system like Sewers.

3. Rapid hardening Portland cement

The cement is manufactured by intimately mixing together calcareous and argillaceous and/or other silica, alumina or iron oxide bearing materials. This cement has the same chemical composition as the ordinary Portland cement but is more finely ground. Its 24 hours strength is nearly equal to that attained by ordinary Portland cement after 3 days. The use of this cement permits early removal of shuttering thus directly affecting saving in time and money. It is generally used in road work and bridge construction where the time factor is very important.

4. Extra rapid hardening cement

Extra rapid hardening cement is a proper modification of rapid hardening cement. It is manufactured by inter grinding Calcium Chloride with rapid hardening portland cement. Normally, calcium chloride with 2 percentage by weight of rapid hardening cement is mixed. Since Extra rapid hardening cement is very sensitive, concrete should be transported, placed, compacted, and finished within 20 minutes after mixing. After the addition of water, a very huge amount of heat is evolved within a short period of time along with hydration. So, this type of cement is perfect for concreting in cold weather.

5. Portland slag cement

In Portland slag cement a Blast furnace slag is a non-metallic product consisting essentially of glass containing silicates and aluminosilicates of lime and other bases and is developed simultaneously with iron in a blast furnace or electric pig iron furnace. Ground granulated slag is obtained by further processing the molten slag by rapidly chilling or quenching it with water or steam and air.

This cement is prepared by intimately grinding Portland cement clinker and ground granulated blast furnace (GGBF) slag with the addition of gypsum and permitted additives. and the proportion of slag should not be less than 25% and not more than 65% of Portland slag cement. The slag contains oxides of lime, alumina, and silica and easily replaces clay or shale used in the manufacture of ordinary Portland cement.Portland slag cement can be used for all purposes for which ordinary Portland cement is used. However, the former has certain advantages: it has lower heat evolution and is more durable. Thus, it can be used in mass concrete structures such as retaining walls, foundation, and dams.

6, Hydrophobic cement

Hydrophobic cement is prepared from ordinary Portland cement clinker by adding certain water repellent chemicals during the grinding process. A water repellent coating is formed over each particle of cement that prevents water or moisture from the air being absorbed by the cement. This film is broken during the mixing of concrete and the normal hydration process takes place in the same manner as with the ordinary Portland cement.

This cement is ideal for storage for longer periods in extremely wet climatic conditions. The hydrophobic agents can be oleic acid, stearic acid, naphthenic acid, etc. This cement is different from waterproofing cement.

7. Sulphate Resisting Cement

Since ordinary Portland cement is susceptible to attack of sulfate, sulfate resisting Cement is developed to use where the soil is infected with sulfates.

Due to the attack of sulphate in O.P.C. cement, there are chances of expansion within the framework of concrete and there are cracks and subsequent disruption.

Many research found that to reduce sulphate attack, cement with low C3A content better results. Sulphates resisting cement has a high silicate content that is with low C3A and low C4AF.

Under the following conditions sulphate resisting cement is used:

i. When concreting is done for Marine structure in the zone of tidal variations.
ii. Where foundation soil is infected with Sulphate.
iii. In marshy soil or sulphate bearing soil.
iv. Concrete construction used for sewerage treatment, etc.

7. Quick setting Cement

Quick setting cement sets very fast. This cement is used for aggressive foundation conditions like where pumping is needed or submersible land area.In quick setting cement, the quick setting property is achieved by reducing the Gypsum content at the time of clinker grinding. Quick setting cement is also used in some typical grouting operations.

8. High alumina cement

This cement is obtained by grinding high alumina clinker consisting of monocalcium aluminates. High alumina cement clinker is obtained by complete or partial fusion of a predetermined mixture of materials mainly containing alumina (Al203) and lime (CaO) with a smaller proportion of iron oxides, silica (Si02) and other oxides. High early strength, the high heat of hydration and very high durability against chemical attack are the characteristics of high alumina cement. It is black in colour. Its rapid hardening properties are due to a higher percentage of calcium aluminate in place of calcium silicate as found in ordinary Portland cement.

9. Supersulphated cement

It is a hydraulic cement having sulphuric anhydride (SO_3) content less than 5% and made by inter grinding mixture of at least 7% granulated blast furnace slag, calcium sulfate and a little amount of lime or Portland clinker. This cement is used in very serious conditions such as marine works, mass concrete jobs to resist the attack of aggressive waters, reinforced concrete pipes in groundwaters, concrete construction in sulphate bearing soils, and in chemical works exposed to the high concentration of sulphates of weak solutions of mineral acid. It can also be used for the underside of bridges over railways and for sewer pipes.

10. Masonry cement

Masonry cement is obtained by intergrading a mixture of Portland cement clinker with inert materials (non-pozzolanic), such as limestone, conglomerates, dolomite, and gypsum, and air-entraining plasticizer in suitable proportions. Masonry cement is slow hardening, has high workability and high water retentivity that makes it especially suitable for masonry work.

11. Oil well cement

Oil-well cement is a special purpose cement for sealing the space between steel casing and sedimentary rock strata by pumping slurry in the oil-well which is drilled for the search of oil. This cement prevents the escape of oil or gas from the oil-well. This cement also prevents from sulphur gases or water containing dissolved salts. This all properties of oil-well cement is obtained by adding the compound composition of cement with retarder agents like starches or cellulose products or acids.

12. Coloured cement

Coloured cement is made by adding colour carrying pigment with a Portland cement clinker. The dose of pigment is 5-10 percentage of Portland cement. For achieving various colors, either white cement or grey Portland cement is used as a base material. The white Portland cement is manufactured as same as OPC.

13. Expansive cement

Expansive cement is a type of cement that shows no change in volume on drying. This type of cement does not shrink while hardening or after that. This type of cement has been developed by using an expansive agent and stabilizer. This cement is used for grouting anchor bolts or grouting machine foundations, grouting the prestressed concrete ducts where volume change is very sensitive for stability.

14. Air-Entraining Cement:

Air entraining cement is manufacture by adding an air-entraining agent in power or in liquid form with OPC cement clinker. There are other external materials added are animal and vegetable fats, oil and another acid with a certain wetting agent like aluminum powder, hydrogen peroxide, etc. by introducing air-entraining agent frost resisting characteristics of hardened concrete is increased. Workability, segregation, and bleeding property of concrete is improved by using this cement.

2.1.7 Review on Types of concrete

There are many different types of concrete, as listed below

1. Normal Strength Concrete

Normal strength concrete is made up of a combination of several fundamental ingredients — aggregate, concrete and sand — in a 1:2:4 ratios. This mixture produces normal strength concrete that can be used for many applications. It takes about 30 to 90 minutes to set, but this is dependent on the weather conditions at the concrete site and the cement’s properties.

It’s normally used for pavements or buildings that don’t need high tensile strength. It is not very good for many other structures since it doesn’t withstand the stresses created by wind loading or vibrations very well.

2. Reinforced Concrete

This form of concrete is widely used in industry and modern construction. Reinforced concrete gets its strength through the help of wires, steel rods or cables that are placed in the concrete before it sets. A more familiar name for these items is rebar. Lately, people have used fibers to reinforce this concrete. These reinforcements resist tensile forces to avoid cracking or breaking. Meanwhile, the concrete itself resists compressive forces to withstand heavy weight. Together, the two materials create a strong bond against many applied forces, such as vehicles.

3. Plain or Ordinary Concrete

This is another concrete that uses the common mix design of 1:2:4 with its components of cement, sand and aggregates. You can employ it to make pavement or buildings where there is not a high demand for tensile strength. It faces the same challenges as normal strength concrete, it doesn't stand up very well to vibrations or wind loading. Plain or ordinary concrete is also used in dam construction. The durability rating of this kind of concrete is very satisfactory.

4. Prestressed Concrete

Prestressed concrete units are used for many large concrete projects. To create prestressed concrete, you must use a special technique. Like reinforced concrete, it includes bars or tendons. But these bars or tendons are stressed before the actual application of the concrete.

When the concrete is mixed and placed, these bars are placed at each end of the structural unit where they are used. When the concrete sets, this unit is put into compression.

This compression enhances the strength of the lower section of the unit and improves its resistance against tensile forces. However, this process requires skilled labor and heavy equipment. Normally, prestressed units are created and assembled on-site. Prestressed concrete is used to build bridges, heavy-loaded structures or roofs that have long spans.

5. Precast Concrete

As with most classes of concrete, precast concrete must be made and cast according to specific measurements. These concrete units are eventually transported to the application site and assembled for use. The advantage of using precast concrete is its speedy assembly. Since the units are manufactured in a factory, they are of very high quality.

6. Lightweight Concrete

Lightweight concrete is any kind of concrete that has a density of less than 1920kg/$m^{3.}$ Lightweight concrete is created by using lightweight aggregates. Aggregates are ingredients that add to the density of the style of concrete. These lightweight aggregates are made up of various natural, artificial and processed materials, which includes, clays, expanded shales, scoria, pumice, perlite, vermiculite. The most important property of lightweight concrete is that it has very low thermal conductivity. Common uses for lightweight concrete include creating long-spanning bridge decks and building blocks. It can also be used to protect steel structures.

7. High-Density Concrete

High-density concrete has a very specific purpose. It is frequently used in the construction of atomic power plants. The heavyweight aggregates used in the creation of high-density concrete help the structure resist radiation.

Crushed rocks are normally used. Barytes, a colorless or white material that consists of barium sulfate and is the principal ingredient in barium, is the crushed rock most often employed.

8. Stamped Concrete

Also known as imprinted or textured concrete, stamped concrete is designed to realistically replicate the look and pattern of natural stones, tiles, brick and granites. Stamped concrete is often used to construct patios, pool decks, interior floors and driveways.

Some of the advantages of stamped concrete include:

- Affordability compared to natural pavers and stone
- Easy maintenance once sealed
- Becomes slip-resistant with a non-skid additive

- Enhances outdoor space and adds value
- Durable and long-lasting
- Extensive pattern and color choices

9. Air-Entrained Concrete

Some types of concrete hold billions of microscopic air cells in every cubic foot. These tiny air pockets relieve the internal pressure on the concrete. They provide tiny chambers where water can expand when it freezes. The air is entrained in the concrete by adding several foaming agents during the mixing process, including, fatty acids, resins, alcohols.

Because this concrete is mixed at the site of application, the mixing and entraining process requires careful engineering supervision. The entrained air adds up to about 3% to 6% of the volume of the concrete. Almost all concrete used in a freezing environment or where there are freeze-thaw cycles is air-entrained.

10. Ready-Mix Concrete

Concrete prepared and bathed in a centrally located plant is known as ready-mix concrete. This concrete is mixed as it is transported to the site in the familiar cement trucks seen often on roads and highways. Once the trucks reach the worksite, the cement can be used immediately because it does not need further treatment. Ready-mix concrete is a specialty concrete that is mixed based on specifications developed with great precision.

11. Self-Consolidated Concrete

Self-consolidating concrete will compact on its own due to its weight when put in place. This non-segregating, highly flow able concrete will fill the formwork and spread easily into place to encapsulate the reinforcement without the need for vibration or mechanical consolidation. This highly workable concrete is best used for applications and areas where there is thick reinforcement.

12. Volumetric Concrete

This concrete was created as an alternative to ready-mix concrete to address the problem of long distances between the concrete plant and construction sites. It requires specialized trucks known as volumetric mobile mixers. They carry the concrete ingredients and the water that will be mixed at the construction site.

Volumetric concrete is extremely useful when a builder requires two different kinds of concrete mix at a single site. Since the concrete can be mixed and delivered as needed, it allows one truck to produce two different mixes of concrete. It is very useful on large sites, basement constructions and multi-projects where you need different types of concrete.

13. Decorative Concrete

Decorative concrete creates visually and aesthetically appealing concrete mixes. Decorative concrete can go through several processes, such as: coloring, molding, polishing, etching, applying decorative toppings. It is ideal for any project in which you want to make an aesthetic statement. It's also a great way to add a bit of "personality" to dull surfaces or structures. For instance, swimming pools and flooring can make great use of decorative concrete.

14. Polymer Concrete

Polymer concrete aggregates, compared to those in other concrete types, are bound together in a matrix with polymer instead of cement. This type of concrete is made of limestone gravels, silica, quartz, granite pebbles and other high-compressive strength materials. If these materials are not dry, clean and dust-free, it can have a negative impact on the concrete's binding ability.

The polymer resin serves as the binder and the aggregate is the compressive stress material. Polymer concrete composites contain a distinct combination of properties in their formulation.

15. Rapid-Set Concrete

It's ideal when you're short on time to complete a project. It has faster set times and is very resistant to low temperatures, so it can be used any time of the year. It's especially useful in winters when the cold weather does not allow you to use many other kinds of concrete.

16. Smart Concrete

As the name suggests, smart concrete is the concrete technology of the future. The creation of this type of concrete makes it easier to monitor the condition of reinforced concrete structures. Smart concrete contains short carbon fibers that are added with a conventional concrete mixer. This process affects the concrete's electrical resistance when under strain or stress. This kind of concrete can be used to detect possible problems before the failure of the concrete.

It is very good at sensing tiny structural flaws. While not widely available yet, it promises to be the building material of the future for cities that face repeated earthquake risk. Smart concrete allows engineers in those cities to check the health of structures after earthquakes, providing a far better assessment of their condition than a visual inspection.

17. Pervious Concrete

This is one of the most common kinds of concrete used to build roads and pavements. It is designed to deal with the problems of stormwater runoff and pools of water and puddles on roadways or airport runways.

Other concrete absorbs water. Roadways that use pervious concrete have fewer problems with hydroplaning, tire spray and snow buildup. It also reduces the need for curbing and storm sewers.

It is composed of a mixture of cement, water and coarse aggregates. It contains no sand, which creates an open-scale, porous structure. This allows water to pass through the layers more easily. Some kinds of pervious concrete will pass several gallons of water through its surface per minute.

18. Vacuum Concrete

In certain applications, such as deck slabs, parking lots and industrial floors, concrete will have a higher water content than necessary when poured into the formwork. In these cases, the excess water must be removed with a vacuum pump before the concrete begins to set. Compared to a normal construction method, the vacuum technique can help make the concrete platform or structure ready to use sooner.

19. Pumped Concrete

If you've ever wondered what types of cement mixtures used in the flooring of a very tall building are, the answer is probably pumped concrete. The secret to pumped concrete is that it is very workable, so it can be conveyed easily via a pipe to an upper floor. This pipe will be a flexible or rigid hose that discharges the concrete to the required area.

Pumped concrete can also be used:

- To create superflat floors on lower structures
- In construction projects like roadways and bridges
- For more personal items, like swimming pools

It is a reliable, efficient and economical way to apply concrete and is often the only way that concrete can be placed in certain locations. Very fine aggregates are used in pumped concrete. The finer the aggregate used in the mix, the freer the concrete flows from the pipe.

20. Limecrete

This concrete uses lime instead of cement, along with lightweight aggregates like glass fiber or sharp sand. It's mainly used for the construction of floors, vaults and domes. Limecrete has many environmental benefits because it is so easily cleaned and is renewable. It can also be used with radiant floor heating.

21. Roll Compacted Concrete

Roll-compacted concrete is a strong, dense concrete used on heavily trafficked highways with vehicles that carry large loads. This concrete emits fewer emissions during the production process, which benefits the environment.

Roll compacted concrete can be found in roadworks, airport runways, car parks, pavements and industrial servicing.

22. Glass Concrete

Another, more modern form of concrete, glass concrete features the use of recycled glass. This form of concrete is used when aesthetic appeal is an important element in the design of the concrete.

Commonly used in the large-format slabs found in flooring or on decorative façades, this concrete can have shining or colored glass embedded during the mixing process to give it a distinctive splash of color or sparkle.

23. Asphalt Concrete

More commonly known as "asphalt" or "blacktop," this is a form of concrete often used for constructing sidewalks, roads, parking lots, airport runways and highways— almost anywhere pavement is needed. Asphalt is a dark mineral composed of bitumens, which are a form of hydrocarbons.

The desire for asphalt grew along with the automobile industry. Known for its durability, workability, skid resistance, stability, fatigue resistance, flexibility and permeability, it still requires a properly designed mixture. It is a composite mixture of aggregates and asphalt. The different mixtures of asphalt are used for different purposes.

24. Shotcrete Concrete

Shotcrete differs from other forms of concrete primarily in the way it is applied. Shotcrete is shot through a nozzle onto a frame or formwork. Since this application requires higher air pressure, the compaction process takes place at the same time as the placing.

Shotcrete can be used to repair damaged wood, concrete or steel structures. It is also commonly used when access to a work area is difficult or when formwork is impractical or cost-prohibitive.

25. High-Strength Concrete

High-strength concrete is any concrete mix that is greater than 40 megapascal (40MPa), which is the tensile strength of concrete. High-strength concrete that meets this determinant can handle much more stress and pressure compared to concrete at 20MPa or 30MPa.

This type of concrete can withstand strenuous conditions before it shears, cracks or breaks. The increased strength in this concrete is accomplished by reducing the water-cement ratio to a low rate.

High-strength concrete above 40MPa is often used for civil and commercial construction, which includes buildings and infrastructure projects, structural beams, columns, loadbearing walls and any other application where increased capacity and durability are required.

26. High-Performance Concrete

Though all high-strength concrete can be labeled as high-performance, not all high-performance concrete (HPC) will be in the high-strength category. HPC meets particular efficiency standards, such as:

- Easy placement
- Heat of hydration
- Environmental standards
- Longevity and durability
- Life-term mechanical properties
- Strength gain in early age
- Toughness
- Permeability and density factors

2.1.8 Review on Gradation of aggregates and its effects on properties of concrete

Aggregate gradation determines the void content within the structure of aggregate and consequently the amount of cement paste that is required to fill the void space and ensure a workable concrete. It is desirable to optimize the aggregate gradation in concrete using Portland cement. Aggregate are the important constituent in concrete. They give body to concrete, reduce shrinkage and affect economy. Earlier, aggregates were considered chemically inert but now it has been recognized that some of the aggregates active and also certain aggregates exhibit chemical bond at the interface of aggregate and paste. The mere fact that they occupy 70%-80% of volume of concrete, their impact on various characteristics of concrete is undoubtedly considerable along with its gradation. (Chirag, et al., 2016)

It is the most expensive and high carbon footprint ingredients, to minimize the void content in the aggregate and therefore the volume of cement paste required to achieve a workable, economical and an environmentally sound concrete for a given application. The optimization of aggregate gradation also improves the rheological, mechanical and durability properties of concrete (Jose, et al., 2009).

Proper aggregate gradation not only ensure a work concrete mixture that can be compacted easily, but also reduces problems associated with plastic concrte such as potential for segregation, bleeding and loss of entrained air and plastic shrinkage cracking. (Tarum, etal 2009)

2.1.9 Review on Quarry dust

Felekoglu, et al., (2006) observed that the incorporation of quarry waste at the same cement content generally reduced the super plasticizer requirement and improved the 28 days' compressive strength of concrete. Concrete containing quarry dust as fine aggregate can be effectively utilized in the construction industry with good quality materials, appropriate dosage of super plasticizer, appropriate mixing methods, and proper curing thereby ensuring sustainable development against environment pollution (Devi &Kannan 2011).

Quarry dust is a by – product of the crushing process which is a concentrated material to use as aggregate for concreting purposes, especially as fine aggregates. In quarrying activities, the rock has been crushed into various sizes, during the process the dust generated is called quarry dust and it is formed as waste. So it becomes as a useless material and also results in air pollution.

Quarry dust should be used in construction works, which will reduce the cost of construction and the construction materials would be saved and the natural resources can be used properly. Most of the developing countries are under pressure to replace fine aggregate in concrete by an alternative material also to some extent or totally without compromising the quality of concrete. Quarry dust has been used for different activities in the construction industry, such as building materials, road development materials, aggregates bricks, and tiles.

2.2.0 Review on relationship between aggregate and void ratio

If aggregate voids are minimized, the amount of paste required for filling these voids is also minimized maintaining workability and strength. Consequently, optimal mixture proportioning will produce good-qualityh and concrete with a minimum amount of cements. Within limits, the less paste at a constant water-cement ratio, the more durable the concrete (Shilstone, 1994).

The workability of concrete changes significantly with grading. Mixtures with high void contents require more paste for a given level of workability. In conclusion, minimizing the aggregates voids content should be one of the objectives of optimization of concrete mixtures. Mixture proportioning methods should be encourage optimization and consequently aggregate optimization. Research shows that there is a clear relationship between shape, texture, and grading of aggregates and the voids content of aggregates (De Larrard, et al., 1999).

2.2.1 Review on river sand (fine aggregate)

To river sand the world is resting over a landfill of waste hazardous materials which may substitutes for natural sand. Irrespective of position, location, scale type of any structure, concrete is the base for the construction activity. In fact, concrete is the second largest consumable material after water, with nearly three tonnes used annually for each person on the earth.

India consumes an estimated 450 million cubic meters of concrete annually and which approximately comes to 1 tonne per Indian. We still have a long way to go by global consumption levels but we have enough sand to make concrete and mortar? Value of construction industry grew at staggering rate of 15% annually even in the economic slowdown and has contributed to 7.8% of the country's GDP (at current prices) for the past eight years.

Thus, it is becoming increasingly discomforting for people like common people who talk about greening the industry to have no practical anser to this vey critical question. In fact, we have been sitting over a landfill of possible substistutes for sand. Industrial waste and by-products from almost all industry, which have been raising hazardous problems both for the environment, agricultureal and human health can have major use in construction activity which may be useful for not only from the economy point of view but also to preserve the environment as well. Some of the researchers did the to find the alternatives for natural sand and they concluded about different industrial waste and their ability to replace the much sought after natural river bed sand.

Copper slag – At present about 33million tones of copper slag is generating annually worldwide among that India contributing 6 to 6.5 million tonnes. 50% copper slag can be used as replacement of natural sand in order to obtain mortar and concrete with required performance, strength and durability. (Jabril, et al 2011).

2.2.2 Review on effects of river sand mining on environment

Sand mining on either side of the rivers, upstream or in-stream, is one of the causes for environmental degradation and also a threat to the bio diversity. Over the alarming rate of unrestricted sand mining which damage the ecosystem of natural habitats of organisms living on the riverbirds, affects fish breeding and migration, spells disaster for the conservation of many bird species, increases saline water in the rivers, etec. Extraction of alluvial material from within or near a streambedhas a direct impact on the stream's physical habitat characteristics.

These characteristics includes the bed elevation, substrate composition and stability, in-stream roughness elements depth, velocity, turbidity, sediment transport stream discharge and temperature. The demand for sand continues to increase day by day as building and construction of new infrastructures and expansion of existing ones is continues thereby placing immense pressure on the supply of the sand resources and hence mining activities are going on legally and illegally without any restrictions. Lack of proper planning and sand management cause disturbance of marine ecosystem and also upset the ability of natural marine processes to replenish the sand. In this situation, the construction industries of developing countries are in stress to identify alternative materials to lesson or eliminate the demand for natural sand. So, quarry waste fine aggregate could be an alternative of natural sand. It is a by-product generated from quarrying activities involved in the production of crushed coarse aggregates.

2.2.3 Review on other alternative to river sand

Washed Bottom Ash (WBA)

The mechanical properties of special concrete made with 30 percent replacement of natural sand with washed bottom ash by weight has an optimum usage in concrete in order to get a required strength and good strength development pattern over the increment ages (Mohd, et al., 2010). Currently india is producing in over 100 million tons of coalash. From which total ash produced in any thermal power plant is approximately 15-20 percent of bottom ash and the rest is fly ash. Fly ash has found many users but bottom ash still continues to pollute the environment with unsafe disposal mechanism on offer. About 20 to 25 percent of the total production in each cluster unit is left out as the waste material quarry dust. The ideal percentage of the replacement of sand with quarry dust is 55 percemt to 75 percent in case of compressive strength. He furteh says that if combined with fly ash (another industrial waste), 100 percent replacement is achieved. The use of fly ash in concrete is desieable because of benefits such as useful disposal of a by – product, increased workability, reduction of cement consumption, increased sulphate resistance, increased resistance to alkali-silica reaction and decreased permeability.Therefore, the concurrent use of quarry dust and fly ash in concrete will lead to the benefits of using such materials being added some of the undesirable effects being negated (Chandana, et al., 2013).

2.2.4 Review on Foundry sand

India ranks fourth in term of total foundry production (7.8 million tonnes) according to the 42nd census of world casting production of 2007. Foundry sand which is very high in silica is regularly discarde by the metal industry. Currentlty ther is no mechanism for its disposal , but international studies say that up to 50 percent foundry sand can be utilized for economical and sustainable development of concrete (Prajapati, et al., 2013).

2.2.5 Granulated Blast furnace slag

According to the report of the working groupon cement industry for the 12th five year plan, around 10 million tonnes blast furnace slag is currently being generated in the country from iron and steel industry. The ompressive strength of cement mortar increases as the replacement level of granulated blast furnace slag (GBFS) increases. He further concludes that from the test results it is clear that GBFS sand can be used as an alternative to natural sand from the point of view of strength. Use of GBFS up to 75% can be recommended (Nataraja, @013)

A mix of copper slag and ferrous slag can yield higher compressive strength of 46.18MPa (100 percent of replacement of sand) while corresponding strength for normal concrete was just 30.23MPa Though she warns that with higher levels of replacement (100 percent) there might be some bleeding issues and therefore she recommended that up to 80 percent copper slag and ferrous slag can be used as replacement of sand (Meenakshi & Sudearvizhi., 2011)

2.2.6 Sheet glass Powder (SGP)

Natural sand was partially replaced (10%, 20%, 30%, 40%, and 50%) with SGP, compressive strength, tensile strength (cubes and cylinders) and flexural strength up to 180 days of age were compared with those of concrete made with natural fine aggregates. Attempts have been made for a long time to use waste glasses as an aggregate in concrete, but it seems that the concrete with glasses always cracks. Hence very limited work has been conducted for the use of ground glass as a replacement for as a concrete replacement. (Mageswari & Vidivelli 2010)

2.2.7 Review on Related Works

Some experiments on quarry dust by (Sahu, et al., 2003) reported significant increase in compressive strength, modulus of rupture and split tensile strength when 40 percent of sand is replaced by quarry rock dust in concrete.

Yusut, et al. (2015) reported about the average compressive strength of concrete made with river sand (fine aggregate) and the one produced with the dune sand (fine aggregate).

Babu, et al. (1997) reported that the physical and chemical properties of quarry rock dust satisfied t6he requirements of code provision of IS 4032/1968 in properties studies. Natural river sand, if replaced by hundred percent quarry dust from Quarries, may sometimes give equal or better than the reference concrete made with Natural sand in terms of compressive and flexural strength studies Nagaraj et al. (1996) studied the consumption of compressive and flexural strength and cost of concrete made with quarry dust.

CHAPTER THREE

MATERIALS AND METHODOLOGY

Introduction

A list of the materials as were used in the course of this study is covered in this chapter, and inclusively their respective properties. The primary essence of this chapter is to ascertain the viability of using quarry dust a substitute for river sand in the production of concrete in order to draw a conclusion if the use of quarry dust in concrete is possible by carrying out related laboratory tests on the concrete produced and comparing it with the normal conventional concrete.

3.1.0 Materials

3.1.1 Ordinary Portland Cement (OPC)

Cement acts as a binder to join the aggregate into a solid mass. It is one of the most important constituent of concrete. Ordinary Portland cement of 53 grade is used in concrete. Cement is a binder material which sets and hardens independently, and can bind other materials together. Cement is made up of four main compounds tricalcium silicate (3CaO SiO2), dicalcium Silicate (2CaO SiO2), tricalcium acuminate (3CaO Al2O3), and tetra-calcium aluminoferrite (4caco Al2O3 Fe2O3).tetra-calcium aluminoferrite (4CaO Al2O3 Fe2O3). In an abbreviated notation differing from the normal atomic symbols, these compounds are designated as C3S, C2S, C3A, and C4AF, where C stands for calcium oxide (lime), S for silica and A for alumina, and F for iron oxide. Small amounts of uncombined lime and magnesia also are present, along with alkalis and minor amounts of other elements. Cement is material, generally in powder form, that can be made into a paste usually by the addition of water and, when molded or poured, will set into a solid mass. Numerous organic compounds used for adhering, or fastening materials, are called cements, but these are classified as adhesives, and term cement alone means a construction material. The most widely used of the construction cements is Portland cement. It is a bluish gray colour obtained by finely grinding the clinker made by strongly heating an intimate mixture of calcareous and argillaceous minerals. The chief raw material is a mixture of high calcium lime stone, known as cement rock, and clay or shale. Blast furnace slag may also be used in some cements is called Portland slag cement. The colour of the cement is due chiefly to iron oxide. In absence of impurities, the colour would be white, but neither the colour nor the specific gravity is a test of quality. Ordinary Portland cement is by far the most important type of cement. Prior to 1987, there were only one grade of OPC which is governed by IS 269- 1976.After 1987 higher grade cements were introduced in India. The OPC was classified into three grades, namely 33 grade, 43 grade, 53 grade depending upon the strength of the cement at 28 days when tested as per IS 4031-1988. If the 28 days strength is not less than 33 N/mm2, it is called 33 grade cement. If the strength is not less than 43 N/mm2, it is called 43 grade cement. If the strength is not less 53 N/mm2, it is called 53 grade cement. But the values of actual strength obtained by this cements at the factory are much higher than BIS specifications.

3.1.2 Aggregates

The component aggregates used in this study are

1. River sand (fine aggregate)
2. Quarry dust (fine aggregate)
3. Stone (Coarse aggregate)

River sand

River sand River sand is one of the important constituents in concrete. It gives body to concrete and reduces shrinkage and effects economy.

Coarse aggregates

The maximum size of coarse aggregate should be 20 mm and minimum size should be 10 mm. The coarse aggregate with angular in shape and the rough surface texture is used.

Quarry dust

Quarry dust is fine rock particles. When boulders are broken into small pieces quarry dust is formed. It is grey in color and it is like fine aggregate.

Water

Water is an important ingredient of concrete and it initiates chemical reaction with cement. Ordinary potable water is used. Water: The quality of water is important because contaminants can adversely affect the strength of concrete and cause corrosion of the steel reinforcement. Water used for producing and curing nconcrete should be reasonably clean and free from deleterious substances such as oil, acid, alkali, salt, sugar, silt, organic matter and other elements which are detrimental to the concrete or steel. If the water is drinkable, it is considered to be suitable for concrete making. Hence, potable tap water was used in this study for mixing and curing. The PH value of water should be in between 6.0 and 8.0 according to IS 456 – 2000.

3.2 Methodology

3.2.1 Collection and preparation of fine aggregates

Mix Ratio (Mix control)

The mix ratio as was used in the course of this study was 1: 2: 4

Summing up the the mix ratio = 1 + 2 + 4 =7

Thus, the respective weights of the respective materials (cement, fine aggregate, coarse aggregate) and volume of water were calculated as shown below

Density of concrete = 2400kg/m

Volume of each concrete cube = Length x width x height

= 0.15 x 0.15 x 0.15

= $3.375 \times 10^{3} m^{3}$ and hence, the volume of concrete used.

Mass of concrete = volume of concrete x density of concrete

= $3.375 \times 10^{-3} m^{3}$ x 2400kg/m

= 8.1kg for one cube

Four cubes = 2 x 8.1kg =16.2kg

To account for losses or wastages, an additional 10% of the total mass is added , thus

0.1 x 16.2kg = 1.62kg and the new total mass becomes

16.2 + 1.62 = 17.82kg

Mass of cement = 1/7 x 17.82kg

= 2.55kg

The water cement ratio of 0.6 gives the volume of water as

Volume of water = mass of cement x 0.6

= 2.55 x 0.6 = 1.53 equivalent to 1.53litre of water

Mass of fine aggregate = 2/7 x 17.82kg

= 5.09kg

Mass coarse aggregate = 4/7 x 35.64kg

= 10.18kg

3.2.2 Concrete cube casting

With the mix ratio of 1 : 2 : 4 as stated above, the concrete ingredients (constituents) which includes, the fine aggregate, quarry dust, and coarse aggregates were batched on the weighing balance in kg units prior to the appropriate mixing with water, and in conformity to a water-cement ratio of 0.6.

3.2.3 Mixing of concrete

The process of making the fresh concretes for each of the percentage replacement with quarry dust, involved measuring and obtaining the actual respective weights in kilogram of each of the concrete components which are river sand, quarry dust, coarse aggregate, cement and water in volume of the water cement ratio of 0.6.

3.3.0 Tests on the grading of aggregates

3.3.1 Specific Gravity Test

Specific gravity is defined as the ratio of the density of a substance to the density of standard substance such as water.

Test apparatus

1. Weighing balance
2. Density bottle
3. Material, water, river sand, quarry dust

Test Procedures

This test was carried out on each of the component aggregates of the concrete mix (i.e river sand, quarry dust, and coarse aggregate) following the procedures as staged below:

1. Rinse the density bottle thoroughly with distilled water, oven dry and cool in a desiccator so as to remove the weight that can affect the experiment.
2. Determine and record the weight of the empty density bottle fitted with a lead (stopper), as W1.
3. Put about 10g – 15g of the dry sample (sand, quarry dust) passing through sieve 40 (425umm) into the density bottle, and weigh as W2.
4. Add distilled water to about half into the density bottle and soak for 3-4hrs, after which a clear water in the density bottle top up the water to the lower meniscus of the density bottle and record the weight W3.
5. Finally fill the density bottle with distilled water to the mark of the lower meniscus and record its weight as W4.

The specific gravity, Gs is calculated as Gs = $\frac{w2-w3}{(w3-w1)-(w4-w2)}$

W_1 This is the weight of empty density bottle and its stopper

W_2 This is the weight of density bottle and its stopper + dry soil sample

W_3 This is the weight of density bottle and its stopper + dry soil sample + distilled water

W_4 This is the weight of density bottle and its stopper + distilled water

Test on fresh concrete

Fresh concrete is concrete at the state when its components are fully mixed but its strength has not yet developed. This period corresponds to the cement hydration stages. The properties of fresh concrete directly influence the handling, placing and consolidation; It spells out the procedures for sampling various production systems like the slump test and the compaction factor test. The specimen must be tested within 15 minutes and must be protected from weather during testing.

Workability

Workability of concrete is defined as the property of of the concrete determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity (uniformity).

The effort required to place a concrete mixture is determined largely by the overall work needed to initiate and maintain flow, which depends on the rheological properties of the cement paste and the internal friction between the aggregate particles, on the one hand and the external friction between the concrete and the surface of framework, on the other hand.

Also workability of fresh concrete is defind as "the amount of mechanical work, or energy, required to produce full compaction of the concrete without segregation" Mindess et al. (2003).

Measurement of workability

Unfortunately, there is no universally accepted test method that can directly measure the workability as defined earlier. The difficulty in measuring the mechanical work defined in terms of workability, the composite nature of the fresh concrete, and the dependence of the workability on the type and method of construction makes it impossible to develop a well – accepted test method to measure workability. The most widely used test, which mainly measures the consistency of concrete, is the “slump test.”

3.3.2 Slump Test

Procedures

1. If this test is carried out in the field, the sample mixed concrete shall be obtained. In the case of concrete containing aggregate of maximum size 38mm, the concrete shall be wet-sieved through one and half inch screen to exclude aggregate particles larger than 38mm.
2. The internal surface of the mould shall be thoroughly cleaned and frred from superfluous moisture and any set concrete before commencing the test.
    a. The mould shall be placed on a smooth, horizontal, rigid and non absorbent surface, such as a carefully leveled metal plate, the mould being firmly held in place while it is being filled.
    b. The mould shall be filled in four layers, and each approximately one-quarter of the height of the mould. Each layer shall be tapped with twenty-five strokes of the rounded end of the tamping rod.
    c. The strokes shall be distributed in a uniform manner over the crossection of the mould and for the second and subsequent layers shall penetrate into the underlying layer.
    d. The bottom layer shall be tamped throughout its depth. After thelayer has been rodded, the concrete shall be struck off level with a trowel or the tamping rod, so that the mould is exactly filled.
    e. After the top layer has been rodded, strikes off the surface of the concrete by means of screeding and rolling of the tamping rod.
    f. Any mortar which may have leaked out between the mould and the base plate shall be cleaned away.
    g. The mould shall be removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside and the slump shall be measured immediately by determining the difference between height of the mould and that of the highest point of the specimen being tested.

h. The above operations were carried out on a ground void of vibration and within a period of two minutes after sampling.

3.4 Test on hard concrete

Curing

Prior to compressive strength test on each of the cubes of partial quarry replacement, is the curing stage, where the hardened concretes are immersed into clean water in a container for days ranging from 7, 14, 21,and 28 days.

Curing is defined as the process of taking care of fresh concrete right after casing. The main principle of of curing is to keep favorable moist conditions under a suitable temperature range during the fast hydration process for concrete. It is a very important stage for the development of concrete strength and in controlling early volume changes. Fresh concrete requires considerable care, just like a baby. Carefully curing will ensure that the concrete is hydrated properly, with good microstructure, proper strength and good volume stability. On the other, careless curing always leads to improper hydration with defects in the microstructure, insufficient strength, and unstable dimensions. One of the common phenomena of careless curing is plastic shrinkage, which usually leads to an early age crack that provides a path for harmful ions and agents to get into the concrete body easily and causes durability problems. Curing is a simple measure to achieve a good quality of concrete.

The concrete cubes were cured for 7, 14, 21, and 28 days in order to determine the maximum strength of the concrete.

3.4.1 Compressive strength test

Compressive strength test is a very well-known test that is used to determine the compressive strength of concrete specimens.

Compressive strength test were conducted on each of the hardened concrete cubes of percentage replacement and including the control concrete cube and the cubes were tested respectively for 7, 14, 21, and 28 days respectively.

Test Apparatus

1. Compression testing machine
2. Spade
3. Concrete cubes 150mm
4. Tamping rod

Procedure

The test was carried out with the following procedures based on ASTM standard (D1037 – 99, ASTM, 1999):

1. Measure the length of the specimen, calculate the cross – sectional area (unit should be on mm2) and record it.
2. Place the specimen in the centre of loading area of the machine.
3. Lower the piston against the top of specimen by pushing the lever. Place the piston on top of the specimen making contact with it.
4. Pull the lever into holding position. Start the compression test by pressing the zero button on the display board.
5. Increase the pressure by turning the valve counter clockwise. Apply the load gradually without shock.
6. Observe the specimen, when it begins to break and stop applying load.
7. Record the ultimate load displaying on the machine display screen.
8. When th piston is back in position clean the machine.
9. Match your record once again with the result on isplay screen and turn off the machine.
10. Calculate compressive strength. The result we got from the testing machine is the ultimate load to break the specimen. But the compressive strength is equal to ultimate load divided by the cross –sectional area of the specimen.

    Compressive strength = crushing load/area

    Unit of compressive strength will be N/mm2. If any specimen compressive strength varies by more than 15% of average result, the result is incorrect and unacceptable.

3.5 Grading Tests of aggregates

3.5.1 Sieve Analysis

The grading of sand and quarry dust was determined by sieve analysis, where a sample of materials of known weight was passed through a set of sieves with decreasing apertures.

Test Apparatus

1. Set of BS sieves
2. Mechanical sieve shaker
3. Weighing balance (0.01g sensitivity)
4. Oven

Particle size distribution for the fine aggregates: coarse aggregate and quarry dust were carried out in accordance with BS 812-103.:1985.

Procedures

The following procedures were undertaken while carrying this test in the laboratory

1. The test sample was dried by oven drying at about 105ºC
2. Approximate sample was taken to weighed and to obtain the required quantity
3. The sieves were the arranged in an oder of decreasing aperture of 4.75mm, 2.36mm, 1.18, 0.6mm, 0.3mm, 0.15 and pan.
4. The set of sieves were set in motion by the mechanical siev shaker for 3-5mins.
5. Any material retained on each sieve is weighed and the results tabulated.
6. The cumulative weight passing each was calculated as a percentage of the total sample.
7. Finally, a grading curve of the sample is plotted in logarithmic chart.
8. The grading curve aid in the determination of the uniformity coefficient and coefficient of curvature.

Summary

This chapter describes in details the methodology used to condct the research on the impact on strength performance of quarry dust concrete starting from the beginning to the end of this research. It also describes the materials and instruments used durig the laboratory work, in order to meet the design objective. The following chapter will show all the data collected from the laboratory works together analysis on the results as it concerns objective

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter covers the overall results of the tests carried out in this research work, covering test such as specific gravity of river sand, quarry dust, slump test, and the compressive strength test on hard concrete.

4.1 Results

4.1.1 Specific gravity test results for river sand (fine aggregate)

The data obtained in specific gravity test were used to compute for the specific gravity value of the soil sample under study

Specific gravity (Gs) = $\frac{M2-M1}{(M4-M1)-(M3-M2)}$; where

M1 This is the weight of empty density bottle and its stopper

M2 This is the weight of density bottle and its stopper + dry soil sample

M3 This is the weight of density bottle and its stopper + dry soil sample + distilled water

M4 This is the weight of density bottle and its stopper + distilled water

Table 4.1 **Specific gravity of Quarry Dust (fine aggregate)**

Sample	Sa	Sb	Sc
M1	27.15	24.60	24.55
M2	37.13	34.57	34.51
M3	84.31	84.64	84.20
M4	78.12	78.53	78.13
Gs	2.71	2.58	2.56

Average specific gravity (Gs)	2.62

Table 4.2 Specific gravity of River sand (fine aggregate)

Sample	Sa	Sb	Sc
M1	27.15	25.18	24.55
M2	37.15	35.26	34.57
M3	86.10	85.80	82.55
M4	79.78	79.48	77.29
Gs	2.71	2.68	2.7
Average specific gravity (Gs)		2.69	

Sieve Analysis (Particle Size Distribution) Test

This test tends to grade the relatively the class of materials contained in the test materials which includes river sand, and quarry dust. Particle size distribution analysis classifies aggregates as either uniformly graded or poorly graded.

Where, D_{60} of the particles are finer than this size.

D_{10} shows that 10% of the particles are finer than this size

D_{30} shows that 30% of the particles are finer than this size

Cu is the coefficient of uniformity and lies between 4 and 6 for well graded soil, uniformly graded if the value is less than 4

Cc is the coefficient of curvature (between 1 and 3 for well graded sand and gravel, but uniformly graded if the value is 1)

$$Cu = \frac{D60}{D10} = \frac{0.47}{0.19}$$

$$= 2.47$$

$$Cc = \frac{(D30)^2}{(D60 \times D10)} = \frac{(0.32)^2}{(0.47 \times 0.19)} = 1.15$$

This shows that the soil (river sand) is uniformly graded

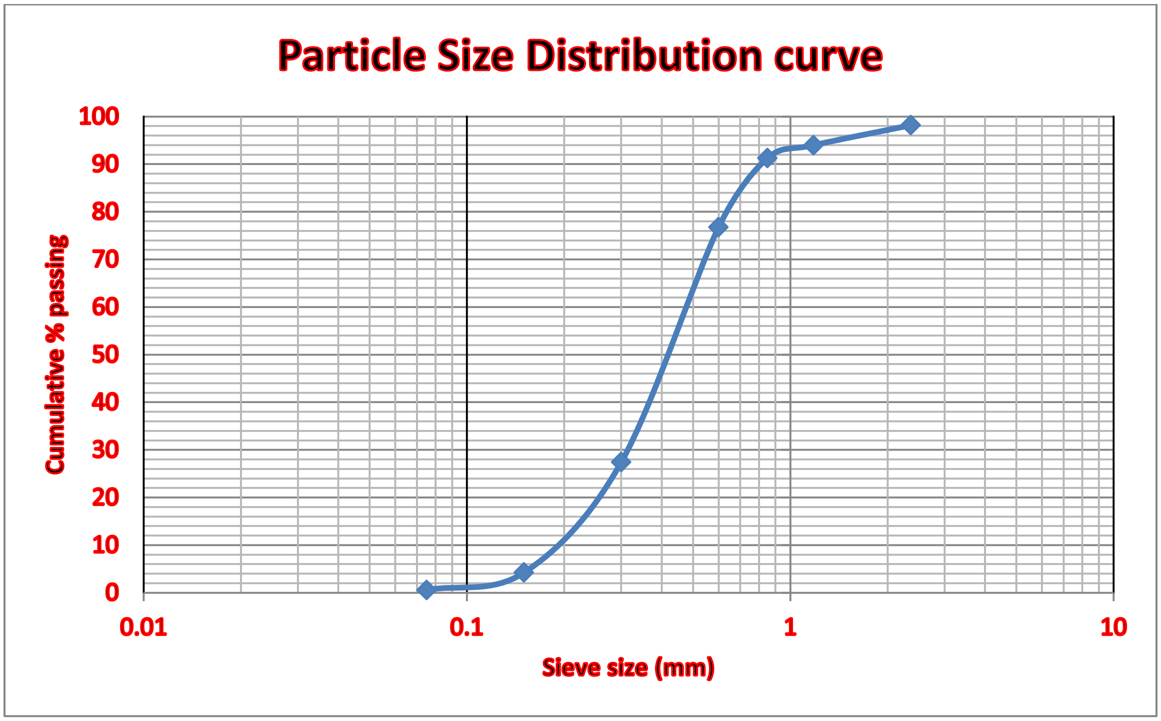

Fig 4.1 : Particle size distribution of river sand

Sieve Analysis results for Quarry Dust (as fine aggregate)

Particle size distribution analysis of the quarry dust used for the purpose of this study, yields the following results

$$Cu = \frac{D60}{D10} = \frac{1.6}{0.09}$$

$$= 12.89$$

$$Cc = \frac{(D30)^2}{(D60 \; x \; D10)} = \frac{(0.39)^2}{(1.16 \; X \; 0.09)}$$

$$= 1.46$$

Thus, this informs that the gravel is uniformly graded

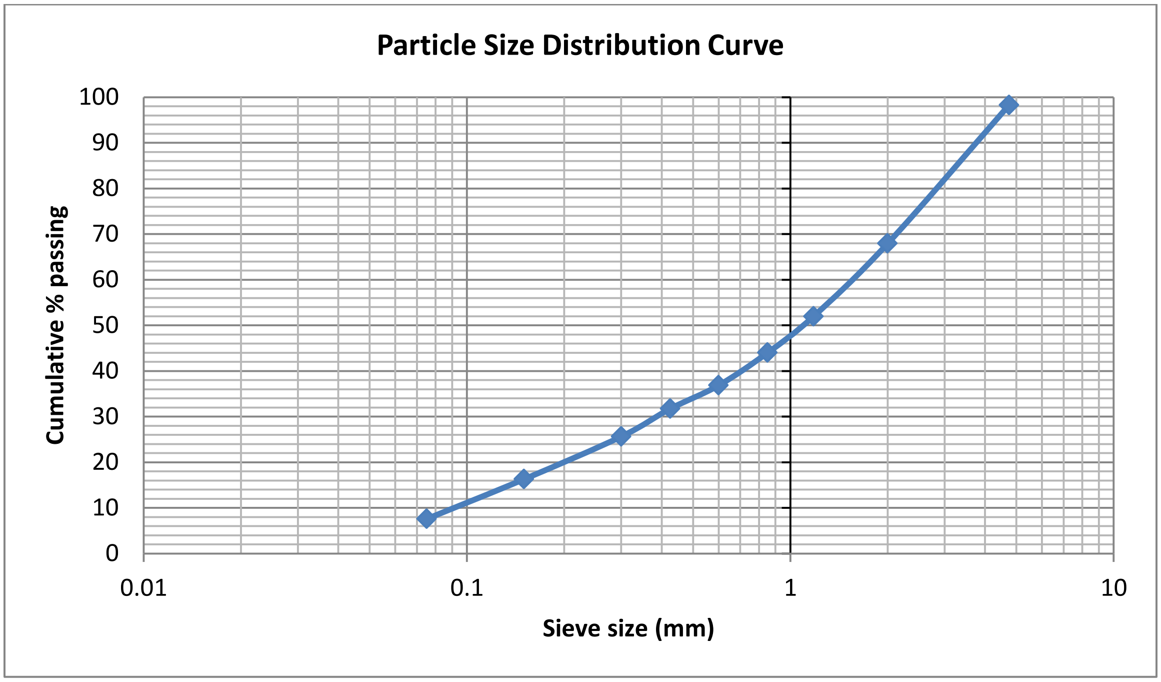

Fig. 4.2: Particle size distribution of quarry dust

Sieve Analysis results for Stone (Coarse aggregate)

The following results show that the particle distributions in the coarse aggregate used for the purpose of this study.

$$Cu = \frac{D60}{D10} = \frac{10.6}{7.0}$$

$$= 1.51$$

$$Cc = \frac{(D30)^2}{(D60\ x\ D10)} = \frac{(10.1)^2}{(10.6\ X\ 7)}$$

$$= 1.37$$

Thus the coarse aggregate is uniformly graded

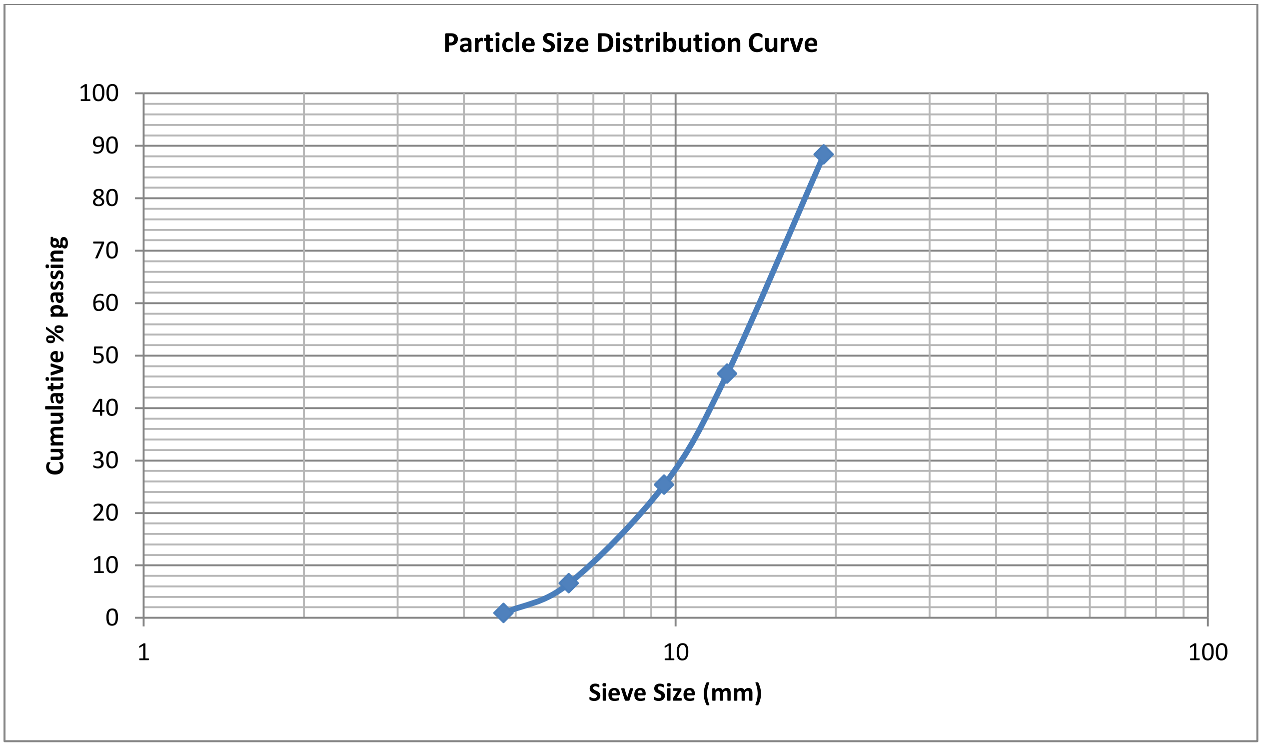

Fig. 4.3 Particle size distribution of coarse aggregate

Slump Test

The graphical result below shows a constant decrease in the height of slump as the percentage of quarry dust is increasing. This is owing to the continual increase in the percentage of quarry dust content in the mix relative to the constant water-cement ratio of 0.6 in the same mix proportion of 1:2:4.

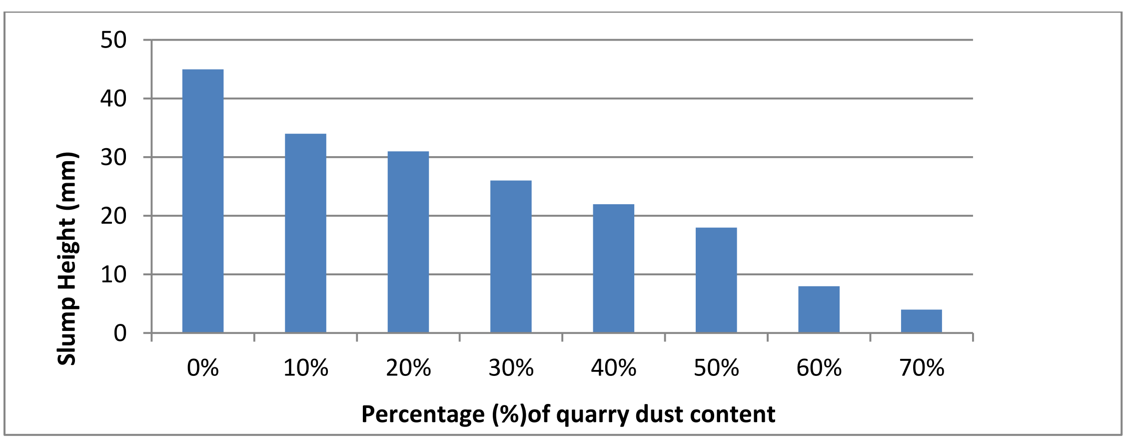

Fig. 4.4 Slump vs. percentage% of quarry dust content

Compression test results

The results obtained on the compression strength of the various percentage (%) of quarry dust content in each concrete cube for days ranging from 7 days, 14 days, 21 days, and maximum of 28 days.

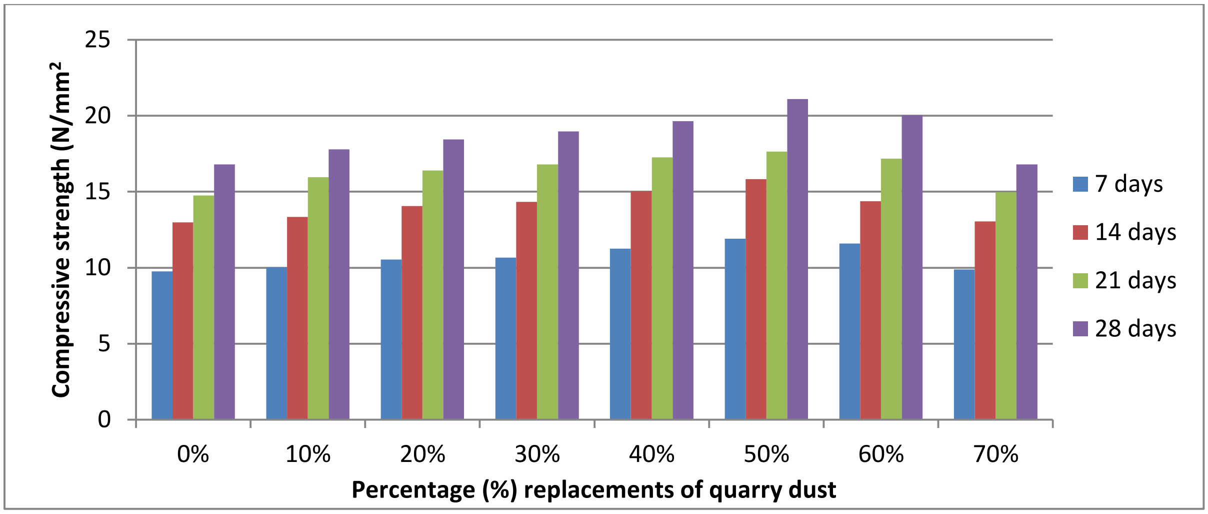

Fig. 4.5 Compressive strength versus percentage (%) quarry dust content

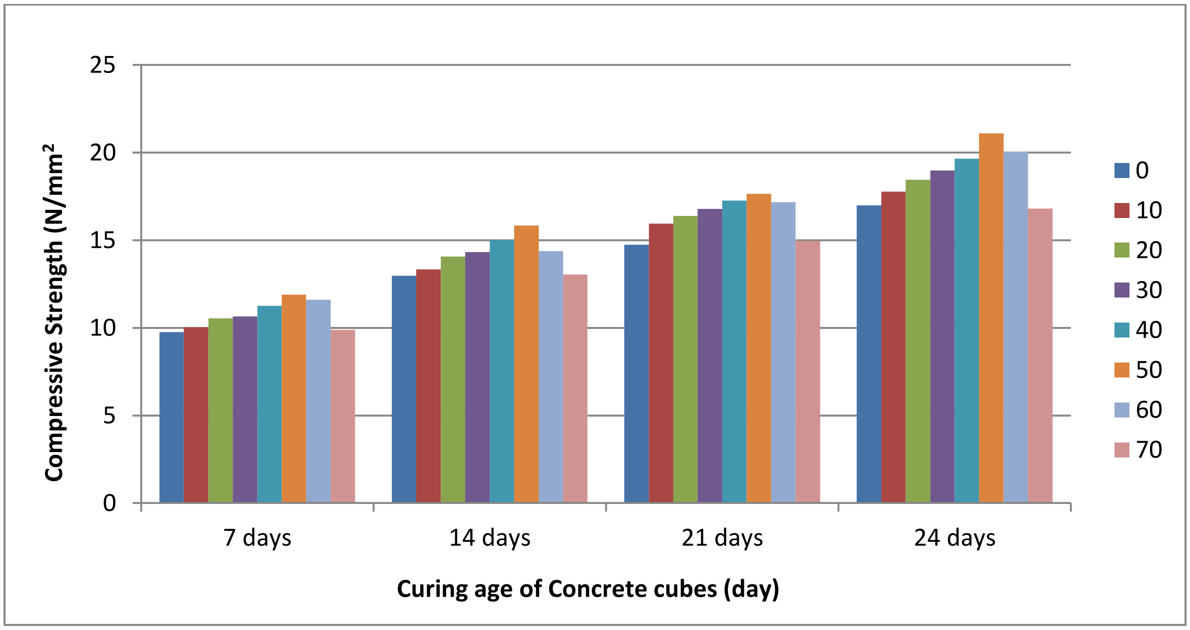

Fig. 4.6 Compressive strength (N/mm2) versus Curing age (days)

CHAPTER FIVE

5.1.0 Discussion

All the concrete mix of normal concrete and that made of quarry content were designed with a fixed ratio of 1:2:4, water-cement ratio of 0.6, and also with the size and type of materials. The only variable parameter is in the percentage content of quarry dust in each concrete cube from 10% to 70%. The difference in the results obtained are due to the effects of fine aggregate replacement with quarry dust on compressive strength, workability. The observations, conclusions and recommendations during the course of this study are well included in this chapter.

5.1.1 Observations

The following observations were noticed in the process of carrying out the study

1. According to the value of compressive strength collected, the values are high and it shows that quarry dust is suitable for use as sand (fine aggregate).All the value of compressive streangth for all the percentages of quarry dust replacement surpasses the minimum value of the compressive strength for normal concrete for the respective curing ages.

2. As the percentage of Quarry dust gradually increases the compressive strength of concrete increases, the compressive strength of concrete will also increase with condition that percentage of quarry dust should not exceed 50%.

3. The percentage replacement of river sand with quarry dust in stages, showed that the later needed much water and cement in order for it to have good workability.

4. The compressive strength of compressed concrete increase with the increase of curing age (maturity), the value of the strength for 28 days higher than every other age maturity (i.e 7 days, 14 days and 21 days.

This study was carried out in order to satisfy the quest for effective alternatives to partially or completely replace fine aggregate (river sand) in the production of a good workable concrete. In this study, the presented data reflects potential consideration for the utility of quarry dust in concrete. However, this study tends to confirm quarry dust replacement in the range of 40% to

50% able to yield to good concrete mix with the best compressive strength suitable for application in structural concrete material.

5.1.2 Conclusion on workability

The workability of quarry dust concrete decreases with increase in the quarry dust content in the concrete mix. This is due to the water absorption characteristic of quarry dust., which absorbs water during the mixing process ad gave low workability as seen from the slump results on the slump test. This study also shows that with high quarry dust content, the mixture got stiffer, causing a reduction in the consistency (a function of workability) of concrete.

5.1.3 Conclusion on compressive strength

The general study on the concrete cubes under compression test shows that replacing 50% of river sand by quarry dust in the concrete mix increases the strength of the composite. The result shows that the composite had low early strength and high final strength when compared with the control mix. Also, the strength was found to decrease when with a higher quantity of quarry dust. This may be due to segregation and voids that exist in the composite due to excess addition of the quarry dust.

5.1.4 Recommendation

From the entire test conducted, quarry dust can be used as a construction material for making concrete. Therefore, I recommend for quarry dust as a construction material, suitable enough as a replacement partially for sand in the production of a good workable concrete, thus the negative effects on the environment due to exploration of sand can be considerably reduced.

REFERENCES

1. Neville, A. and Brooks, J. (1990). Concrete technology. 2nd ed. Harlow, Essex, UK: Longman Scientific & Technical.

Aziz, M. A.(1973). A Text-Book of Engineering Materials. Dhaka, Bangladesh: University Campus.

3. Voigt, T., Ye, G., Sun, Z., Shah, S.P., and Van Breugel, K., (2005) "Early age microstructure of Portland cement mortar investigated by ultrasonic shear waves and numerical simulation" Cement and Concrete, Research,35(5),858-8.

4. Mindess, S., Toung. J.F., and Darwin, D., (2003) "Concrete" 2nd ed., Upper Saddle River, NJ; USA, *Pearson Education.* `

5. Lew, H. S. and Reichard, T. W., (1978) " Mechanical properties of concrete at early ages," *Journal of the American Concrete Institute, 75(10), 533-542.*

6. Sabramaniam, K. V., Lee, J., and Christensen, B. J., (2005) "Monitoring the setting behavior of cementitious materials using one-sided ultrasonic measurement" *Cement and Concrete Research 35(5), 850-857.*

7. Pessiki, S.P., and Carino, N.J., (1988) "Setting time and strength of concrete using the impact-echomethod," *ACI Material Journal*, 85,389-399.

8. Sutherland, J., Human, D., and Chrimes, M., (2001) "*Historic concrete": background to appraisa*, London: Thomas Telford.

9. U. S. National Research Council (1999), "Material science and engineering: forging stronger links to Users."

10. Li, Z., Xiao, L., and Wei, X., (2007) "Determination of concrete setting time using electrical resistivity measurement" *Materials in civil Engineering, ASCE, 19(5), 423-427.*

11. Lee, H.K., Lee, Kim, Y.H., Yim, H., and Bae, D.B. (2004) *"Ultrasonic in-situ monitoring of setting process of high performance concret": Cement and Concrete Research, 34 (34), 631-640.*

12. ASTM (1995). "Standard test method for setting time of concrete mixtures by penetration resistance," C-403, Philadelphia.

13. Jin, X. and Li, Z. (2000) "Investigation on mechanical properties of young concrete," *Materials and Structures, RELIM, 33, 627-633.*

14. Bu, J., Tian, Z., Zheng, and Tang, Z. (2017). "Effect of sand content on strength and pore structure of cement mortar". *Journal of Wuhuh University of Technology Mater.Sci. Ed., 32(2), 382-390.*

15. Encyclopedia Britannica, Inc. (1991) *"The new encyclopedia Britannica"* 15th edition, Chicago, IL: Encyclopedia Britannica.

16. Gardener, N. J. (1990) "Effects of temperature on the early-age properties of type I, type III, and type I/fly ash concrete" *ACI Materials Journal* (American Concrete Institute), 87(1), 68-78.

17. Neville, A. M. and Brooks, J.J., (1994) *"Concrete Technology"* Longman.

18. Ozama K., Mekawa, K., Kunishima, M., and Okamura, H., (1989) "Development of high performance concrete based on durability design of concrete structure" *Proceedings of the second East-Asia and Pacific conference on structural engineering and construction (EASEC-2),* 445-450.

19. Jin, X., Shen, Y., and Li, Z. (2005) "Behaviour of high-and normal-strength concrete at early ages," *Magazine of Concrete research,* 57(6), 339-34.

20. Richard, P. and Cheyrezy M., (1995) "Compostion of reactive powder concretes," *Cement and Concrete Research 25(7),* 1501 – 1511.

APPENDIX I

Sieve analysis result for Quarry Rock Dust (fine aggregate)

Sieve size (mm)	Weight retained (g)	% Weight Retained	% Cumulative Retained	% Passing (finer)
4.75	5.16	1.72	1.72	98.28
2.00	91.07	30.36	30.08	67.92
1.18	47.89	15.96	48.04	51.96
0.85	23.97	7.99	56.03	43.97
0.6	21.46	5.15	63.183	36.82
0.425	15.32	5.11	68.29	31.71
0.3	18.26	6.09	74.38	25.62
0.15	28.08	9.36	83.74	16.26
0.075	26.1	8.7	92.44	7.56
Tray	22.59	7.56	100	0
Total	**300g**			

Sieve analysis result for River Sand (fine aggregate)

Sieve size (mm)	Weight retained (g)	% Weight Retained	% Cumulative Retained	% Passing (finer)
2.00	7.26	1.82	1.82	98.18
1.18	16.79	4.20	6.02	93.98
0.85	10.92	2.73	8.75	91.25
0.6	57.88	14.47	23.22	76.78
0.425	78.19	19.55	42.77	57.23
0.3	119.44	29.86	72.63	27.37
0.15	92.68	23.17	95.80	4.20
0.075	14.54	3.64	99.44	0.56
Tray	2.3	0.58	100	0
Total	**400g**			

Sieve analysis result for stone (coarse aggregate)

Sieve size (mm)	Weight retained (g)	% Weight Retained	% Cumulative Retained	% Passing (finer)
19.0	210	11.67	11.67	88.33
12.5	752	41.78	53.45	46.55
9.52	381	21.17	74.62	25.38
6.30	339	18.83	93.45	6.55
4.75	102	5.67	99.12	0.88
Pan	18	1.0	100	0

Total Sample 1800g

Result of Slump test

%Replacement (quarry dust)	Slump (mm) Δh
0	45
10	34
20	31
30	26
40	22
50	18
60	8
70	4

APPENDIX II

Density data of respective percentage replacements

Percentage (%) replacement of quarry dust	Cubes	Volume (m^3)	Average weight in (kg)	Density in (kg/m3)	Average Density in (kg/m^3)
0% Control	Cube 1 Cube 2	3.375×10^{-3} 3.375×10^{-3}	8.71 8.68	2580.74 2571.85	2576.30
10%	Cube 1 Cube 2	3.375×10^{-3} 3.375×10^{-3}	8.49 8.53	2515.56 2527.41	2521.49
20%	Cube 1 Cube 2	3.375×10^{-3} 3.375×10^{-3}	8.39 8.41	2485.93 2491.85	2488.89
30%	Cube 1 Cube 2	3.375×10^{-3} 3.375×10^{-3}	8.41 8.48	2491.85 2512.59	2502.22
40%	Cube 1 Cube 2	3.375×10^{-3} 3.375×10^{-3}	8.46 8.46	2506.67 2506.67	2506.67
50%	Cube 1 Cube 2	3.375×10^{-3} 3.375×10^{-3}	8.48 8.47	2512.59 2509.63	2511.11
60%	Cube 1 Cube 2	3.375×10^{-3} 3.375×10^{-3}	8.44 8.35	2497.77 2474.07	2485.92
70%	Cube 1 Cube 2	3.375×10^{-3} 3.375×10^{-3}	8.39 8.36	2485.93 2477.04	2481.48

APPENDIX III

% Quarry Dust Replacement	Cubes	7 days (N/mm^2)	14 days (N/mm^2)	21 days (N/mm^2)	28 days (N/mm^2)
0% Control	Cube 1	9.23	12.46	14.38	16.35
	Cube 2	10.28	13.50	15.12	17.62
	Average	**9.75**	**12.98**	**14.75**	**16.99**
10%	Cube 1	9.46	12.97	15.69	18.43
	Cube 2	10.61	13.71	16.21	17.13
	Average	**10.04**	**13.34**	**15.95**	**17.78**
20%	Cube 1	10.85	14.25	16.57	18.65
	Cube 2	10.23	13.89	16.21	18.24
	Average	**10.54**	**14.07**	**16.39**	**18.45**
30%	Cube 1	11.07	14.45	17.03	19.16
	Cube 2	10. 25	14.21	16.55	18.78
	Average	**10.66**	**14.33**	**16.79**	**18.97**
40%	Cube 1	11.18	14.85	17.45	19.95
	Cube 2	11.31	15.19	17.06	19.34
	Average	**11.25**	**15.02**	**17.26**	**19.65**
50%	Cube 1	12.21	15.92	17.79	21.52
	Cube 2	11.58	15.75	17.48	20.68
	Average	**11.90**	**15.84**	**17.64**	**21.10**
60%	Cube 1	11.88	14.56	17.41	20.22
	Cube 2	11. 32	14.18	16.92	19.87
	Average	**11.60**	**14.37**	**17.17**	**20.05**
70%	Cube 1	9.36	12.49	14.67	16.37
	Cube 2	10. 39	13.61	15.24	17.24
	Average	**9.88**	**13.05**	**14.96**	**16.81**