EFFECT OF IRON ORE TAILINGS ON COMPRESSIVE STRENGTH AND WATER ABSORPTION OF CONCRETE

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIRMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING IN CIVIL ENGINEERING (STRUCTURALENGINEERING)

OCTBER, 2023

DECLARATION

I hereby declare that this thesis titled: **"Effect of Iron Ore Tailings on Compressive Strength and Water Absorption of Concrete"** is a collection of my original research work and has not been presented for any other qualification anywhere. Information from other sources (published and unpublished) has been duly cited and acknowledged.

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The thesis titled: **“Effect of Iron Ore Tailings on Compressive Strength and Water Absorption of Concrete”** by **ISYAKU**, **Adamu** (MEng/SIPET/2018/8792) meets the regulations governing the award of the degree of MEng, Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

I dedicate this project to ALLAH who in his infinite mercy have been protecting and providing me with everything. I also dedicated this Project to my parents, my lovely wife Fatima, my family members and my friends for their endless support throughout my education. Finally, my Project supervisor and my lecturers for their tireless effort in teaching me, may ALLAH bless them (Ameen).

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ABSTRACT

Waste management and recycling are some of the core principles in engineering, utilizing materials that could constitute to environmental hazard is paramount in civil engineering. There are a lot of Iron ore tailings that accumulates as debris in Itakpe and some other part of Nigeria. The leachate could contaminate the underground water table of the surrounding aside from that over dependence on the use of river sand in construction activity means that sand mining exploration is on the increase in which the river bed could be over exploited. These are some of the challenges that lead to the research on the "Effect of iron ore tailings on compressive strength and water absorption of concrete made with Iron Ore Tailings (IOT) as a partial replacement of fine aggregate". However, the research was anchored on the following objectives; determine the physical properties of concrete and Iron Ore Tailings (IOT), Carry out concrete mix design with 0% to 40 % of at the interval of 10% increment of Iron Ore Tailings as replacement of sand using DOE mix design method, determine the compressive strength of the resulting hardened concretes and to determine the water absorption property of the resulting hardened concretes. To achieve this 90 specimens of concrete cube were cast and cured for 7, 14, 21 and 28 days. The specific gravity of the iron ore tailings was 3.14, while the twenty-eight days (28days) compressive strength of 49.6N/mm2 showed that 30% of the IOT replacement for river sand was quite satisfactory. The 40% IOT replacement for sand also meet the satisfactory strength requirements of concrete compare with the control. The workability of the IOT concrete decreases with increase in the percentage of IOT replaced with river sand. Water absorption on the other hand decreases as the IOT percentage increases. The study recommends that further researches on the percentage replacement of IOT should be above 40% with a replacement interval of not less than 5% in order to outline the gradual increase in the strength.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Concrete is a composite mixture of aggregates embedded in a cement matrix which fill the space between the aggregates and tie them together as a result of the reactions between the mineral constituents. The use of concretes as building material predates before the Roman Empire (Aniweteli, 2023). It was widely used in the Middle East, Greece and Egypt for building before the Romans made extensive use of it for road construction. In each of these usages, the components of concrete diverse and from the mid-eighteen century till date concrete has been the most frequent building materials. Following the patent of Portland cement in the 1824 by Joseph Aspdin, concrete became the most accepted construction material for the installation of infrastructure and buildings in the advanced world (Guyon *et al*, 2021). As there has not been a better alternative over the years modern structures in developed and developing nations are mostly built in concrete. Concrete is a synthetic stone-like material used for various constructional purposes and contrived by mixing cement and various aggregates. Better still, concrete is a composite material, which is made up of filler and a binder. Concrete as the most widely used man-made construction materials is second only to water as the most utilized substance on the planet (Bamigboye *et al.*, 2015). Concrete posses so many properties that make it attractive for engineering purpose, but for this study the compressive strength and water absorption behavior of concrete will be considered. As rightly stated earlier on, Strength and durability of concrete are most important parameter to determine the life and serviceability of the structure. Durability mostly depends on penetrability of water, chloride ion, sulphate ion, alkali and acid ions (Carmichael *et al*., 2019).

Compressive strength is the ability of concrete to accept the compressive force of broad unity, to control the quality of the concrete that is achieved. In the testing of the normal concrete split tensile strength, all the specimens are split apart. This happens because of the horizontal force due to the maximum load spread over the cylinder blanket (Betaubun and Musamus, 2018). Concrete has very good compressive strength and resistance to fire (Ede and Aina, 2015), however the tensile strength is just about 10% of the compressive strength which has been responsible for many recent researches aimed at improving the general strengths of concrete (Zongjin, 2011; Ede *et al*., 2015). Viewed from its function, concrete is required to have high strength so that the quality of concrete becomes the main thing needed, besides that related to the efficiency of concrete time generally must reach the age of 28 days to achieve maximum compressive strength, so that when not reached the maximum time but the concrete is given excessive load it is possible that the concrete will collapse and collapse (Munhoz and Medeiros, 2019).

Water absorption in concrete is an action which happens only due to capillary suction in absence of any external pressure. But, because of technical limitations for in-situ measurement devices, it is necessary to apply a small pressure head in water absorption tests. lower water absorptions were found in concrete with partial replacements by mineral admixtures, due to the pore refinement that reduced its connectivity. However, the effects are not yet fully understood. For example, concrete curing can play an important role in these relations. Bem *et al*. (2018), concluded that the curing process influences the permeability of the concrete. This reflected in higher water absorption rates and electrical resistivity and lower compressive strengths. According to these authors, better results were found when specimens were cured immersed in water or, at least, stored in a moist chamber. But to ascertain the absorption behavior of concrete that have iron ore tailings (IOT) is one of the objective of this study, because absorption behavior of concrete is very crucial for the durability and safety of structures that are concrete.

For years, numerous researches have been done on how iron ore tailings can be used as aggregates in concrete. it is a prime concern to all stakeholders who are into iron ore mining (Kuranchie *et al*., 2015). Experiment to determine the suitability of iron ore tailings (IOT) as fine aggregate replacement of sand (RS) for concrete used for rigid pavement was carried out by Ugama *et al.*, (2014) and several other authors (Kuranchie *et al.*, 2015; Shettima *et al.*, 2018), which confirms the usability of iron ore tailings for concrete work. They asserted that the study would add value to the tailings by utilizing them as a replacement for aggregates in concrete which is part of waste management approach in civil engineering.

1.2 Statement of the Research Problem

One of the prevalent environmental problems associated with Iron Ore Tailings is the formation of acid mine drainage which can be a potential source of surface and ground water pollution (Adedayo, and Onitiri, 2012; Cassiano *et al.*, 2012). IOT also consume a lot of land that could be used for other meaningful purposes, and thus compromises the good looks of the environment in these areas (Thomas *et al*., 2013; Yellishetty *et al*., 2008). There are chances of potential of erosion from these IOT dumpsites into the environment (Yellishetty *et al*., 2012). In recent times, one of the current practices is that a smaller percentage of these tailings are returned to the mined-out areas as backfills to fill the void created, while majority of them are stockpiled in the environment or returned to a special tailings wall built for storage purposes.

To minimize the problems that are emanatial by the mine tailings, one potential application area to explore is its utilization in building and construction. This is because there is a greater potential in this sector where recycled waste products could be considered as reliable construction and building materials. An example is the use of these mine tailings as aggregates in concrete (Shetty *et al*., 2014; Thomas *et al.*, 2013 Thomas and Gupta, 2013; Yellishetty *et al.,* 2008).

1.3 Aim and Objectives of the Study

The aim of this study is to evaluate the effect of iron ore tailings on compressive strength and water absorption of concrete made with Iron Ore Tailings (IOT) as a partial replacement of fine aggregate. The aim is achieved through the specific objectives of this study are to

i. Determine the physical properties of the constituent materials concrete and chemical properties of Iron Ore Tailings (IOT).
ii. Determine the effect of successive addition of IOT and partial replacement of sand on compressive strength of the resulting hardened concretes
iii. Determine the effect of successive addition of IOT and partial replacement of sand on water absorption property of the resulting hardened concretes
iv. Compare the strength and water absorption properties of the hardened concretes.

1.4 Justification of the Study

The massive waste generation going on in the iron ore industry indicates that thousands tons of dry tailings is produced daily in mines (Adedayo and Onitiri, 2012). These tailings contain toxic heavy metals which pollute the environment, water and soil at abandoned copper mines and waste sites (Kuranchie *et al.,* 2015). One of the core challenges of civil engineering is the adoption of concept of sustainable development which involves the utilization of waste materials and by-products at reasonable cost with the lowest possible environmental impact. Similarly, too, rapid increase in consumption of river sand due to the increased in construction activity means that sand mining exploration increased in which the river bed is over exploited. Therefore, the success of this research will go a long way in reducing the high consumption of natural resources such as fine aggregate (sand) which may be scarce there by reducing the accumulation of waste arising from the mining of Iron Ore. On the other hand, using IOT as a partial replacement of fine aggregate material, will reduce the volume of solid waste generated from mining of Iron ore and also serve as waste to wealth initiative.

1.5 Scope of the Study

This study evaluate the effect of iron ore tailings on compressive strength and water absorption of concrete made with Iron Ore Tailings (IOT) as a partial replacement of fine aggregate. The study will include the physical properties of concrete constituent material. The percentage replacement of IOT with Fine aggregate would be at 0, 15, 30, 45, 60 and 75% respectively. The study would comprise the evaluation of the water absorption property on the hardened concrete. The resulting concrete will be evaluated and analyzed in order to make recommendations on the appropriate and optimum use of IOT as replacement of fine aggregate in concrete production.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Normal Weight Concrete

Concrete is a strong building material and the use of concrete could be traced back before the Roman Empire. It was broadly used in the Middle East, Greece and Egypt for building before the Romans made wide use of it for road construction. In each of these usages the components of concrete differs and from the mid-eighteen century till date concrete have been the most common building materials (Bamigboye *et al.,* 2015). After the patent of Portland cement in the 1824 by Joseph Aspdin, concrete became the most adopted material for the construction of infrastructure and buildings in the advanced world. Concrete according to Ayobami *et al.,* (2017) is one of the most utilized construction materials and is second only to water as the most utilized substance on the planet .Concrete is the most versatile heterogeneous construction material and the impetus of infrastructural development of any nation. In civil engineering practice and construction works around the world depend to a very large extent on concrete. It is the world's most widely used construction materials because of its properties (Olafusi *et al.,* 2015).

Concrete is by far a multipurpose and most widely used construction material worldwide. It can be engineered to satisfy a wide range of performance specifications, different from other building materials, such as natural stone or steel, which generally have to be used as they are. Concrete is part of construction materials that have been in use for buildings, bridges, roads, and others. Concrete is a mixture of fine aggregate, coarse aggregate, Portland cement and with other brand cement, and water. However there are some that use additional materials (additives) to become a homogeneous unit (Candra *et al.*, 2020). According to Hasan and Kabir (2011), concrete is readily available, relatively cheap, flexible to handle and it gives shape and any desired form. While Anejo and Damen (2014) opined that concrete is made of a cementatious material (cement, lime, pozolans or any combination of these), aggregates (fine and/or coarse) and water. There could be some additives and/or admixtures added to the basic mix to vary the properties of the concrete when it is fresh or hardened.

Concrete is essentially a mixture of two components: aggregates and paste. The paste, comprised of Portland cement and water, binds the aggregates (usually sand and gravel or crushed stone) into a rocklike mass as the paste hardens as a result of the chemical reaction of the cement and water (Bamigboye *et al.*, 2015). Concrete is a synthetic stone-like material used for various constructional function, it is manufactured by mixing cement and various aggregates. In a nutshell, concrete could be a composite material, which is made up of filler and a binder. Concrete is the most versatile heterogeneous construction material and the impetus of infrastructural development of any nation. Civil engineering practice and construction works around the world depend to a very large extent on concrete. It is the world's most widely used construction materials because of its properties. Concrete can be described as a multi-phase composite material that comprises of three phases; namely the mortar, mortar/aggregate interface, and the coarse aggregate phase (Abdullahi, 2017).

Plain concrete made of Portland cement, coarse and fine aggregate and water is usually called the first generation of concrete while the steel bar–reinforced concrete is the second generation concrete (Ede *et al*., 2015). Bamigboye *et al.*, (2015) stated other factors such as aggregates, cement, mixing procedures and skill of operators, placement and consolidation.

It varies according to so many variables such as quality of constituent materials (cement aggregates, water and admixtures), skill of the manufacturers, management placement procedures and environmental issues (Zongjin, 2011; Ede *et al.*, 2015). Shetty (2005) also reported that in concrete, aggregates and paste are the major factors that affect the strength of concrete.

2.2 Utilization of Waste in Concrete

We have a biggest problem to solve in our society that is to diminish the environmental issues that prevailing during the infrastructural development in the recent years. The utilization of recycled materials and solid wastes in the construction practices becoming a new trend in the environmental conservation point of view. The solid wastes and recyclable materials that are produced from the industrial revolution or by man-made activities or from agricultural waste products are converted into useful product (Kathurba *et al.*, 2014). The properties of solid wastes and recyclable materials should be addressed before utilization in the construction activities. The primary motto of waste utilization in the construction practices would be cost effective and environmentally friendly. The main purpose of these studies is to use as recycled solid waste in an appropriate manner (Tang *et al*., 2020).

Normally, recyclable materials would be having appropriate composition, chemical, physical and mechanical properties. Before utilization or replacement of recyclable materials to conventional materials, recyclable material properties to be addressed to get a better raw material for better life span of the building (Sasitharan *et al.*, 2012). For the better understanding of the replacement approved conventional materials, their chemical and physical properties need to be checked along with optimum usage of specific waste materials. The recycled solid waste materials are somewhat different from the natural raw materials. The recycled waste material should be carefully evaluated for each of the planned uses (Catalin *et al.*, 2016). The characteristics of each and every recycled solid waste material should be clear to the engineer when working with this type of materials.

Solid waste can be used in many ways. Solid waste can used as partial replacement either of fine aggregates, coarse aggregates and supplementary cementitious materials for the production of cost effective concrete. Regarding utilization of solid waste many research studies had been conducted. The main objectives of most of the research works were based on the properties of solid waste on the physical, chemical and the mechanical properties of construction products and to reduce environmental pollution which is increasing day by day (Tong *et al*., 2013). Some works gives the how the solid wastes can be utilized efficiently in construction or construction materials. Though further more research is required for the better understanding of the effects of solid waste and their properties and durability aspects of replacement approved construction products. The use of solid wastes is considered as follows (Safiuddin *et al*., 2010):

I Using different types of processed waste materials for raw materials in construction.

ii The solid waste materials should be optimally used to produce useful construction materials.

iii For load-bearing construction materials solid waste materials can be effectively used.

iv To produce environment-friendly and sustainable construction materials solid waste materials can be recycled and reused in a effective manner.

v Many researchers are still conducting experiments to test the durability of construction materials which is made of recycled solid waste materials.

vi By adding recycled solid waste along with the raw materials, we may produce higher grade construction materials.

vii Compared to the original raw materials these materials are much more cost-efficient and they show better life time performance.

viii Solid waste-based construction material's performance has been evaluated in real time construction.

2.3 Factors Affecting Strength of Concrete

2.3.1 Water-cement ratio

It is water cement ratio that basically governs the property of strength. Lesser the water cement ratio, greater will be strength. The water-cement ratio (w/c ratio) is a crucial factor in concrete mix design and significantly influences the strength and durability of concrete. It represents the ratio of the weight of water to the weight of cement in a concrete mix (Safiuddin *et al.*, 2010)

2.3.2 Type of cementing material

It affects the hydration process and therefore strength of concrete. Cement is a key construction material used in the production of concrete, mortar, and various other construction applications. There are several types of cement materials, each with different properties and suitable for specific applications (Chen *et al*., 2021).

2.3.3 Amount of cementing material

It is the paste that holds or binds all the ingredients. Thus greater amount of cementing material greater will be strength. The amount of cementing material (usually cement) required in a concrete mix depends on several factors, including the desired strength and characteristics of the concrete, the water-cement ratio, and the volume of concrete needed (Chen *et al*., 2021).

2.3.4 Type of aggregate

Rough and angular aggregates are preferable as they provide greater bonding. Air content The amount of air improves the concrete resistance on freezing and thawing. But in excess lead to failure.

2.3.5 Admixtures

Chemical admixtures like plasticizers reduce the water cement ratio and increase the strength of concrete at same water cement ratio. Mineral admixtures affect the strength at later stage and increase the strength by increasing the amount of cementing material.

2.4 Properties of Fresh Concrete

2.4.1 Workability of concrete

The capability of being handled and flows into formwork or around any reinforcement, with assistance of compacting equipment. The higher workability concretes are easier to place and handle but obtaining higher workability by increasing water content decreases strength and durability. Workability is often referred to as the ease with which a concrete can be transported, placed and consolidated without excessive bleeding or segregation. It is obvious that no single test can evaluate all these factors. In fact, most of these cannot be easily assessed even though some standard tests have been established to evaluate them under specific conditions (Chen *et al*., 2021).

Consistence is sometimes taken to mean the degree of wetness; within limits, wet concretes are more workable than dry concrete, but concrete of same consistence may vary in workability. Because the strength of concrete is adversely and significantly affected by the presence of voids in the compacted mass, it is vital to achieve a maximum possible density. This requires sufficient workability for virtually full compaction to be possible using a reasonable amount of work under the given conditions. Presence of voids in concrete reduces the density and greatly reduces the strength: 5% of voids can lower the strength by as much as 30%. To determine the consistency in workability four tests are followed (Huber and Helm, 2020);

i Slump test

ii Compacting factor test

iii Vee Bee test and

iv Flow table test

2.4.2 Segregation and bleeding

2.4.2.1 Segregation

It can be defined as the separation of the constituent materials of concrete. A good concrete is one in which all the ingredients are properly distributed to make a homogeneous mixture. There are considerable differences in the sizes and specific gravities of the constituent ingredients of concrete. Therefore, it is natural that the materials show a tendency to fall apart. Segregation may be of three types:

i Coarse aggregate separating out or settling down from the rest of the matrix.

ii Paste separating away from coarse aggregate.

iii Water separating out from the rest of the material being a material of lowest specific gravity.

A well-made concrete, taking into consideration various parameters such as grading, size, shape and surface texture of aggregate with optimum quantity of waters makes a cohesive mix. Such concrete will not exhibit any tendency for segregation. The cohesive and fatty characteristics of matrix do not allow the aggregate to fall apart, at the same time; the matrix itself is sufficiently contained by the aggregate. Similarly, water also does not find it easy to move out freely from the rest of the ingredients (Chen *et al*., 2021). The conditions favorable for segregation are

i Badly proportioned mix where sufficient matrix is not there to bind and contain the aggregates.

ii Insufficiently mixed concrete with excess water content.

iii Dropping of concrete from heights as in the case of placing concrete in column concreting.

iv When concrete is discharged from a badly designed mixer, or from a mixer with worn out blades.

v Conveyance of concrete by conveyor belts, wheel barrow, long distance haul by dumper, long lift by skip and hoist are the other situations promoting segregation of concrete.

Vibration of concrete is one of the important methods of compaction. It should be remembered that only comparatively dry mix should be vibrated. It too wet a mix is excessively vibrated; it is likely that the concrete gets segregated. It should also be remembered that vibration is continued just for required time for optimum results. If the vibration is continued for a long time, particularly, in too wet a mix, it is likely to result in segregation of concrete due to settlement of coarse aggregate in matrix.

2.4.2.2 Bleeding

This in concrete is sometimes referred as water gain. It is a particular form of segregation, in which some of the water from the concrete comes out to the surface of the concrete, being of the lowest specific gravity among all the ingredients of concrete. Bleeding is predominantly observed in a highly wet mix, badly proportioned and insufficiently mixed concrete. In thin members like roof slab or road slabs and when concrete is placed in sunny weather show excessive bleeding (Surahyo *et al*., 2019).

Due to bleeding, water comes up and accumulates at the surface. Sometimes, along with this water, certain quantity of cement also comes to the surface. When the surface is worked up with the trowel, the aggregate goes down and the cement and water come up to the top surface. This formation of cement paste at the surface is known as Laitance. In such a case, the top surface of slabs and pavements will not have good wearing quality. This laitance formed on roads produces dust in summer and mud in rainy season (Svintsov *et al*., 2020).

Water while traversing from bottom to top, makes continuous channels. If the water cement ratio used is more than 0.7, the bleeding channels will remain continuous and un segmented. These continuous bleeding channels are often responsible for causing permeability of the concrete structures. While the mixing water is in the process of coming up, it may be intercepted by aggregates. The bleeding water is likely to accumulate below the aggregate. This accumulation of water creates water voids and reduces the bond between the aggregates and the paste (Surahyo *et al*., 2019).

The above aspect is more pronounced in the case of flaky aggregate. Similarly, the water that accumulates below the reinforcing bars reduces the bond between the reinforcement and the concrete. The poor bond between the aggregate and the paste or the reinforcement and the paste due to bleeding can be remedied by re vibration of concrete. The formation of laitance and the consequent bad effect can be reduced by delayed finishing operations. Bleeding rate increases with time up to about one hour or so and thereafter the rate decreases but continues more or less till the final setting time of cement (Surahyo *et al*., 2019).

2.4.2.3 Prevention of bleeding in concrete

Bleeding can be reduced by proper proportioning and uniform and complete mixing.

i Use of finely divided pozzolanic materials reduces bleeding by creating a longer path for the water to traverse.

ii Air-entraining agent is very effective in reducing the bleeding.

iii Bleeding can be reduced by the use of finer cement or cement with low alkali content. Rich mixes are less susceptible to bleeding than lean mixes.

The bleeding is not completely harmful if the rate of evaporation of water from the surface is equal to the rate of bleeding. Removal of water, after it had played its role in providing workability, from the body of concrete by way of bleeding will do well to the concrete. In early bleeding when the concrete mass is fully plastic, may not cause much harm, because concrete being in a fully plastic condition at that stage, will get subsided and compacted. It is the delayed bleeding, when the concrete has lost its plasticity, which causes undue harm to the concrete. Controlled re vibration may be adopted to overcome the bad effect of bleeding.

2.5 Properties of Hardened Concrete

2.5.1 Modulus of elasticity

The modulus of elasticity of a given concrete is dependent on the relative amounts of aggregate and paste and their individual moduli. The modulus of elasticity of normal weight concrete is typically higher because of the higher modulus of the normal weight aggregate as compared to that of the lightweight aggregate. Normally the modulus of elasticity for normal weight concrete ranges from 3 to 4 x106 psi. Lightweight concretes usually have a modulus of elasticity of about ½ to ¾ that of a normal weight concrete, the lower modulus of elasticity of lightweight concrete by specifying an equation which includes a term for the unit weight. This equation should be further investigated for typical high-performance, high-strength lightweight concretes, because the modulus term is an extremely important component of pre-stress loss and deflection calculations. If the modulus is not accurately predicted, the other calculations will also be in error. Modulus of elasticity values for high-performance lightweight concretes is in the range of 2,980 ksi to 4,680 ksi. and about 3,000 ksi for high-performance lightweight concrete (Sharma and Bishnoi, 2020).

2.5.2 Drying shrinkage

Drying shrinkage is the reduction in concrete volume due to water loss, and is important because it can affect the extent of cracking, pre-stress loss and warping in concrete structures. For normally cured concretes, lightweight concretes exhibit greater drying shrinkage than normal weight concretes at lower strengths. At higher strengths, the drying shrinkage of lightweight concretes is similar to that of normal weight concretes. The use of partial replacement of lightweight sand with normal weight sand has been shown to reduce the drying shrinkage. Steam curing aids in reducing the drying shrinkage of lightweight concrete by approximately 10 to 40%. The lower ranges of these drying shrinkage values are similar to typical normal weight concretes (Noordien, 2020).

2.5.3 Creep

Creep is the increase in strain over time at a constant stress. The effects of creep can be either beneficial or detrimental to concrete structures. Creep can be beneficial by reducing concentrations of stress over time. However, creep can be detrimental because it may lead to excessive long term deflection and prestress loss, or loss of camber. For normal curing, lightweight concrete typically has a higher specific creep (creep per psi of sustained stress) than normal weight concrete. The range of typical creep values for lightweight concrete can be narrowed by using normal weight sand in the mixture. Also, increasing the compressive strength from 3000 to 5000 psi significantly reduces the creep. Steam curing for lightweight concrete aids in reducing the creep by about 25 to 40% of the creep of similar concrete subjected only to moist curing. The steam cured lightweight concretes have slightly higher creep values compared to normal weight concretes with the same compressive strengths. These differences are reduced at higher compressive strengths (Ren *et al*., 2020).

2.5.4 Thermal properties

The coefficient of thermal expansion for lightweight concretes typically ranges from 4 to 5 x 10-6 in. / in. / °F. This is dependent on the amount of natural sand used in the mixture.

specifies using 6.0 x 10-6 in. / in. / °F for normal weight concrete and 5.0 x 10-6 in. / in. / °F for lightweight concrete. The lower coefficient of thermal expansion can be an advantage in bridges because the self-equilibrating and restraint stresses from thermal gradients will be smaller (Noordien, 2020).

2.5.5 Freezing and thawing resistance

Freezing and thawing resistance and permeability are important factors in the durability of concrete. For freezing and thawing resistance, properly proportioned and placed lightweight concrete has been found to perform as well or better than normal weight concrete. The permeability of lightweight concrete has been found to be equal to or less than that of normal weight concrete. This is attributed to the elastic compatibility of the constituents and the enhanced bond between the coarse aggregate and the cement paste. Reduced permeability and increased resistance to the effects of freezing and thawing lead to a more durable concrete that is better able to resist corrosion of steel in concrete (Noordien, 2020).

2.6 Iron Ore Tailings Concrete

2.6.1 Iron tailings as aggregates

Aggregates constitutes about 70–80% of a concrete mix (Shetty *et al.,* 2014; Thomas and Gupta, 2013). As the natural granite quarries for aggregates are gradually decreasing due to over reliance, however alternative materials such as iron ore tailings are used as natural aggregates in concrete (Thomas *et al*., 2013). If mine tailings are considered as a partial or complete replacement of natural aggregates in concrete, majority of these tailings could be recycled and used sustainably, by turning these mine tailings into useful resource and providing cheaper alternatives in concrete production (Ugama *et al*., 2014). The processing path associated with the iron ore beneficiation is such that it's tailings with particle sizes ranging from fine to coarse are segregated properly, both fine and coarse aggregates for concrete usage (Kuranchie *et al.*, 2015). There are numerous studies on the use of IOT as part of concrete mix across the globe, most the literatures seems to accept the use of IOT as aggregate replacement or grounded as partial replacement of cement.

Sujing *et al*., (2014) investigated and found that 100% replacement of natural aggregate by the tailings significantly decreased the workability and compressive strength of the material. Also showed, when the replacement level was no more than 40%, for 90 days standard cured specimens, the mechanical behavior of the tailings mixes was comparable to that of the control mix, and for specimens that were steam cured for 2 days, the compressive strengths of the tailings mixes decreased by less than 11% while the flexural strengths increased by up to 8% compared to the control mix. Concluded stiffness and hardness of the tailings were on average lower than those of the natural sand. Incorporation of the tailings into the mix increased the water demand and lowered the flow ability of the fresh material due to the high specific surface area and rough surface of the tailings.

Sharma and Bishnoi (2020) used iron ore tailings powder as cement replacement for developing green ECC (Engineered Cementitious Composite) and concluded that the replacement of cement by less reactive IOTs in ECC reduces the matrix fracture toughness. Increasing the replacement of cement beyond 40% replacement ratio reduces the compressive strength of ECC.IOTs in powder form are used to partially replace cement to enhance the environmental sustainability of ECC. Mechanical properties and material greenness of ECC containing various proportions of IOTs are investigated. The newly developed versions of ECC in the study, with a cement content of 117.2–350.2 kg/m3, exhibit a tensile ductility of 2.3–3.3%, tensile strength of 5.1–6.0 N/mm^2, and compressive strength of 46–57 N/mm^2 at 28 days. The replacement of cement with IOTs results in 10–32% reduction in energy consumption and 29–63% reduction in carbon dioxide emissions in green ECC compared with typical ECC.

Aravindkumar *et al.*, (2012) studied on fatigue behavior of high volume fly ash concrete (HVFAC) and conventional concrete (PCC) under constant amplitude fatigue loading. Comparative studies on total number of 95 prism specimens of HVFAC and 100 prism specimens of PCC were tested under constant amplitude fatigue loading. All prism specimens were of size 75mm×100mm×500mm and were tested under flexural fatigue loading using haiver sine wave loading. Frequency of fatigue loading was kept at 4Hz. Studies indicated that lognormal model was acceptable for fatigue life distributions at all stress levels for both HVFAC and PCC. The parameters of distribution exhibited dependency on stress levels and type of concrete. Relations between stress level and fatigue life were developed for both HVFAC and PCC. These relations were found to be dependent on type of concrete. A total number of 24 prism specimens were tested under compound fatigue loading. It was found that Miner‟s hypothesis gives both unsafe and over safe predictions of failure. Miner‟s sum was found to be dependent on type of compound loading and sequence of loading.

2.7 Compressive Strength

The compressive strength is the most critical property that gives a very good overall idea of the quality of concrete, the tensile strength being negligible in comparison. Prakash *et al.*, (2019), stated that compressive strength is the most important properties of concrete as it resists the compressive stress created by the structure. In concrete construction, it is necessary to ensure the compressive strength, based upon the material proportion added to it. Concrete has very good compressive strength (Ede and Aina, 2015). According to Abdullahi, (2017) The compressive strength of concrete is dependent on the water/cement ratio, degree of compaction, ratio of cement to aggregate, the bond between mortar and aggregate, and grading, shape, strength and size of the aggregate. This submission was further justified by Castro and Ferreira, (2016) who asserted that studies have related high strength concrete to the constituents required, the mix design parameters, the effect of various chemical and mineral admixtures on the strength of concrete. Whilst a number of studies have considered the development of a rational or standardized method of concrete mix design for high strength concrete no widely accepted method is currently available. Abdullahi, (2017) further stated that the strength of concrete at the interfacial zone is essentially reliant on the integrity of the cement paste and the nature of the coarse aggregate. Joseph and Raymond (2014) also found that concrete develops an average of 26 % of the 28 days strength in 1 day and 85 % in 21 days and concluded that concrete develop strength rapidly at early age compared to later ages. Furthermore the compressive strength of concrete is tested at the age of 28 days from curing and it is considered as the design strength (Chopra *et al*., 2016 and Young *et al.*, 2019).

The most frequent design compressive strengths required by the construction industry for cast-in-place, precast, and pre-stressed structures range from 3000 to 8000 psi. These design strengths are economically met with the use of lightweight aggregate. Some lightweight aggregate concretes can obtain strengths above 8000 psi; however, not all lightweight aggregates are capable of obtaining these strengths. A common concept used to indicate the maximum compressive and/or splitting tensile strengths of concretes using lightweight aggregate is a “strength ceiling.” A mixture reaches its strength ceiling when, using the same aggregate, it possesses only slightly higher strength with higher cement content. This property is predominantly influenced by the coarse aggregate fraction of the mixture. The strength ceiling can be increased by reducing the maximum size of the coarse aggregate. As with normal weight concrete, water reducing and mineral admixtures can be used with lightweight concrete to improve the workability, placing, and finishing.

2.8 Shrinkage

The phenomenon is defined as the shrinkage of young concrete which occurs due to rapid and excessive drying. The cracking occurs when the concrete surface dries and shrinks so fast, that the induced tensile strains exceed the strain capacity of the very young concrete. It may clearly affect the aesthetics, durability and serviceability of the structure by accelerating the ingress of harmful materials that might cause damage in future, corrosion of the reinforcement (Di Luzio et at., 2020).

The total shrinkage that any concrete element experiences during its lifespan is, as known, caused by various contracting mechanisms. Among others, observable fact such as evaporation, hydration and/or carbonation can participate in the total shrinkage of the cementitious materials (Sayahi, 2016). However, the effect of these process on the concrete’s total shrinkage is strongly time dependent and hence, the total shrinkage of concrete can be divided into: (a) early-age shrinkage which represents the shrinkage in the first 24 hours after mixing, and (b) long-term shrinkage for the time beyond (Sayahi, 2016).

2.8.1 Plastic shrinkage

Early age shrinkage in concrete may generate to deleterious cracking which in some occasions can dramatically blight the aesthetics, durability and serviceability of a structure (Boshoff and Combrinck 2013). Plastic- and autogenous shrinkage are the two main phenomena by which early-age shrinkage is caused. The former occurs due to excessive loss of water for example by evaporation, whereas the latter is a result of hydration and chemical reactions (Sayahi, 2016).

Plastic shrinkage cracking is frequently associated with hot weather concreting in arid climates. It occurs in exposed concrete, primarily in flat work but also in beams and footings and may develop in other climates whenever the evaporation rate is greater than the rate at which the water rises to the surface of recently placed concrete by bleeding. The main driving force behind the phenomenon is thus believed to be rapid and excessive loss of water, which mainly takes place in form of surface water evaporation (Pereira *et al*., 2023).

Many parameters may influence the cracking tendency of concrete at its early age. Among others, w/c ratio, type of cement, fibres, admixture, member size, fines content, temperature of the concrete surface and ambient conditions (that is relative humidity, air temperature and wind velocity) may increase or decrease the risk of cracking (Boshoff and Combrinck 2013).

In literature according to Sayahi (2016) it is concluded that the fresh concrete experiences three different structural phases (states) in the first 24 hours after mixing:

i. Plastic: the concrete at this stage is still liquid, plastic, viscoelastic and workable.

ii. Semi-plastic: commences after the initial setting, where a stiff skeleton starts to form and the concrete gradually becomes rigid.

iii. Rigid: begins after the point of final setting. At this stage the maximum hydration heat is probably reached and the strength of the concrete increases due to the ongoing hydration.

2.8.2 Drying shrinkage

The loss of moisture from concrete after it hardens, and hence drying shrinkage, is inevitable unless the concrete is completely submerged in water or is in an environment with 100 percent relative humidity. Thus, drying shrinkage is a phenomenon that routinely occurs and merits careful consideration in the design and construction of concrete structures.

The actual mechanisms by which drying shrinkage occurs are complex, but it is generally agreed upon that they involve the loss of adsorbed water from the hydrated cement paste. When concrete is initially exposed to a drying condition - one in which there is a difference between the relative humidity of the environment and that of the concrete - it first loses free water. In the larger capillary pores these results in little or no shrinkage. In the finer water-filled capillary pores (2.5 to 50 nm size) due to loss of moisture, curved menisci are formed, and the surface tension of water pulls the walls of the pores. Thus, internal negative pressure develops when the meniscus forms in the capillary pores. This pressure results in a compressive force that leads to shrinkage of concrete. Continued drying also leads to the loss of adsorbed water, a change in the volume of unrestrained cement paste and an increase in the attraction forces between the C-S-H hydration products that leads to shrinkage (Sayahi, 2016).The thickness of the adsorbed water layer has been reported to increase with increasing humidity (Sayahi, 2016).Therefore, it is conceivable that a higher water content would lead to a thicker layer of adsorbed water, and hence, more drying shrinkage. The drying shrinkage of concrete can be determined in the laboratory by using ASTM C 157/C 157M, “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete”, and it is usually expressed as a percent or in millionths (x 10-6). Physically, concrete that experiences a drying shrinkage of about 0.05 percent (500 millionths or 500 x 10^{-6}) will shrink approximately 0.6 in. per 100 ft (50 mm for every 100 m). There are several factors that affect drying shrinkage. These include the characteristics of the concrete mixture ingredients and their proportions, design and construction practices, and environmental influences.

2.9 Water Absorption Characteristics of Concrete

For structures that are to be exposed to severe environments, it is imperative that the concrete be of high quality and durability. When using lightweight concrete in structures, it is important that a high quality lightweight aggregate be used. These high quality aggregates have been shown to absorb very little water. This is ascribed to the enhanced bond between the cement paste and the aggregate. This improved bond slowdown absorption and allows for a dense, durable concrete.

Both cement, fine aggregate as well as mineral admixtures may have particles which have about the same particle size or are little bigger than the pores in the surface layer of the lightweight aggregate. Thus, some of the open pores on the aggregate surface may be intercepted by these particles (Raju *et al.*, 2020).

In all concrete, a part of the water is also absorbed on the solid particles. In addition, some of the water is exhausted by the early reactions of the cement hydration which take place simultaneously with the water absorption by the light weight aggregate. Therefore, all the water in the fresh concrete is not available for aggregate absorption. The process in which molecules of substances stick on to the concrete surface either by physical bonds or as consequence of chemical bonds is called adsorption. Water absorption, or absorptivity, is water flow in unsaturated porous materials due to pressure differences caused by capillary and gravitational forces (Mohammadi, 2013).

The viscosity of the cement paste also affects the water absorption by aggregate. A low water-cement ratio causes a high viscosity of the cement paste which gives reduced water absorption. This effect may vary depending on whether the cement paste is absorbed into the aggregate or not. Punkki, (1995) did not observe any penetration of cement paste into high-strength lightweight aggregate. Thus, it appears that only water is absorbed by the aggregates. The water absorption by aggregate is continuous throughout the dormant period of the cement hydration and ends at a stage between the initial and the final set. The maximum time of water absorption in fresh concrete becomes visible between two and four hours, depending on type of cement and admixtures used. Then, water may move back out of the aggregate into the cement paste and thus support further hydration. However, water can move out of the aggregate to the cement paste only if the biggest capillary pores are empty. Therefore, the time when the water begins to move depends on the cement paste properties and it is normally several days. The water absorption by lightweight aggregate from fresh concrete can be split into four different stages (Punkki, 1995).

Stage I corresponds to the water absorption during mixing. This water absorption is very fast, and the water is being absorbed uniformly from the whole cement paste. The pace of water absorption is probably not uniform during the whole mixing time but is higher in the beginning. The next stage includes the water absorption after mixing but before compaction of the concrete. Gradients of water content in the cement slurry may form, but they will, at least partly, level out during compaction. The water absorption continues even after compaction (stage III), but the rate of absorption is probably very slow. In that stage, distinct gradients of water absorption are probably formed. Stage IV may take place later on, after the setting of cement has started.

Ekwulo and Eme (2017) stated that one of the most important properties of a good quality concrete is low permeability, especially one resistant to freezing and thawing. A concrete with low permeability resists ingress of water and is not as susceptible to freezing and thawing. For low quality concrete, water enters pores in the cement paste and even in the aggregate and when excess water in concrete evaporates, it leaves voids inside the concrete element. Incomplete compaction and presence of voids in concrete may result in high water absorption leading to concrete of low strength. By proper selection of ingredients and mix proportioning, and following good construction practices almost impervious concrete can be obtained. Several researches has been carried out on concrete water absorption but little or no attention has been given to the effect of aggregate size on concrete water absorption (Akyildiz, 2018).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used for the production of the concrete cubes were sand, iron ore tailings, aggregates (coarse and fine), water and cement. For the purpose of this work 90 concrete cubes of 15 cm^3 were produced at the concrete laboratory of the department of civil engineering Federal polytechnic Bida, Niger state.

3.1.1 Sand

The sand employed for this study was river sand having bulk density 1352 kg/m^3 and fineness modulus 2.78 was used. The specific gravity was found to be 2.80. The particle size distribution is plotted as shown in Figure 3.1. The gradation of sand used, is within limits specified in ASTM C 157/157M. And it's suitable for concrete works. Particle size curve (RS), the sample was transported to the concrete laboratory of the department of civil engineering Federal polytechnic Bida, Niger state. Preliminary analysis was carried out to ascertain its suitability for making concrete cubes.

3.1.2 Coarse material

The coarse aggregates used for this study were obtained from quarry site in Muko village along Bwari Area council in Abuja. It is literally ay particle greater than 0.19 in but generally range between 3/8 and 1.5 in in diameter.

3.1.3 Iron ore tailings

The iron ore tailings were obtained from Itakpe iron ore mill in Itakpe, Kogi State. The the crude sample of Itakpe Iron Ore dumped tailings is a haematite rich mineral and has been found to be coarsely packed and interlocked with magnetite and silica with silica as major impurity

3.1.4 Water

The source of water was from the underground water using borehole to pump it into the over-head tank and supplied to the laboratory in Federal polytechnic Bida. The water is portable and clean. It therefore satisfies the require specification in (BSI 812, 1975) required for making concretes.

3.1.5 Cement

The cement employed for this study is the Dangote cement. The cement is found easily and abundantly in most cement stores in Nigeria. It is an Ordinary Portland cement conforming to ASTM C 157/157M specification.

3.2 Methods

3.2.1 Particle size analysis

This test was conducted according to (BSI 1377, 1990) seven sieves were used and these are sieves sizes 5.00mm. 2.36mm, 1.18mm, 600um, 150um, 75um and the bottom pan. An electronic balance accurate to 0.01g was employed (BSI 1881, 1993).

The sieve sets were meshed with wire after thorough cleansing using iron brush to remove particles that are stock in them. The empty sieves were weighed with electronic balance and recorded. The sieves were stalked in descending order of their weight. About 1000 g of the air dried samples was poured through the top sieve and shaken thoroughly so that materials finer than 5.00mm can pass through and weight of the sieve and particles retained was weighed and these process was repeated for the successive sieves sizes up to the last sieve. This test was also done for the iron ore tailings. The expressions in equation 3.1 to 3.5 is presented in chapter 4.

$$Percentage\ Retained = \frac{Mass\ Retained}{Total\ Mass\ of\ Sample} \tag{3.1}$$

$$Percentage\ Passing = 100 - CummulativePercentage\ Retained \tag{3.2}$$

$$Finness\ modulus(F_m) = \frac{\sum CummulativePercentage\ Retained}{100} \tag{3.3}$$

$$Uniformity\ coeficient(C_u) = \frac{D_{60}}{D_{10}} \tag{3.4}$$

$$Coeficient\ of\ concavity(C_c) = \left(\frac{D_{30}^2}{D_{10} \times D_{60}}\right) \tag{3.5}$$

3.2.2 Specific gravity test

Laboratory test of specific gravity was carried on the IOT and the sand according to BS (BSI 1377, 1990). The gas jar (1 litre in capacity) was fitted with rubber bung, a ground glass plate and water sprayer. The gas jar was dried and weight to the nearest 0.2 g (m_1). About 200 g of the air-dried OIT or soil sample was introduced into the gas jar. The gas jar, ground glass plate and content were weighed to the nearest 0.2 g (m_2). About 500 g of water was added to OIT or soil sample and the rubber stopper was inserted into the gas jar and immediately the gas jar was shaken by hand until the particles were in suspension.

The stopper was removed carefully and any soil or OIT adhered to the stopper or tp of the jar was carefully washed into the gas jar. The fort formed was dispersed with fine spray of water. Water was added to the gas jar within 2 mm of the top. The IOT or soil was allowed to settle for few minutes then the gas jar was filled to brim with more water. The ground glass plate was then placed on the top of the jar and they were carefully dried on the outside and whole weighed to nearest 0.2 g (m_3).

The gas jar was emptied, washed out thoroughly and filled to the brim with water. The gas jar plate was dried carefully on the outside and the whole weighed to nearest 0.2 g (m_4). The procedure was repeated for Gravel to obtain their average. The specific gravity is thus calculated using this formula:

$$Gs = \frac{m2 - m1}{(m4 - m1) - (m3 - m2)} \qquad (3.5)$$

Where;

M_1 = Mass of gas jar and plate

M_2 = Mass of gas jar and plate, and material

M_3 = Mass of gas jar and plate, material and water

M_4 = Mass of gas jar, plate, and water

3.2.3 Bulk density test

Bulk density test was carried out on Gravel according to BS 812 recognizes two degree of compaction BS (BSI 812, 1975), the loose (un-compacted) and compacted. The test was carried out in a metallic cylinder of 1 litre capacity. The cylinder mould was initially weighed (W1). For the un-compacted bulk density test, the IOT or sand was gently placed in the cylindrical mould so that it over flow and then leveled by rolling a rod across the top. This was weighed (W2) and bulk density was calculated.

For the compacted bulk density, the container was filled in three stages each time the volume was tamped 35 times with rod. After the mould was completely filled and compacted, the weight of the mould and content was noted as (W2) and the compacted bulk density for Gravel were calculated accordingly. Two tests were carried out in each case. The bulk density was calculated using this formula:

$$\text{Bulk density} = \frac{Weight of material\ (loose or compacted}{Volume of cylinder} \qquad (3.6)$$

3.2.4 Mix design of concrete

Mix design was carried out to select the most suitable materials combination of IOT, sand, coarse, cement and water that will produce concrete cubes of 3375mm^3. For the purpose of this study 90 cubes were cast using a DOE method of mix design as earlier stated, at different replacement levels of fine with IOT. For each replacement 15 cubes were cast. The replacement levels are shown in the table below.

Table 3.1: Mix proportion of concrete mixes incorporating iron ore tailings

Constituents	K0(kg/m^3)	k 10(kg/m^3)	K 20(kg/m^3)	K30(kg/m^3)	K40 (kg/m^3)
PLC	396.2	396.2	396.2	396.2	396.2
Coarse aggregate	1009	1009	1009	1009	1009
Natural sand	645.3	580.8	516.2	451.7	387.2
Iron ore tailings	0	64.5	129.1	193.6	258.1
Water	210	210	210	210	210

3.2.5 Slump test, compacting factor test and sample production

From the concrete mix design adopted, weight method of batching was used by weighing the required quantity of cement and IOT needed for the respective percentage replacements of IOT with cement then water was measured based on the specified water cement raio.Also sand and gravel need was measured and the constituent was mix thoroughly to uniform paste and workable consistencies.Then a standard truncated slump cone of bottom diameter 200mm,top diameter 100mm and height of 300mm was used to carry out slump test for the concrete mix for two consective trial,by compacting concrete mixed into the slump corn in three layer using a tamping rod 600mm long and 16mm diameter. The cone was removed gently and placed upside down beside the concrete and slump measured using metre rule. Also compacting factor test was carried out using a cylinder 300mm high and 150mm diameter by allowing concrete to fall from the compacting factor machine into the cylinder and weighed, also another trial was compacted into the cylinder using the tamping rod and weighed. Finally the mixed concrete was compacted into a 150 × 150 × 150mm cube mould in three layer at 25 blows per layer using the tamping rod,allowing the concrete to hardern for 24 hours,after which the cube was demoulded and submerged into a water tank of 2400mm long, 1200mm wide and 800mm deep.

$$Compacting\ Factor = \frac{Weight\ of\ Partialy\ Compacted\ Concrete}{Weight\ of\ Fully\ Compacted\ Concrete} \quad (3.7)$$

$$Density = \frac{Mass\ of\ cube}{Volume\ of\ cube} \quad (3.8)$$

3.2.6 Water absorption

Water absorption Test (BS 1881, Method for determination of water absorption part, (BSI 1881, 1983)

Three specimens were obtained by coring from the full thickness of the concrete when this was between 32 mm and 150 mm, or by obtaining a core 75 mm long when the thickness of the specimen is greater than 150 mm. The diameter of each core was 75 mm. The cores were drilled perpendicular to the surface and in such a manner as not to damage the core. Each core was marked clearly with its identification mark immediately after cutting, and the orientation of the core was recorded.

The three specimens were then placed in the well ventilated drying oven so that each one is not less than 25 mm from any heating surface or from each other. The specimens were oven dried for 72 hours. It was ensured that the specimens were not placed in the same oven during the drying process to allow free access of air to all surfaces of the specimens. On removal from the oven, each specimen was cooled for 24 hours in the dry airtight desiIOTtors. Each specimen were weighed and immediately completely immersed in the tank, with its longitudinal axis horizontal and at a depth such that there is 25mm of water over the top of the specimen. The specimens were left immersed in the water for 30 min. Each specimen was removed, shaken to remove the bulk of the water and dried with a cloth as rapidly as possible until all free water was removed from the surface. Each specimen was weighed.

$$water\ Absorption = \left(\frac{Ww - Wd}{Wd}\right) \text{x } 100 \qquad (3.9)$$

Where;

Ww = wieght of wet sample, Wd= weight of oven dried sample.

3.2.8 Compressive strength test

The compressive strength of the cubes was determined in accordance with the standard procedures given in (BSI 2028, 1970; BSI 1881-122, 1983). The weight of the samples was always taken before the compressive strength test was carried out. Three sample cubes were crushed for 3, 7, 14, 21 and 28 days after casting at different replacement level using compressive strength test machine in the concrete laboratory of the department of civil engineering, Federal polytechnic Bida, Niger state. Each specimen was placed centrally on the machine and soft boards were placed beneath and above it in such a way that it is in line with the center of the platens of the machine. The soft board takes care of any dimensional defects and gives a leveled crushing surface. It distributes the load uniformly over the cubes beds. It was ensured that the machines dial pointer was at zero at the commencement of the crushing test. With the cubes sample in position the load was applied and increased continually until failure occurred. The maximum load carried by the specimen before failure was recorded. The maximum load divided by the net area of the specimen gives the compressive strength of the cubes.

$$Comperessive\ Strenght = \frac{Crushing\ Load}{Surface\ Area\ of\ Cube} \tag{3.10}$$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Chemical Composition of IOT

Table 4.1 shows the chemical composition of Itakpe IOT and the total percentage of Silicon dioxide (SiO_2) was 69.80% and Aluminum Oxide (Al_2O_3) was 2.71%, Iron Oxide (Fe_2O_3) was 47.5%. This value is within the minimum requirement for additives for concreting (ASTM C157/C15). This value is closer to the values obtained by Ugama *et al.*, (2014) for IOT usage in concreting.

Table 4.1: Chemical Composition of Itakpe Iron Ore Mine Tailings

SN	Components	Values (%)
	SiO_2	69.80
	Al_2O_3	2.71
	Fe_2O_3	47.50
	TiO_2	0.18
	CaO	1.30
	MgO	0.29
	P	0.07
	S	0.08
	Total Alkali ($Na_2O + K_2O$)	1.25

4.2 Particle Size Analysis

Figure 4.1 and 4.2 shows the result of the particle size analysis performed on Gravel sample. The result obtained complies with the grading limit of zone 1 as given in (BSI 1881-103, 1983). The curve obtained is similar to what was obtained by Bamigboye *et al.*, (2015) and therefore the soil sample and IOT are suitable for construction work.

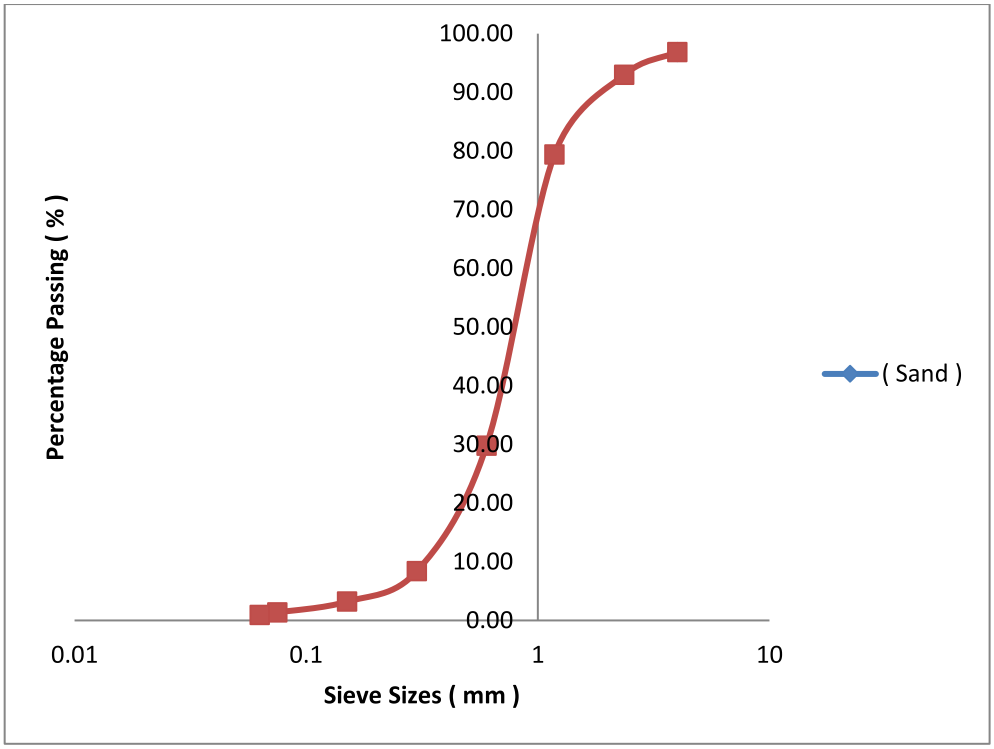

Figure 4.1: Particle Size Curve of Sand

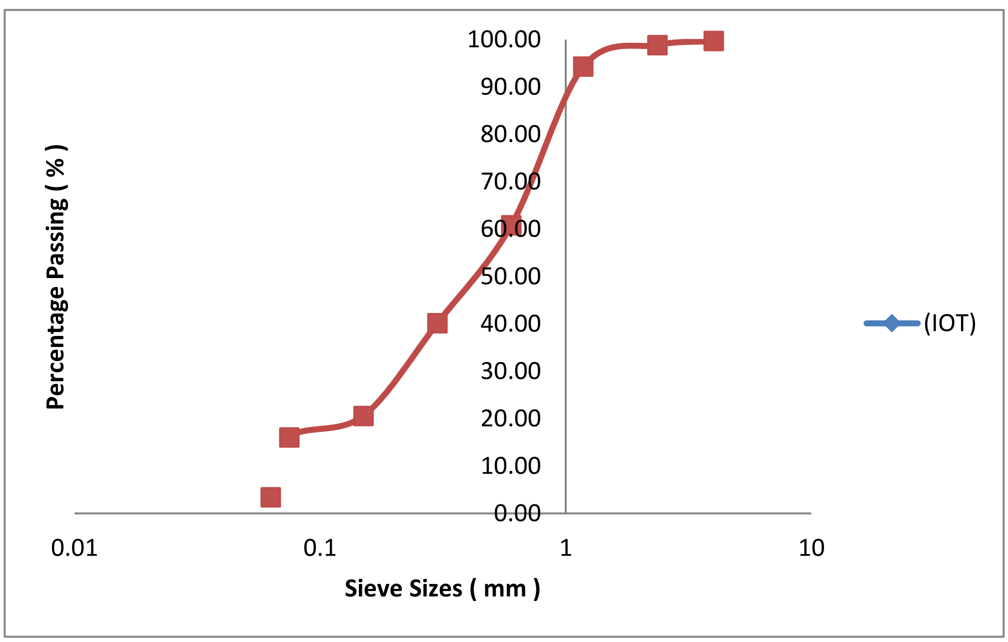

Figure 4.2: Particle Size Curve of IOT

4.3 Specific Gravity

Table 4.2 shows the specific gravity test of the sand and IOT. The specific gravity of IOT was found to be 3.14 this value is close to what was obtained by Ugama *et al.*, (2014), who obtained 2.85 for IOT, however the value of specific gravity is less than the value of cement, which is 3.15. Further, the specific gravity of sand was found to be 2.68. The value obtained falls within the limit for natural aggregates with value of specific gravity between 2.6 and 2.7 as reported by Abdullahi (2017).

Table 4.2: Specific Gravity of Gravel

		Sand		**IOT**	
		Test 1	**Test 2**	**Test 1**	**Test 2**
Mass of gas, jar, plate, soil and water (m_3)	g	387.6	426.0	570.3	600
Mass of gas, jar, plate and soil (m_2)	g	142.6	184.7	126.1	152.9
Mass of gas, jar, plate and water (m_4)	g	359.2	389.7	553.2	581.3
Mass of gas, jar and plate (m_1)	g	97.4	126.7	100.9	125.6
(m_2-m_1)	g	45.2	58.0	25.2	27.3
(m_4-m_1)	g	261.8	263.0	452.3	455.7
(m_3-m_2)	g	245.0	241.3	444.3	447.1
(m_4-m_1) - (m_3-m_2)	g	16.8	21.7	8.1	8.6
$Gs = \frac{(m2-m1)}{(m4-m1)-(m3-m2)}$		2.69	2.67	3.11	3.17
Mean specific gravity		2.68		3.14	

4.4 Slump and Compacting Factor Test

Table 4.3 shows the results of the slump test. The test reveals that the mix with 40 % of IOT content requires greater water content to achieve a reasonable workability. It is observed that concrete workability reduced with increase in the percentage of IOT in the mix. This may be due to the fineness and therefore large surface area of the IOT which resulted in the need for large amount of water necessary to wet all the particles in the mix, this trend was similarly visible in Ugama *et al.,* (2014).

Table 4.3: Slump and Compacting Factor Test

Percentage Replacement of IOT	Slump (mm)	Compacting factor
0	60	0.83
10	52	0.85
20	48	0.87
30	42	0.90
40	40	0.91

4.5 Bulk Density of Gravel

Table 4.4 shows the result of the un-compacted and compacted bulk density for Gravel. The compacted and un-compacted bulk densities for gravel are 1656 kg/m^3 and 1472kg/m^3 Ugama *et al.,* (2014) obtained the compacted bulk density of 1352 kg/m^3 which is less than the value obtained. The test result indicates that Gravel is not a lightweight material. Bulk density depends on how densely the particles are packed.

Table 4.4: Bulk Densities of Gravel

Compacted Bulk Density		**Gravel**	
		Test 1	Test 2
Wt of empty cylinder (w1) kg		1071	1071
Wt of empty cylinder + Wt of loose materials (w2)kg		3836	3879
Wt of loose materials (w3)	kg	2765	2808
Vol. of empty cylinder (v)	cm^3	1683	1683
Uncompacted bulk density	$\frac{w3}{v}$ kg/m^3	1643	1668
Mean bulk density	kg/m^3	**1656**	
Uncompacted Bulk Density		**Gravel**	
		Test 1	Test 2
Wt of empty cylinder (w1)	kg	1071	1071
Wt of empty cylinder + Wt of loose materials (w2)	kg	3537	3559
Wt of loose materials (w3)	kg	2466	2488
Vol. of empty cylinder (v)	cm^3	1683	1683
Compacted bulk density	$\frac{w3}{v}$ kg/m^3	1465	1478
Mean bulk density	kg/m^3	**1472**	

4.6 Compressive Strength

The variation in of the compressive strength with age at curing are presented in Table 4.4 and supplementary tables in the appendix, similar the graphs depicting the information are also in Figures 4.3, 4.4 and 4.5, which could be observed that the compressive strength generally increased with age at curing. However, the incremental rate is smaller at 40% of the IOT while the optimum replacement was at about 30% IOT. This finding is not too far from Ugama *et al*., (2014) who found that tested specimens and load cases for different percentages of iron ore tailing (IOT) showed increases in load bearing capacities as curing age increased. Also, with increase in content of iron ore tailing (IOT), however compressive strengths of specimens reduced almost linearly. The 28-day test cylinders had an average compressive strength of 4.367 KN/mm^2 for concrete with 20% IOT, but less than the compressive strength of the control concrete of 4.502KN/mm^2. However, in the case of this study at 30% of IOT which is optimum replacement level the compressive strength at the 28 days was 49.6 N/mm^2which was higher than the control mix with 0% IOT at 28 days strength of 45.7 N/mm^2. This implies that the replacement of fine aggregates with IOT for this study could be up to 30% for greater strength. However, replacement up to 40% (46.8 N/mm^2) is also feasible since the strength at 28 days exhibited is still greater than the control strength.

Table 4.6: Compressive Strength Result

	COMPRESSIVE STRENGTH (N/mm^2)				
	3 days	7 days	14 days	21 days	28 days
0% IOT and 100% sand	12.5	21.1	32.1	39.8	45.7
10% IOT and 90% sand	12.7	21.4	32.6	40.6	46.5
20%IOT and 80% sand	13.3	22.1	35.5	41.6	47.7
30%IOT and 70% sand	13.8	22.9	34.7	43.2	49.6
40% IOT and 60% sand	12.8	21.8	32.9	40.8	46.8

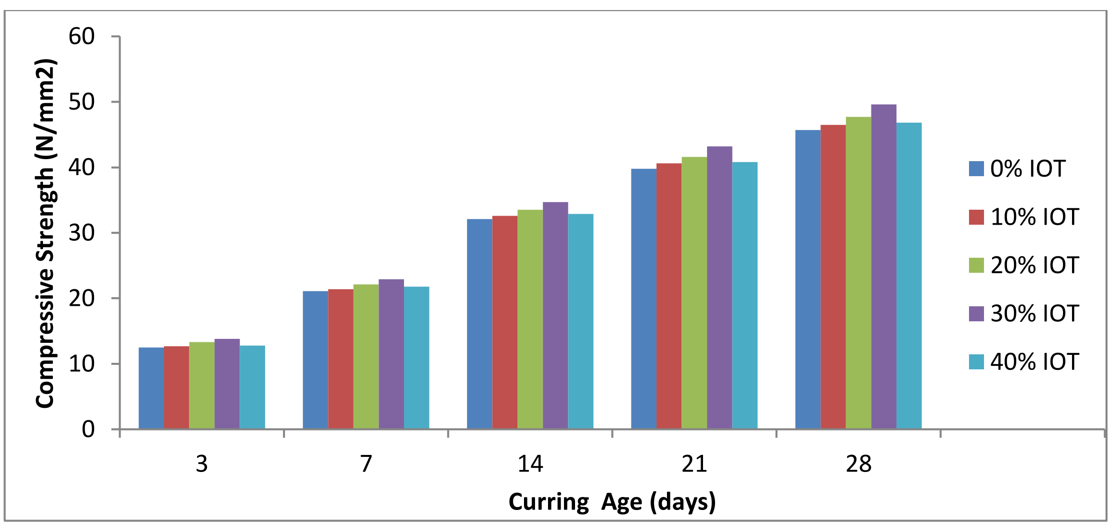

Figure 4.3: Variation in of the compressive strength with curing age

4.6 Compressive Strength at 28 Days

The effect of IOT content on the water absorption of specimens at 28 days is presented in Figure 4.4 Obviously; all of the IOT specimens absorb less water than K0. A decrease in water absorption is observed with increasing the IOT substitution for 28 days curing age. The values for 10 %, 20 %, 30 % and 40 % replacement are 13.33 %, 24.7 %, 41 %, and 51.4 % at 28 days, respectively. The above results show that water absorption decreases with increasing IOT content, thus making the specimen highly impermeable. The hydration products increase and some fine IOT particles fill the macro pores and micro pores in the concrete (Zhang *et al.*, 2020). Therefore, IOT have a positive effect on impermeability. Tan *et al.*, (2020) also found that low water adsorption had a positive impact on concrete durability. Due to the large amount of cement used in the preparation of specimens, a large number of cement particles will not participate in the hydration, and there will be gaps between these non-hydrated cement particles and the hydration products, which is detrimental to the development of strength. However, for the water absorption test, the decrease in water absorption is mainly due to the gradual densification of internal structure. On the one hand, the hydration products increase with the increase of curing age. Besides, the increasing amount of iron ore tailings replacement fills the internal pores in specimens.

Table 4.5: Compressive Strength Result at 28 Days

Type of specimen	28 days Compressive strength of concrete mixes (N/mm^2)
K0	45.8
K10	46.5
K20	47.8
K30	49.6
K40	46.8

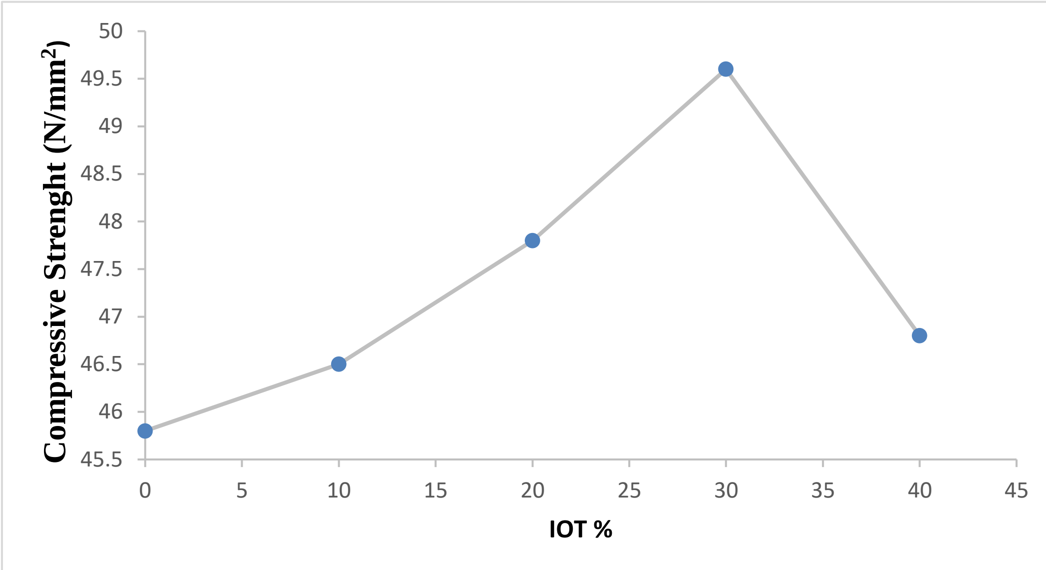

Figure 4.4: 28 Days Compressive Strength against Percentage Replacements

4.7 Water Absorption Result

The effect of IOT content on the water absorption of specimens at 28 days is presented in Figure 4.4 Obviously; all of the IOT specimens absorb less water than K0. A decrease in water absorption is observed with increasing the IOT substitution for 28 days curing age. The values for 10%, 20%, 30% and 40% replacement are 13.33%, 24.7%, 41%, and 51.4% at 28 days, respectively. The above results show that water absorption decreases with increasing IOT content, thus making the specimen highly impermeable. The hydration products increase and some fine IOT particles fill the macro pores and micro pores in the concrete (Zhang *et al.*, 2020). Therefore, IOT have a positive effect on impermeability. Tan *et al.*, (2020) also found that low water adsorption had a positive impact on concrete durability. Due to the large amount of cement used in the preparation of specimens, a large number of cement particles will not participate in the hydration, and there will be gaps between these non-hydrated cement particles and the hydration products, which is detrimental to the development of strength. However, for the water absorption test, the decrease in water absorption is mainly due to the gradual densification of internal structure. On the one hand, the hydration products increase with the increase of curing age. Besides, the increasing amount of iron ore tailings replacement fills the internal pores in specimens.

Table 4.6: Water Absorption Result at 28 Days

Percentage replacement of IOT	**28 days water absorption of concrete (%)**
0	1.05
10	0.91
20	0.79
30	0.62
40	0.51

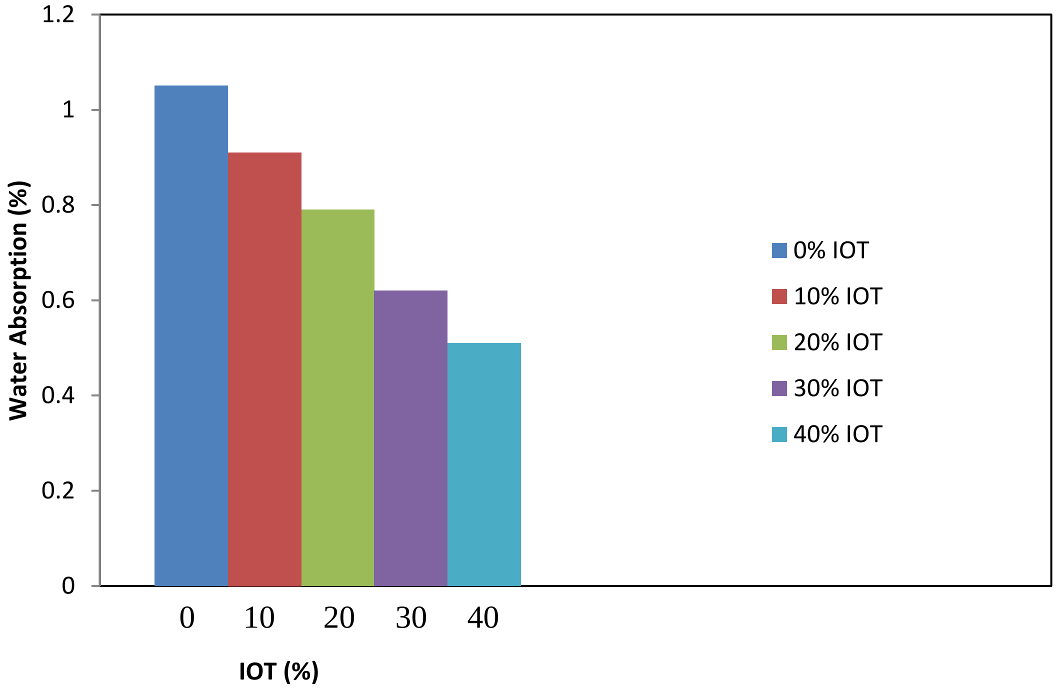

Figure 4.5: 28 Days Water Absorption

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In line with the aim of this study which is to "determine the effect of partial replacement of Iron Ore Taillings (IOT) with fine aggregates on the compressive strength and water absorption of concrete" and other specific objectives that are involved in this study, this study comes up with the following submission:

Iron Ore Tailings used for this study have acceptable physical properties such well graded particle size distribution, Bulk density and specific gravity that are in compliance with international specifications such as (BSI 1881, 1993) and ASTMC157/C157M that guides such requirements for fine aggregates.

The fresh concrete mix with 40 % of IOT content requires greater water content to achieve a reasonable workability which implies that as the IOT content is increased the concrete become less workable and as such requires more water for workability.

The bulk density both compacted and uncompacted shows that both IOT are heavy weight materials.

The replacement of fine aggregates with IOT could be up to 32.5% for greater strength. However, replacement up to 40% (46.8 N/mm^2) is also feasible since the strength at 28 days exhibited is still greater than the control strength. The compressive strength generally increased with age at curing.

Water absorption results show that water absorption decreases with increasing IOT content, thus making the specimen highly impermeable.

5.2 Recommendations

The following recommendations are made for further research;

i. The percentage replacement of IOT should be beyond 40% with a replacement interval of not less than 5% in order to outline the gradual increase in the strength

ii. Water absorption should be carried out at age interval of 3, 7, 14 and 28 days. In order to show the progressive changes in the water absorption properties of the resulting concrete.

iii. Subsequent research to utilize the usage of software in carrying out mixed design using DOE method where every parameter will be properly utilized.

5.3 Contribution to knowledge

Waste management and recycling are some of the core principles in engineering, utilizing materials that could constitute to environmental hazard is paramount in civil engineering. Discharge of iron ore tailing in mining site are some of environmental problems associated with mining sites. The study to examine effect of iron ore tailings on compressive strength and water absorption of concrete however, the research reveals that compressive strength of 49.6N/mm2 at 30% of the IOT replacement for river sand was quite satisfactory and Water absorption on the other hand decreases as the IOT percentage increases from 1.05% to 0.51%.

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Appendix

Table 1: 3 Days Compressive Strength at Various Percentage Replacement

Age									**3days**							
%repl	A	V	Weight (g)			Unit weight (g/cm3)			Avrg (g/cm3)	Crushing load (kN)			strenght (N/mm2)			Avrg (N/mm2)
0%	225	3375	8450	7900	8050	2.5	2.3	2.39	2.41	280	285	278	1.2	1.27	1.24	12.36
10%	225	3375	8400	8550	8600	2.49	2.5	2.55	2.52	285	290	280	1.3	1.29	1.24	12.44
20%	225	3375	8700	8950	8400	2.58	2.7	2.49	2.57	295	300	305	1.3	1.33	1.36	13.56
30%	225	3375	8800	8900	9050	2.61	2.6	2.68	2.64	315	310	305	1.4	1.38	1.36	13.56
40%	225	3375	8500	8400	8700	2.52	2.5	2.58	2.53	282	295	285	1.3	1.31	1.27	12.67

Table 2: 7 Days Compressive Strength at Various Percentage Replacement

Age									**7days**							
%repl	A	V	Weight (g)			Unit weight (g/cm^3)			Avrg (g/cm^3)	Crushing load (kN)			strenght (N/mm^2)			Avrg (N/mm^2)
0%	225	3375	8200	8350	8580	2.43	2.5	2.54	2.48	475	478	473	2.1	2.12	2.1	21.02
10%	225	3375	9000	8400	8350	2.67	2.5	2.47	2.54	479	483	485	2.1	2.15	2.16	21.56
20%	225	3375	8400	8900	8600	2.49	2.6	2.55	2.56	495	505	490	2.2	2.24	2.18	21.78
30%	225	3375	9000	8950	9200	2.67	2.7	2.73	2.68	510	515	520	2.3	2.29	2.31	23.11
40%	225	3375	9100	8200	8350	2.7	2.4	2.47	2.53	495	485	490	2.2	2.16	2.18	21.78

Table 3: 14 Days Compressive Strength at Various Percentage Replacement

Age									14days							
%repl	A	V	Weight (g)			Unit weight (g/cm^3)			Avrg (g/cm^3)	Crushing load (kN)			strenght (N/mm^2)			Avrg (N/mm^2)
0%	225	3375	8400	8450	8350	2.49	2.5	2.47	2.49	725	722	720	3.2	3.21	3.2	32.00
10%	225	3375	8650	8400	8500	2.56	2.5	2.52	2.52	738	730	735	3.3	3.24	3.27	32.67
20%	225	3375	8700	8550	8600	2.58	2.5	2.55	2.55	760	754	750	3.4	3.35	3.33	33.33
30%	225	3375	8800	8750	8700	2.61	2.6	2.58	2.59	780	785	775	3.5	3.49	3.44	34.44
40%	225	3375	8550	8600	8450	2.53	2.5	2.5	2.53	740	735	743	3.3	3.27	3.3	33.02

Table 4: 21 Days Compressive Strength at Various Percentage Replacement

Age									21days							
%repl	A	V	Weight (g)			Unit weight (g/cm3)			Avrg (g/cm3)	Crushing load (kN)			strenght (N/mm2)			Avrg (N/mm2)
0%	225	3375	8450	8000	8050	2.5	2.4	2.39	2.42	895	900	890	4	4	3.96	39.56
10%	225	3375	8900	8400	8350	2.64	2.5	2.47	2.53	918	910	915	4.1	4.04	4.07	40.67
20%	225	3375	8600	8550	8800	2.55	2.5	2.61	2.56	940	930	935	4.2	4.13	4.16	41.56
30%	225	3375	8800	8650	9050	2.61	2.6	2.68	2.62	970	972	975	4.3	4.32	4.33	43.33
40%	225	3375	8700	8550	8100	2.58	2.5	2.4	2.50	920	910	923	4.1	4.04	4.1	41.02

Table 5: 28 Days Compressive Strength at Various Percentage Replacement

Age									**28days**						
%repl	A	V	Weight (g)			Unit weight (g/cm3)			Avrg (g/cm3)	Crushing load (kN)			strenght (N/mm2)		Avrg (N/mm2)
0%	225	3375	8450	8100	8050	2.5	2.4	2.39	2.43	1030	1028	1025	4.6	4.57	4.56	45.56
10%	225	3375	8400	8550	8600	2.49	2.5	2.55	2.52	1048	1043	1045	4.7	4.64	4.64	46.44
20%	225	3375	8850	8500	8700	2.62	2.5	2.58	2.57	1078	1070	1075	4.8	4.76	4.78	47.78
30%	225	3375	8900	9100	9050	2.64	2.7	2.68	2.67	1110	1120	1115	4.9	4.98	4.96	49.56
40%	225	3375	9050	8500	8200	2.68	2.5	2.43	2.54	1050	1057	1055	4.7	4.7	4.69	46.89