VARIATION IN THE STRENGTH PROPERTIES OF CONCRETE USING WASTE GLASS AS PARTIAL REPLACEMENT FOR DIFFERENT COARSE AGGREGATES GRADING

BY

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ABSTRACT

The Reuse of waste glass in concrete production is among the attractive option of achieving waste reduction and preserving the natural resources from further depletion thereby protecting the environment and achieving sustainability. This present study examined the variation in the strength properties of concrete using waste glass aggregate (WGA) as partial replacement for different coarse aggregates grading. 20mm and =(25mm coarse aggregates were partially replaced with WGA of respective sizes in different percentages of 0%, 10%, 20% and 30%. Physical properties such as specific gravity, bulk density, slump, and workability of fresh concrete and strength properties such as compressive strength and tensile strength of hardened concrete of grade M25, mix ratio 1:1:2 were tested after 7, 14, 28, 56 and 90 days. The results of the physical properties revealed that the WGA exhibited lower specific gravity value of 2.70, bulk density of 1364kg/m^3, moisture content of 0% as compared to granite of specific gravity value of 2.74, bulk density 1660kg/m^3, and moisture content of 0.01%. The compressive strength results of both 20mm and 25mm WGA increases as the curing age of the concrete increases progressively from 7days up to 90days. At 7 and 90 days the compressive strength results of 20mm aggregate of the control mix concrete were 30.05N/mm^2 and 42.60N/mm^2 respectively while that of 20mm 30% WGA partial replacement were 32.14N/mm^2 and 45.70N/mm^2 respectively, and for 25mm aggregate control mix concrete were 29.74N/mm^2 and 49.80N/mm^2 respectively, while that of 25mm, 30% WGA partial replacement were 28.71N/mm^2 and 45.50 N/mm^2 respectively. The tensile strength for all the ages reached optimum value at 10% partial replacement WGA for both 20mm and 25mm. At 28days, the tensile strength result of 20mm aggregate of the control mix concrete was 2.86N/mm^2, while 20mm 10% WGA replacement was 2.90N/mm^2, and for 25mm aggregate control mix concrete, tensile strength result was 3.11N/mm^2 while that of 25mm WGA 2.55N/mm^2. The results of the strength properties showed that the concrete grade M25 adopted was suitable for the WGA partial replacement as the compressive strength results for all ages did not fall below 25N/mm^2.

DEDICATION

This project is dedicated to God Almighty, who has been my source of strength and from who all knowledge comes from. And also to my family who has been supportive in all my chosen endeavors.

DECLARATION

This project is a result of my work and has not been copied in part or whole from any other source except where duly acknowledged. As such, all use of previously published work from books, journal, magazines, internet and so on has been acknowledged within the main report to an entry in the reference list.

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CERTIFICATION

This is to certify that this proposal was written by OPASINA COLLINS AYOMIDE (CVE/13/1066) under my supervision and is approved for its contribution to knowledge and literary presentation. All sources of information are specifically acknowledged by means of references, in partial requirements for the award of Bachelor of Engineering (B.Eng.) degree in Civil Engineering, Federal University Oye Ekiti.

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LIST OF ABBREVIATIONS

AAV	Aggregate Abrasion Value
ASTM	American Society for Testing Materials
BS	British Standard
I.S	Indian Standard
LWC	Light Weight Concrete
OPC	Ordinary Portland Cement
RGA	recycled glass aggregate
WC	Water Content
W/C	Water Cement ratio
WGA	waste glass aggregate

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CHAPTER ONE

1.0 INTRODUCTION

1.1 General Background

1.1.1 Concrete and Waste Glass

Concrete is a composite inert material comprising of binder (cement), mineral filler (body) or aggregate and water. It is the name given to a mixture of particles of stone bound together with cement. Because the major constituent of concrete is of particles of broken stones usually gravel, and sand, which is termed the aggregate usually occupying 60-70% of the total volume of concrete. The material which binds the aggregate is the cement. Portland cement was developed in 1824 and derives its name from Portland limestone in Dorset because of its resemblance to this rock. Raw materials used in Portland cement are Calcium carbonate ($CaCO_3$), Silica Alumina and Iron Oxide (clay or shale), and mart (Jackson and Dhir,1988). The great demand of concrete is due to its structural strength and stability and also its favorable properties as a structural material, among which are its high compressive strength and its property as a fire-resistant element to a considerable extent.

Glass on the other hand is a hard, usually transparent substance formed by melting and cooling without crystallizing (Encarta Dictionaries). The usage of glass cannot be overemphasized as it is used in buildings, dishes and other domestic wares; by the construction industry in the shape of windows and mirrors; by the medical industry in the making of medical equipment and most importantly by the food and beverage industry to make millions of packaging bottles. As usage the of glass increases, so does the amount of waste glass generated. Although, used glass can be recycled but it involves a lot of energy in doing so and this calls for disposal into landfills thereby constituting environmental pollution. Previous researches have shown that glass could serve as alternative material in place of conventional material (granite) in the production of concrete if properly cleaned, crushed and screened. The relative abundance of glass readily makes it available for use and consequently reduces the cost of producing concrete.

Weihua *et al.,* (2000) suggested that the use of crushed waste glass as an aggregate in concrete has several advantages in terms of strength. The relative abundance of glass makes it available for production of concrete; this will consequently lead to low cost of production thereby making concrete structures (buildings) relatively cheap. On this note, the percentage of glass in concrete should not be much. Previous research has shown that Ground waste glass was used as aggregate for mortars and no reaction was detected with fine particle size, thus indicating the feasibility of the waste glass reuse as aggregate in mortars and concrete. Estimated cost for building is more and some construction materials like natural aggregates are also becoming rare, as a result becoming expensive. Therefore waste glass becomes the ingredient in achieving an economic construction and also ensuring sustainability of the fast depleting natural forms of aggregate

1.2 Constituents of Concrete

The major constituents of concrete are

1. Water
2. Cement
3. Aggregate
4. Admixtures (for special uses)

1.2.1 Water

Water is one of the most important elements in concrete production. Water is needed to begin the hydration process by reacting with the cement to produce concrete. There has to be a sufficient amount of water available so that the reaction can take its full course but if too much water is added, this will in fact be a decrease in the strength of the concrete. The water-cement ratio is an important concept because other than the recipe for the concrete mix, the amount of water used would also determine its final strength. On the other hand if too little water were added, there would not be enough water available to finish the reaction, thus some of the cement would harden and bond with other dry cement shorting the hydration process.

1.2.2 Cement

Cement acts as "glue" that binds the concrete ingredients together and is very important for the strength of the composite. There are many different kinds of cements. But the most commonly used is Portland cement. Portland cement is an hydraulic cement which sets and hardens by chemical reaction with water and is capable of doing so under water. Water is the element that is used to begin the hydration reaction where cement reacts with the water to produce a rock like substance. The reaction is also exothermic, where heat is released in the chemical reactions. This is an important fact because in very large structure like concrete dams, the heat released can pose a potential problem.

When the chemical reaction has reached the end, the initial cement past is transformed into a substance, which has tremendous strength. But using too much cement in concrete is expensive, and thus aggregates would take the place of cement without reducing its strength and reduce the cost.

1.2.3 Aggregates

The aggregates used in concrete are of two categories which are coarse and fine aggregates. Coarse aggregates in general are larger than 2 mm in diameter and fine aggregates are defined to be smaller than 2 mm. Aggregates that are used in concrete have to pass the standards set in ASTM. The economics part of concrete is to use as little cement as possible and still obtain the required strength. Thus, when concrete is formed, the coarse aggregates with its large volume would make up a large portion of the concrete. The fine aggregates would fill in the voids created form the coarse aggregate and reduce the amount of cement required. Plate 1.1 showed categories of aggregates that exists.

Plate 1.1: Different types of aggregates

1.3 Concrete Production Process

1.3.1 Mixing

The cement is mixed with the other ingredients: aggregates (sand, gravel, or crushed stone), admixtures, fibers, and water. Aggregates are pre-blended or added at the ready-mix concrete plant under normal operating conditions. The mixing operation uses rotation or stirring to coat the surface of the aggregate with cement paste and to blend the other ingredients uniformly. A variety of batch or continuous mixers are used. It is also mixed in a variety of mix ratio depending on the use. For the purpose of this project, the mix ratios adopted is 1:1:2 (1 is cement ratio; 1 is fine aggregate ratio; 2 is coarse aggregate ratio).

1.3.2 Transport to Work Site

Once the concrete mixture is ready, it is transported to the work site. There are many methods of transporting concrete, including wheelbarrows, buckets, belt conveyors, special trucks, and pumping. Pumping transports large quantities of concrete over large distances through pipelines using a system consisting of a hopper, a pump, and the pipes.

1.3.3 Placing and Compacting

Once at the site, the concrete must be placed and compacted. These two operations are performed almost simultaneously. Placing must be done so that segregation of the various ingredients is avoided and full compaction with all air bubbles eliminated can be achieved. Whether chutes or buggies are used, position is important in achieving these goals. The rates of placing and of compaction should be equal; the latter is usually accomplished using internal or external vibrators. An internal vibrator uses a poker housing a motor-driven shaft. When the poker is inserted into the concrete, controlled vibration occurs to compact the concrete. External vibrators are used for precast or thin in situ sections having a shape or thickness unsuitable for internal vibrators. These type of vibrators are rigidly clamped to the formwork, which rests on an elastic support. Both the form and the concrete are vibrated. Vibrating tables are also used, where a table produces vertical vibration by using two shafts rotating in opposite directions.

1.3.4 Curing

Once it is placed and compacted, the concrete must be cured before it is finished to make sure that it doesn't dry too quickly. Concrete's strength is influenced by its moisture level during the hardening process: as the cement solidifies, the concrete shrinks. If site constraints prevent the concrete from contracting, tensile stresses will develop, weakening the concrete. To minimize this problem, concrete must be kept damp during the several days it requires to set and harden.

1.4 Aim and objectives

Within the scope of this study, the main aim is to investigate the variation in the compressive strengths of concrete over a range of glass percentage and different grading of coarse aggregates

The objectives are:

i. To provide appropriate solution to problem encountered in waste glass management

ii. To identify the effects of adding waste glass on the fresh properties of concrete

iii. To carry out physical and chemical analysis in order to determine the material to be used for the research

iv. To identify the variation in the strength properties of concrete for different grading of the coarse aggregates

v. To determine the optimum waste glass content to be added as a partial replacement of coarse aggregate.

1.5 Statement Problem

Previous researches have shown that glass could serve as alternative material in place of conventional material (granite) in the production of concrete if properly cleaned, crushed and screened. In order to make concrete industries sustainable, the use of waste material in place of natural resources is one of the best approaches. Waste glass is the least expensive of all concrete constituents and is much less expensive than natural aggregates, because of it availability all over the dumpsites mainly because of its difficulty in being disposed and recycled. In other to mend the bridge between sustainability, proper disposal and cost, the use of waste glass in concrete production becomes a very useful ingredient in achieving this.

1.6 Justification of the project

Waste glass is the least expensive of all concrete constituents and is much less expensive than natural aggregates, thus the idea is to replace as much of the natural aggregates as possible to save money and to reduce the amount of disposable wastes, as well, but care has to be taken in order not to weaken the concrete by adding too much glass.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Aggregates

Aggregates form a very large percentage of concrete works, and they are gotten from different sources through various form of engineering processes over the decades. Aggregates are the important constituent in concrete, they are inert solid bodies such as gravel textured rocks and sand-like materials. Aggregates come in different sizes and textures: coarse, fine or very fine. Most aggregates come from nature: crushed rock or gravel for coarse aggregates; natural sand or finely crushed rocks for fine aggregates. (Concrete Technology 2015)

Aggregates are graded by passing it through a set of sieves with progressively smaller mesh sizes. All material that passes through sieve #4 [0.187 in. (4.75 mm) openings] is conventionally referred to as fine aggregate or sand, while all material that is retained on the #4 sieve is referred to as coarse aggregate, gravel, or stone. The aggregate constitutes typically 70% - 80% of the concrete volume and therefore, its properties largely determine the properties of the concrete. For the concrete to be of good quality, the aggregate has to be strong and durable and free of silts, organic matter, oils, and sugars. Otherwise, it should be washed prior to use, because any of these impurities may slow or prevent the cement from hydrating or reduce the bond between the cement paste and the aggregate particles (Alex, 2015).

It may be mentioned that many properties of aggregates namely, chemical and mineral composition, petro-graphic description, specific gravity, hardness, strength, physical and chemical stability pore structure etc. depend mostly on the quality of the parent rock. But there are some properties possessed by the aggregates which are important so far as concrete making is concerned which have no relation with the parent rock, particularly, the shape and size. While it is to be admitted that good aggregates from good parent rocks can make good concrete, it may be wrong to conclude that good concrete cannot be made from slightly inferior aggregates obtained from not so good parent rocks. Aggregates which are not so good can be used for making satisfactory concrete owing to the fact that coating of cement paste on aggregates bring about improvement in respect of durability and strength characteristics. Therefore selection of aggregates is required to be done judiciously taking the economic factor in consideration. Several factors may be considered in making the final selection of aggregates where more than one source is available (Concrete Technology 2015).

2.2 Classification of Aggregates

Aggregates can be classified in several different ways: whether they are natural or manufactured; whether they are crushed or naturally processed; whether they are inert or reactive; based on their specific gravity; and based on the sizes of their particles. Based on the specific gravities, three categories as normal weight aggregates, lightweight aggregates, and heavyweight aggregates. On the basis of size, one can distinguish between fine aggregates, consisting mostly of small materials passing No. 4 sieve (3/16 in.) and retained on No. 200 sieve and coarse aggregates, mostly consists of large particles retained on the 4.75mm (No.4) sieve (ASTM C125-07, 2007)

2.2.1 Classification of Aggregate According to Sze

Concrete is produced with coarse aggregates that range from 5 mm to 50 mm size with 20 mm being very common. The grading of an aggregate is defined as the frequency of distribution of the particle sizes of a particular aggregate. Particle size distribution significantly affects some properties of concrete like packing density and voids contents. Consequently, the workability, segregation, durability and some other characteristics of concrete are greatly affected (Karthik *et al.*, 2007).

Past researchers have it that uniformly distributed mixtures produce better workability than gap-graded mixtures (Golterman *et al.*, 1997), and is desirable for the efficient utilization of the matrix. Uniformly distributed aggregates lead to higher packing, which result in concrete with higher density and less permeability (Golterman *et al.,* 1997), and improved abrasion resistance (Mehta and Monteiro, 1993).

According to (Quiroga and Fowler, 2004), size distribution divides aggregates in three categories as coarse aggregates, fine aggregates and micro-fines. Excessive coarse aggregate can produce concrete with poor abrasion resistance while excessive sand can produce mixes requiring increased water for effective finishing. Smaller nominal maximum size of aggregate has a larger surface area compared to larger nominal size of aggregates. This results in a high bonding strength at the interface zone around the smaller aggregate particles when concrete is under loading (Neville, 1997).

Yaqub and Bukhari, (2006), studied the effect of size of coarse aggregate on compressive strength of high strength concrete. The study concluded that aggregate sizes of 10mm and 5mm showed higher strength than all other sizes of aggregates.

2.2.2 Classification of Aggregate According To Shape

Shape refers to the geometry of the aggregate. Shape is related to sphericity, form, angularity, and roundness. The shape of aggregate particles influences paste demand, placement characteristics such as workability, strength, void content, packing density and cost. (Rached *et al.,* 2009). From the standpoint of economy in cement requirement for a given Water/cement ratio, rounded aggregates are preferable to angular aggregates. On the other hand, the additional cement required for angular aggregate is offset to some extent by the higher strengths and sometimes by greater durability as a result of the interlocking texture of the hardened concrete and higher bond characteristics between aggregate and cement paste (Concrete Technology, 2015).

Two important aspects of shape which are desirable for concrete production are roundness and sphericity. While the roundness describes the relative sharpness of the edges and corners of a particle (Quiroga and Fowler, 2004), the sphericity measures the ratio of the surface area of the particle to its volume. A broad classification of shapes of coarse and fine aggregates are given in Table 2.1.

Table 2.1: Classification of Particle Shapes of Aggregates Neville and Brooks {2008)

CLASSIFICATION	DESCRIPTION
Rounded	Fully water-worn or completely shaped by wearing
Irregular	Naturally irregular or partly shaped by attrition and having rounded edges
Flacky	Materials of small thickness relative to the other two dimensions
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces
Elongated	Materials in which the length is considerably larger than the other two dimensions
Flaky and Elongated	Materials having the length considerably larger than the width and the width considerably larger than the thickness.

The two comparable charts for visual assessment of particle shape are shown in Figure 2.1, and Figure 2.2

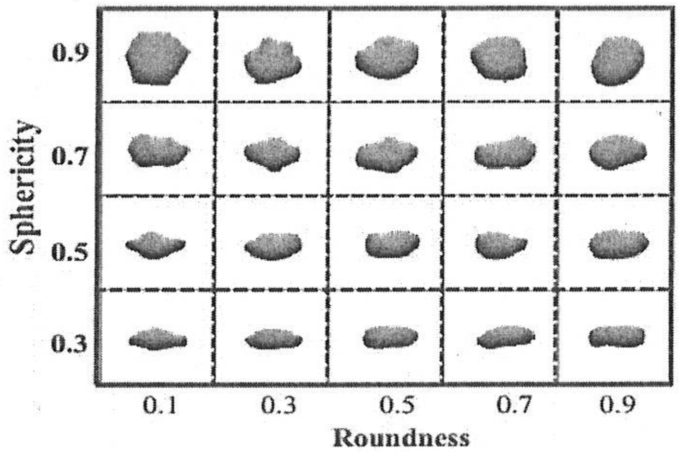

Figure 2.1: Visual assessment of particle shape derived from measurement of sphericity and roundness (Quiroga and Fowler, 2004)

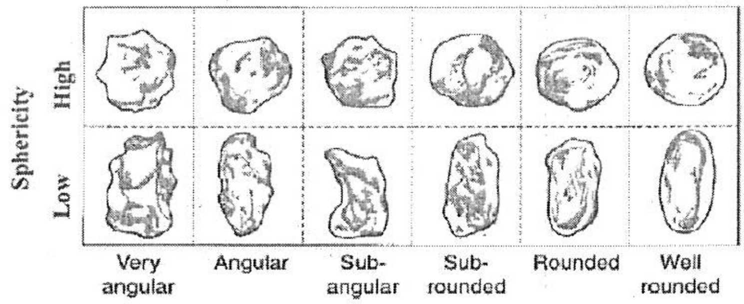

Figure 2.2: Visual assessment of particle shape based on morphological observations (Quiroga and Fowler, 2004)

A lot has been said on whether the angular aggregate or rounded aggregate will make better concrete. Angular aggregate are superior to rounded aggregates from the following two points of view (Concrete Technology, 2015);

i. Angular aggregates exhibit a better interlocking effect in concrete, which property makes it superior in concrete used for roads and pavements.

ii. The total surface area of rough textured angular aggregate is more than smooth rounded aggregate for the given volume. By having greater surface area, the angular aggregate may show higher bond strength than rounded aggregates.

The higher surface area of angular aggregates with rough texture requires more water for a given workability than rounded aggregates. This means that for a given set of conditions from the point of view of water/cement ratio and the consequent strength, rounded aggregates gives higher strength. Superimposing plus and minus points in favour and against these two kinds of aggregates it was concluded that, for water/cement ratio below 0.4 the use of crushed aggregates resulted in strength up to 38 per cent higher than the rounded aggregate. With an increase in water/cement ratio the influence of roughness of surface of the aggregate reduced, presumably because the strength of the paste itself becomes paramount, and at a water/cement ratio of 0.65, no difference in strength of concrete made with angular aggregate or rounded aggregate was observed Concrete Technology (2015).

2.3 Waste Glass

Park, *et al.,* (2004), reported that the quantities of waste glass have been on the rise in recent years due to an increase in industrialization and the rapid improvement in the standard of living. Unfortunately, the majority of waste glass is not being recycled but rather abandoned, and is therefore, the cause of certain serious problems such as the waste of natural resources and environmental pollution. For these reasons, this study has been conducted through basic experimental research in order to analyze the possibilities of recycling waste glasses (crushed waste glasses from Korea such as amber, emerald green, flint, and mixed glass) as fine aggregates for concrete. Test results of fresh concrete show that both slump and compacting factors are decreased due to angular grain shape and that air content is increased due to the involvement of numerous small-sized particles that are found in waste glasses.

In addition, the compressive, tensile and flexural strengths of concrete have been shown to decrease when the content of waste glass is increased. In conclusion, the results of this study indicate that emerald green waste glass when used below 30% in mixing concrete is practical along with usage of 10% SBR latex. In addition, the content of waste glasses below 30% is practical along with usage of a pertinent admixture that is necessary to obtain workability and air content.

2.4 Waste Glass as an Aggregate

Weihua *et al.,* (2000) suggested that the use of crushed waste glass as an aggregate in concrete has several advantages in terms of strength.

Meyer *et al.,* (2001), discussed the various steps that need to be taken by recyclers in the use of glass which are to collect the glass, separate it from the other materials, clean it and crush it to obtain the appropriate grading to meet the specifications for specific applications as aggregate in concrete, either in commodity products, with the only objective being to utilize as much glass as possible, or in value-added products that make full use of the physical and esthetic properties of color-sorted crushed glass.

According to an experimental, (Palmquist, 2003) made use of glass, in crushed or cullet form, as another type of recycled material, as an aggregate in concrete. This recycled material has been studied in concrete masonry blocks, and tests on concrete with glass aggregate, including workability, permeability, and shear strength, have been performed to determine the suitability of the material in construction. Glass aggregates in comparison to natural aggregates are stiff with high elastic moduli, but the smooth flat surfaces of the crushed glass cause the bond between the glass and the cement paste to be poor. As a result, the compressive strength of the concrete with glass aggregate is lower than the concrete with natural aggregate.

Another factor, which lowers compressive strength and causes excessive lateral expansion, is the strong reaction between alkali cement and the reactive silica in glass. However, the elastic modulus of concrete with glass aggregate is higher than the concrete with natural aggregate due to the high elastic modulus of the glass aggregate as compared to the modulus of the natural aggregate.

Topçu *et al.,* (2007), stated in their study that the use of waste glass or glass cullet (GC) as concrete aggregate is becoming more widespread each day because of the increase in resource efficiency. Recycling of wastes is very important for sustainable development. When glass is used as aggregate in concrete or mortar, expansions and internal stresses occur due to an ASR. Furthermore, rapid loss in durability is generally observed due to extreme crack formation and an increase in permeability

Caijun and Keren, (2007), reviewed the three possible uses of waste glasses in production of cement and concrete, where their results can be summarized as follows: Firstly, the use of waste glasses as concrete aggregate has a slight negative effect on the workability, strength and freezing-thawing resistance of cement concrete. However, the main concern is expansion and cracking of the concrete containing glass aggregates. It needs to control the pH of the system below 12 in order to prevent potential corrosion of glass aggregates and expansion of the concrete, which may be achieved by the replacement of Portland cement with pozzolanic materials such as fly ash, silica fume and meta-kaolin,

Secondly, waste glasses cans be used as raw materials for cement production as siliceous sources. However, it will increase the liquid content in the clinker, results in the formation of some Na-compounds and increase in the alkali content in the cement. The effect will be dependent on the amount of waste glass used. If the percentage of waste glass used in the raw materials is low, the effects can be very minimal.

Finally, grinded glass powders exhibit very good pozzolanic reactivity and can be used as cement replacement. As expected, its pozzolanic reactivity increases as its finesses increase. Alkalis in the glass powder can cause alkali-aggregate reaction and expansion if aggregates are alkali-reactive. Results from ASTM C-1260 testing indicate that the alkali–aggregate reaction expansion decreases as glass replacement increases, and will be under the deleterious limit if the glass replacement is 50% or more. The combined use of other supplementary cementing materials such as coal fly ash, ground blast furnace slag and meta-kaolin can also decrease the expansion from alkali–aggregate reaction. Lithium salt can be a very effective additive to prevent the alkali–aggregate reaction expansion of concrete containing glass powders.

(Hong *et al.,* 2007) investigated and stated that the increasing awareness of glass recycling speeds up inspections on the use of waste glass with different forms in various fields. One of its significant contributions are to the construction field where the waste glass was reused for value-added concrete production. Literature survey indicates that the use of waste glass as aggregates in concrete was first reported over 50 years ago.

The concomitant ASR by using glass in concrete and its unique aesthetic properties have been investigated since then. However, no complete solution to ASR has been found and the application of glass in architectural concrete still needs improving. Laboratory experiments were conducted in the University of Sheffield to further explore the use of waste glass as coarse and fine aggregates for both ASR alleviations as well as the decorative purpose in concrete. Their research presented mainly the latter aspect, in which study, both fresh and hardened properties of architectural concrete were tested. Results demonstrated that the use of waste glass as aggregate facilitates the development of concrete towards a high architectural level besides its high performances, thereafter, the increasing market in industry

In the research of (Lee et al., 2008), waste glass and stone fragments from stone slab processing are recycled as raw materials for making artificial stone slabs using vibratory compaction in a vacuum environment. Waste glass powder (40%) and fine granite aggregates (60%) are mixed with unsaturated polymer resins (8%) as binder. Under compaction pressure of 14.7 MPa, vibration frequency of 33.3 Hz and vacuum condition at 50 mm Hg, artificial stone slabs with high compressive strength of 148.8 MPa, water absorption below 0.02%, density of 2.445, and flexural strength of 51.1 MPa are obtained after 2 min compaction. The artificial stone slabs fabricated in this study prove to be superior to natural construction slabs in terms of strength and water absorption

According to Taha and Nounu, (2008), they reported that the compressive strength of their concrete mixes did not exhibit distinguished differences when recycled glass sand was used to replace natural sand

Ismail and Al-Hashmi, (2009) investigated the properties of concretes containing waste glass as fine aggregate. The strength properties and the alkali silica reaction (ASR) expansion were analyzed in terms of waste glass content. An overall quantity of 80 kg of crushed waste glass was partially replacing sand at 10%, 15%, and 20% within a 900 kg of concrete mixes. The results proved 80% pozzolanic strength activity given by waste glass after 28 days. The flexural strength and compressive strength of specimens with 20% waste glass content were 10.99% and 4.23%, respectively, higher than the ordinary control specimen results at 28 days. The mortar bar tests showed that the fine crushed waste glass helped reduce expansion of concrete by 66% as compared with the ordinary control mix.

Kou and Poon, (2009), investigated the effects of recycled glass cullet on fresh and hardened properties of self-compacting concrete. Recycled glass was used to replace river sand (in proportions of 10%, 20% and 30%), and 10 mm granite (5%, 10% and 15%) in making the self-compacting concrete mixes. The experimental results showed that the slump flow, blocking ratio, air content of the recycled glass self-compacting concrete mixes increased with increasing recycled glass content. The results revealed that the compressive strength, tensile splitting strength and static modulus of elasticity of the recycled glass self-compacting concrete mixes were decreased with an increase in recycled glass aggregate content. Moreover, the drying shrinkage of the recycled glass self-compacting concrete mixes decreased when the recycled glass content increased.

Federico and Chidiac, (2009), investigated the incorporation of waste bottle glass into concrete mixes as a supplementary cementing material and concluded that the pozzolanic properties of waste glass as an ASR are related to particle size and percent addition. In addition, lithium additives control ASR expansion; however, the mechanism of this control has yet to be defined.

Davorin, (2009), experimental study highlighted the issue of constructing and recycling lightweight concrete (LWC) with aggregates containing expanded glass. The characteristics of recycling LWC such as density, compressive strength, and thermal conductivity are investigated, and compared with normal existing concrete from lightweight aggregates. The results indicated that it is possible to recycle LWC construction waste, and the described method showed great possibilities for increasing the use of construction waste materials from LWC containing expanded glass, in order to benefit from better use of the available capacity from existing construction waste.

The engineering characteristics of density, compressive strength and thermal conductivity from the new recycled material were compared with normal existing concrete from lightweight aggregates, such as changes in dependency on the type and parts of waste as well as its new binding components. Thus, a new recycled material has been created with new characteristics of density, compressive strength and thermal conductivity, which is conform to the compressive strength class and rules on heat protection and energy efficiency use in buildings. Laboratory density, compressive strength, and thermal conductivity tests results showed that LWC can be produced by the use of waste LWC with aggregates containing expanded glass. However, the use of waste LWC with aggregates containing expanded glass seems to be necessary for the production of cheaper and environmentally friendly LWC.

Idir *et al.,* (2010), stated that the demand for recycled glass has considerably decreased in recent years, particularly for mixed glass. Glass is cheaper to store than to recycle, as conditioners require expenses for the recycling process. In order to provide a sustainable solution to glass storage, a potential and incentive way would be to reuse this type of glass in concretes.

Depending on the size of the glass particles used in concrete, two antagonistic behaviors can be observed: alkali–silica reaction, which involves negative effects, and pozzolanic reaction, improving the properties of concrete. Their work dealt with the use of fine particles of glass and glass aggregates in mortars, either separately or combined.

Two parameters based on standardized tests were studied: pozzolanic assessment by mechanical tests on mortar samples and alkali-reactive aggregate characteristics and fines inhibitor evaluations by monitoring of dimensional changes. It is shown that there is no need to use glass in the form of fines since no swelling due to alkali–silica reaction is recorded when the diameter of the glass grains is less than 1 mm. Fine glass powders having specific surface areas within the range from (180 to 540) m/kg reduced the expansions of mortars subjected to ASR, especially when glass aggregates of diameters larger than 1 mm are used. This study aimed to evaluate the preventive role of pozzolanic glass fines in counteracting the deleterious effect of alkali-reactive glass aggregates. It has been shown that in his study that the use of both types of glass particles is pertinent.

Saccani and Bignozzi, (2010), studied the ASR expanding behavior of different types of glass which was derived from cullet with different chemical composition. The glass reactivity was determined in different alkaline solutions based on sodium and/or calcium hydroxide to simulate concrete environment. The expansion of mortar containing different amounts of the investigated glass as fine aggregate has been carried out in different conditions. An attempt to link the behavior to the solubility and chemical reactivity of the glass was proposed along with the hereafter conclusions.

The main conclusions from their experimental research study carried out can be as follows:

i. Glass chemical composition strongly influences the expansion behavior of mortar samples containing cullet as aggregate. In view of glass recycle broadening, expanding compositions should be determined and selective procedures introduced for the treatment of post-consumer glass;

ii. the investigated experimental conditions highlight that the lead-silicate glass (CR) always leads to critical expanding conditions for the relevant mortar samples; iii) a direct correlation between glass solubility and mortar expansion has been underlined and a buffering effect of Ca2 towards glass solubility has been confirmed.

Tan and Du, (2013), reported that the sharper edges and higher aspect ratio of glass particles resulting from the crushing process and the brittle nature of glass enabled more air to be retained at the surface of glass particles in comparison to natural aggregates.

Topcu *et al,* (2004), established that using waste glass gathered from colored soda bottles as partial replacement for coarse aggregate (with proportion up to 60%) did not have a significant effect upon the workability of the concrete and only slight reduction was reported in its strength. Also (Verdugo 2013) investigated the practicability, versatility and feasibility of utilizing recycled glass as a concrete aggregate in the form fine aggregates, coarse aggregates and fine glass powders. He concluded that the results looked promising since strength tests showed that the concrete mixes in question have moderate to high strengths, and hence that the concrete derived from recycled glass could be effectively applied to a multitude of services including structural applications.

Liang *et al.,* (2007), used coloured glass as a coarse and fine aggregate in order to achieve a high performance and aesthetic level of concrete. They proved that high compressive strength concrete with the value above 40N/mm^2 can be obtained by using coloured glass as aggregates beside other materials as partial replacement of cement.

Idi, (2009), Demand for recycled glass has considerably decreasing in recent years. Glass is cheaper to store than to recycle, as it is expensive for the recycling process. There are several alternatives for the reuse of waste glass. According to previous studies, all the applications, which require pre-conditioning and crushing of waste glass, are more or less limited and unable to absorb all the quantities of waste glass available. In order to provide a sustainable solution to glass storage, a potential and incentive way would be to reuse this type of glass in concrete.

In their work (Topçu & Canbaz, 2004), considered waste glass as coarse aggregates in the concrete mix. The effects of waste glass on workability and strength of the concrete with fresh and hardened concrete tests were analyzed. As a result of the study conducted, waste glass was determined not to have a significant effect upon the workability of the concrete and only slightly in the reduction of its strength.

Kou and Poon, (2009), investigated the effects of recycled glass cullet on fresh and hardened properties of self-compacting concrete. Recycled glass was used to replace river sand (in proportions of 10%, 20% and 30%), and 10 mm granite (5%, 10% and 15%) in making the self-compacting concrete mixes. The experimental results showed that the slump flow, blocking ratio, air content of the recycled glass self-compacting concrete mixes increased with increasing recycled glass content. The results revealed that the compressive strength, tensile splitting strength and static modulus of elasticity of the recycled glass self-compacting concrete mixes were decreased with an increase in recycled glass aggregate content. Moreover, the drying shrinkage of the recycled glass self-compacting concrete mixes decreased when the recycled glass content increased.

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Secondly, waste glasses cans be used as raw materials for cement production as siliceous sources. However, it will increase the liquid content in the clinker, results in the formation of some Na-compounds and increase in the alkali content in the cement. The effect will be dependent on the amount of waste glass used. If the percentage of waste glass used in the raw materials is low, the effects can be very minimal.

Finally, ground glass powders exhibit very good pozzolanic reactivity and can be used as cement replacement. As expected, its pozzolanic reactivity increases as its finesses increase. Alkalis in the glass powder can cause alkali-aggregate reaction and expansion if aggregates are alkali-reactive. Results from ASTM C-1260 testing indicate that the alkali–aggregate reaction expansion decreases as glass replacement increases, and will be under the deleterious limit if the glass replacement is 50% or more. The combined use of other supplementary cementing materials such as coal fly ash, ground blast furnace slag and meta-kaolin can also decrease the expansion from alkali–aggregate reaction. Lithium salt can be a very effective additive to prevent the alkali–aggregate reaction expansion of concrete containing glass powders.

Abdullah, (2007), investigated the possibility of improving the compressive strength of concrete over a range of waste glass percentages as replacement for fine and coarse aggregate. He concluded that the optimum value of concrete mix with water-cement ratio of 0.4 was determined as approximately 0.265. This study investigated the use of WG as partial replacement of coarse aggregate in concrete. The concrete cube specimens were tested for density, compressive strength and workability at 7, 14 and 28 days, with various glass to coarse aggregate proportions of (0%, 5%, 10%, 15%, 20% and 25%).

In the experiment study conducted by (Abdulwahab and Ajamu, 2016), They made use of materials like fine aggregate (sharp sand), coarse aggregate (granite and glass), binder (cement) and water. The coarse aggregate comprises of both crushed glass and crushed stone (granite) of sizes 10 to 12.5mm. Portable water was used for the mixing and curing. A water-cement ratio of 0.5 was used for the experiment and slump test was done at intervals to determine the amount of water in the mix and hence its workability. The experimental procedure is a sequential approach in which the aggregate (fine) was spread uniformly on a hard, clean and non-porous surface. Thereafter, cement was added until uniformity in mix was achieved. After which the coarse aggregates (glass and granite) was added in varying proportions of 100:0, 80:20, 60:40, 40:60 until 80% replacement of glass was obtained as against the 100% granite. Water was applied gradually until uniformity in colour and consistency was obtained. A concrete mould of 150mm x 150mm x 150mm and 36 cubes was produced for the quality assurance. The compressive strength of concrete with broken glass as partial replacement was compared with that of the conventional concrete at the end of 7, 14 and 28 days of curing (soaked in clean water).

In an experiment conducted by (Agarna *et al.*, 2016), an investigation was conducted to study on the viability of using waste of glass and steel as an alternative material applied as partial replacement of aggregates in manufacturing concrete. Aggregates were replaced by waste of steel and glass aggregate as 10%, 20% and 30% by M20grades of concrete. The concrete cubes were tested for compressive strength at 7, 14, 28 days is obtained at room temperature. Split tensile strength and flexural strength of concrete are found at the age of 28 days. The concrete cubes were tested for compressive strength at 7, 14, 28 days is obtained at room temperature. With the control concrete, i.e.0%, 10%, 20%, 30% of the natural aggregate is replaced with the waste glass and steel. Three cube samples were cast on the mould of size 150x150x150 mm for each 1:1.50:3.0 concrete mixes with partial replacement of coarse aggregate with w/c ratio as 0.50 were also cast and water curing was continued till the respective tensile strength

The aggregate of size less than 20 mm and greater than 12.5 mm are used, cubes mould of 150x150x150 mm are used. Cylindrical moulds of size 150 mm diameter and 300 mm height are used for casting specimen for split tensile test. For flexural strength, beam moulds of size 500x100x100 mm of internal dimension are used. Moulds are removed after 24hours of casting and cured in water up to the date of testing.

2.5 Results from Reviews

2.5.1 Result and Discussion

The Tables 2.2 below show the result of the quality control tests (compressive strength and slump values) of specimens produced in the course of this research work of (Abdulwahab and Ajamu, 2016) The figure 2.6 below is a bar chart showing the variation in the strength of the concrete produced with 100% granite (control experiment) and concrete with varying percentage of glass (test experiment). The strength reduces as the percentage of glass replacement increases.

Table 2.2: Workability of the specimens produced

Specimen (%)	Granite: Glass	Mix ratio	Water/Cement ratio	Slump (mm)
A	(1 0 0 : 0)	1 : 2 : 4	0 .55	40
B	(8 0 : 2 0)	1 : 2 : 4	0 .55	*58*
C	(6 0 : 4 0)	1 : 2 : 4	0 .55	*30*
D	(4 0 : 6 0)	1 : 2 : 4	0 .55	*25*
E	(2 0 : 8 0)	1 : 2 : 4	0 .55	*20*

2.5.2 Workability Tests of Fresh Concrete Slump cone test

The slump is taken for each mixing of concrete with 0%, 10%, 20%, and 30% replacement of RGA. The results show that slump of concrete made with natural aggregates is higher while the concrete with 30% replacement of RGA has fewer slumps, as shown in Table 2.3 by the varying water to cement ratio.

Table 2.3 w/c ratio

Coarse aggregate w/c ratio (glass with steel waste)	w/c ratio M20
100-0	0.489
90-10	0.495
80-20	0.500
70-30	0.512

2.5.3 Compressive Strength of Concrete Cubes

Compressive strength of concrete can be defined as the measured maximum resistance of a concrete to axial loading. Compression test is the most common test used to test the hardened concrete specimens because the testing is easy to make. The strength of the concrete specimens with different percentage of recycled aggregate replacement can be indicating through the compression test.

The findings of (Agarna *et al.,* 2016) as shown in Table 2.4, revealed that the compressive strength is the average of 3 measurements tested at the age of 7days, 14days and 28days, as shown in Figures 2.3, 2.4, 2.5 respectively. Specimen of cube tested in compression testing shows that the early compressive strength of concrete made of natural coarse aggregate and waste glass steel coarse aggregate is approximately same.

Concrete acquires maximum increase in compressive strength at 20% aggregate replacement as compared with concrete with only aggregate.

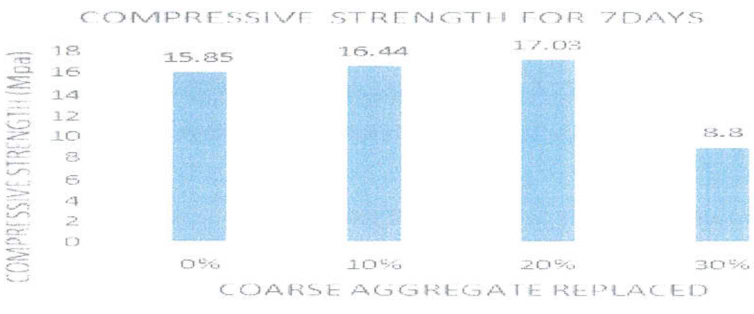

Figure 2.3: Compressive strength results for 7days

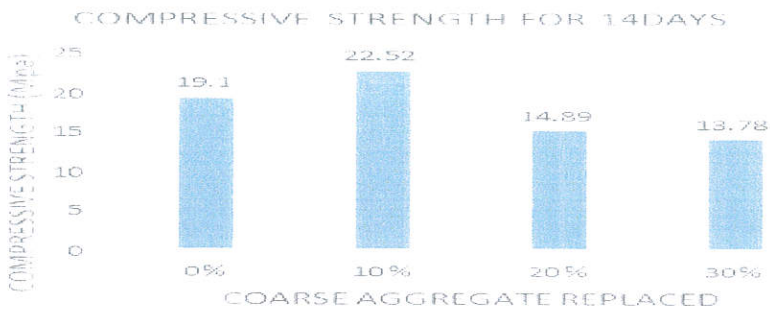

Figure 2.4: Compressive strength results for 14days

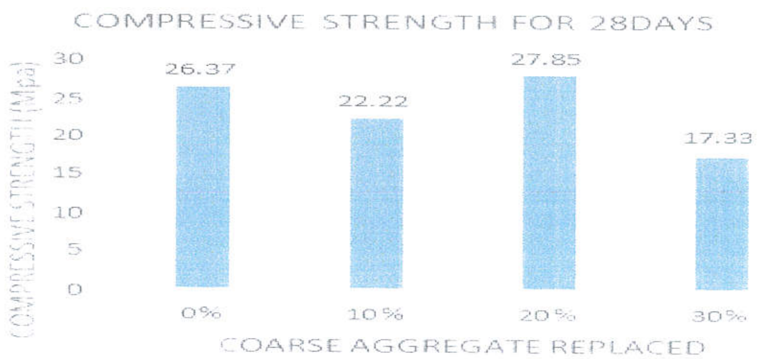

Figure 2.5: Compressive strength results for 28 days

Table 2.4: Compressive strength results for 28days

S /NO	Mix ratio	Average compressive strength		
		7days	14days	28days
1	0%	15.85	19.10	26.37
2	10%	16.44	22.52	22.22
3	20%	17.03	14.89	27.85
4	30%	8.8	13.78	17.33

In the research work and experimental investigation of (Abdulwahab and Ajamu, 2016). The compressive strength of concrete with broken glass as partial replacement was compared with that of the conventional concrete at the end of 7, 14 and 28 days of curing (soaked in clean water). The result shows the variation in the strength of the concrete produced with 100% granite (control experiment) and concrete with varying percentage of glass (test experiment). The strength reduces as the percentage of glass replacement increases, as shown in Table 2.5 and Figure 2.6 below.

Table 2.5: Compressive strength and Density of the specimens produced

Specimen	Granite: : Glass	Average density Kg/m^3			Average compressive strength N/mm2)		
		7 Days	1 4 Days	2 8 Days	7 Days	14 Days	2 8 Days
A	(1 0 0 : 0)	2718	2722	2730	1 6. 6 7	1 8. 6 7	2 3. 7 8
B	(8 0 : 2 0)	2636	2611	2617	1 3.0 2	1 4. 4 4	1 9. 9 1
C	(6 0 : 4 0)	2393	2400	2382	1 2. 2 2	1 2. 5 8	1 4. 3 6
D	(4 0 : 6 0)	2212	2270	2203	1 1. 6 9	1 2. 1 3	1 3. 2 4
E	(2 0 : 8 0)	1982	2003	2034	1 1. 2 4	1 1 /6 8	1 2. 6 7

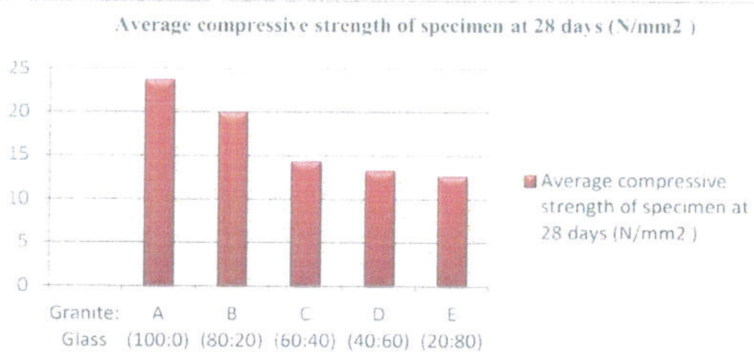

Figure 2.6: Compressive strength of concrete with varying percentage of glass as coarse aggregate

Boopathi *et.al* 2017 in their experimental investigation on partial replacement of coarse aggregate by recycled concrete aggregate and crushed waste glass in concrete, revealed that the replacement percentage is up to 40% with the conventional coarse aggregate. The composite replacement of recycled concrete aggregate is 10%, 20%, 30%, 40% and waste crushed glass is 10%, 20%, 30%, and 40% for alternate virgin coarse aggregate in cement concrete, are shown in Tables 2.6 and 2.7 respectively. The test results proved that the sample 2, i.e. RCA 30% + CG 20% can be used as a partial replacement for coarse aggregate. This sample mixing provides high compressive and tensile strength, which gives a proof that it can be used for structural members for beam, column, slab, roof, and retaining wall etc. When compared to the conventional concrete, the RC beam containing sample 2 gives maximum load with minimum deflection. i.e., it shows high flexural strength.

Table 2.6: partial replacement of coarse aggregate by crushed waste glass in concrete

Crushed waste glass used (%)	Strength at 7days (N/mm^2)	Strength at 28days (N/mm^2)
0	11.3	26.1
10	16.3	26.0
20	14.4	25.4
30	12.7	24.7
40	11.8	23.4

Table 2.7: partial replacement of coarse aggregate by recycled concrete aggregate

Recycled concrete aggregate used (%)	Strength at 7days (N/mm^2)	Strength at 28days (N/mm^2)
0	11.3	26.1
10	13.2	24.3
20	15.5	23.8
30	14.4	24.6
40	16.5	26.2

In the work of (Shalini singh, 2017), where he experimented and investigated on the feasibility of partial replacement of coarse aggregate with waste glass in concrete, The compressive strength of the block was tested on 7 and 28 days and a mix of 1:1.6:4 at a w/c of 0.48. The result showed that there is a decrease in compressive strength with increase in the percentage of the waste glass, and that there is a marginal increase in strength of concrete at 10% replacement, as shown in Table 2.8 and Figure 2.7

Table 2.8:compressive strength of cubes at 7days and 28 days

S/NO	Percentage replacement	7 days compressive strength	28 days compressive strength
1	0%	16	26
2	5%	11	21.33
3	10%	15.63	24. 6
4	20%	15.16	23.61
5	30%	13	21

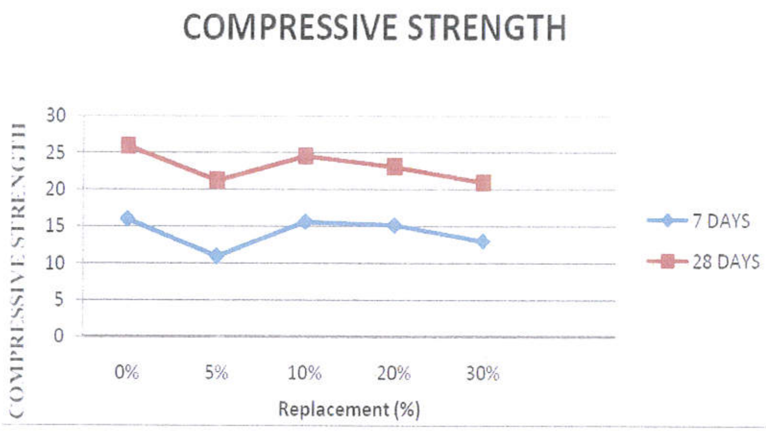

Figure: 2.7 compressive strength of the cubes with varying percentages of glass

2.5.3 Tensile Strength

The capacity of a material or structure to withstand loads tending to elongate; resist tension (being pulled apart); measured by the maximum stress that a material can withstand while being stretched or pulled before breaking.

Salahuddin *et al.,* (2017), in an experimental investigation on concrete by partial replacing of coarse aggregate with recycled coarse aggregate and fine aggregate with crushed glass, the Split tensile strength tests were conducted on standard cylinders of dimension 15cm diameter and 30cm depth, specimens each for plain concrete, of M20 mix. RCA and crushed glass concrete were casted at varying percentages of RCA+CG (0%, 10%, 20%, 30%, and 40%). For each case, 7 & 28days strength values were obtained by loading under a compression testing machine as shown in Figure 2.8 and Figure 2.9 for 7days and 28days respectively. It was observed that the crushed glass help in increasing the tensile property of concrete. The tensile properties and cracking pattern of concrete shows that it can be particularly useful in construction activities.

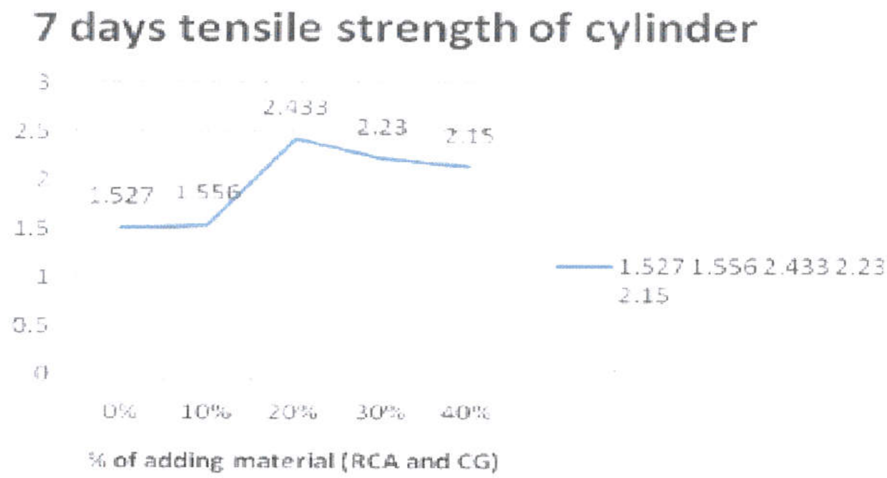

Figure 2.8 tensile strength at 7 days for cylindrical cube at different glass replacement for M20.

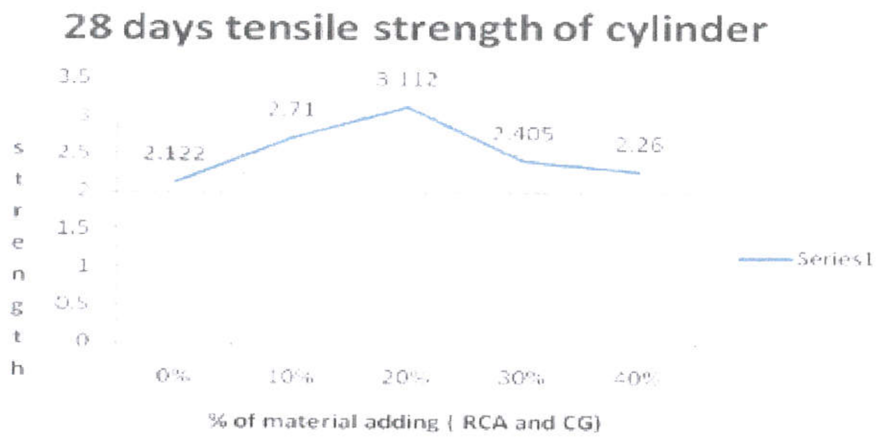

Figure 2.9; showing the tensile strength at 28 days for cylindrical cube at different glass replacement for M20.

Agarna *et al.*, (2016), found out that the split tensile strength of conventional concrete was found to be 2.05 N/mm^2, as shown in Table 2.9, and the strength is maximum at 10% replacement of natural aggregate by steel waste and waste glass which shows that the replacement of coarse aggregate with waste steel and increases the tensile strength.

Table 2.9: tensile strength at different replacement

S/NO	Mix ratio	Split tensile Strength (N/mm^2)
1	0%	2/05
2	10%	2.55
3	20%	2.26
4	30%	1.98

2.5.4 Flexural Strength

Boopathi.*et al.,* (2017) in their experimental investigation on partial replacement of coarse aggregate by recycled concrete aggregate and crushed waste glass in concrete, revealed that the replacement percentage is up to 40% with the conventional course aggregate. The composite replacement of recycled concrete aggregate is 10%, 20%, 30%, 40% and waste crushed glass is 10%, 20%, 30%, and 40% for alternate virgin coarse aggregate in cement concrete, are given in Table 2.10. The test results proved that the sample for every percentage replacement of 3 beams have been casted. The 3 beams were tested on the 28th day. Totally 72 beams were casted and 7^{th} day testing has been completed.

Table 2.10 flexural strength at 7days and 28days

Percentage of crushed waste glass used (%)	Flexural strength at 7days (N/mm^2)	Flexural strength at 28days (N/mm^2)
0	3.7	6.8
10	4.6	6.4
20	4.4	6.1
30	3.9	5.7
40	3.5	4.9

2.6 Conclusions from Reviews

Based on these reviews and results, the following conclusions can be drawn.

i. The workability of concrete followed a decreasing trend with the addition of fine glass aggregate, due to the angular nature of the glass particles. Despite this trend, the concrete was deemed workable and was within the specified tolerance intervals.

ii. Compressive strength was found to increase with the addition of waste glass to the mix up until the optimum level of replacement.
iii. The reduction of mortar strength can be attributed to the high-water cement ratio and absence of rough surface of waste glass aggregate, which is essential for bonding and structuring of fresh mortar.
iv. Waste glass when grounded to a very fine powder shows some pozzolanic properties as it contains high SiO2 and therefore to some extent it replaces the cement and contributes for strength development.
v. With the addition of waste glass aggregate, compressive strength of mortar decreases.
vi. Workability of concrete mix increases with increase in waste glass content.
vii. With increase in waste glass content, percentage water absorption decreases.
viii. The use of waste glass aggregate usually reduces the water demand.
ix. With the addition of waste glass aggregate, density of mortar increases.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Theoretical Background

The experimental program of the research was carried out to explore the effect of using crushed waste glass as a partial replaced aggregate in the fresh concrete. The waste glass was crushed into small pieces that resemble the size of gravel and granite. Then the crushed glass was mixed into fresh concrete and then the effect of recycled crushed glass on the strength properties of concrete were observed.

3.2 Materials Design and Preparation

3.2.1 Waste Glass

The waste glass materials used throughout this experimental study were gathered from dumpsites and restaurants in Ikole-ekiti. These materials were primarily wine bottles, soft drink bottles and alcoholic drink bottles as shown in Plate 3.1. The whole quantity of waste glass was crushed manually using a metallic rammer and a metallic basin as shown in Plate 3.2, and were later separated into sizes of different grades using manual hand method as shown in Plate 3.3. Necessary precautions were taken to ensure safety, so as to reduce the risk involved in the use of broken glass.

Plate 3.1: Waste glass collected before breaking.

Plate 3.2: Process of breaking the waste glass.

Plate 3.3 Waste glass after being broken and separated

3.2.2 Aggregates

The aggregates used in this project were sourced from the school environment. Aggregates are broken down into two main categories, which are coarse and fine aggregates.

3.2.2.1 Fine Aggregate

Natural sand is the fine aggregate chiefly used in concrete mix. Sand may be obtained from sea, river, lake, etc., but when used in a concrete mix, it should be properly washed and tested to ascertain that it is free from clay, silt, and such organic matters. Commonly used fine aggregate in R.C.C. work is sand. It is either round or angular in grains and is often found mixed in various gradation of fineness, as shown in Plate 3.4 below.

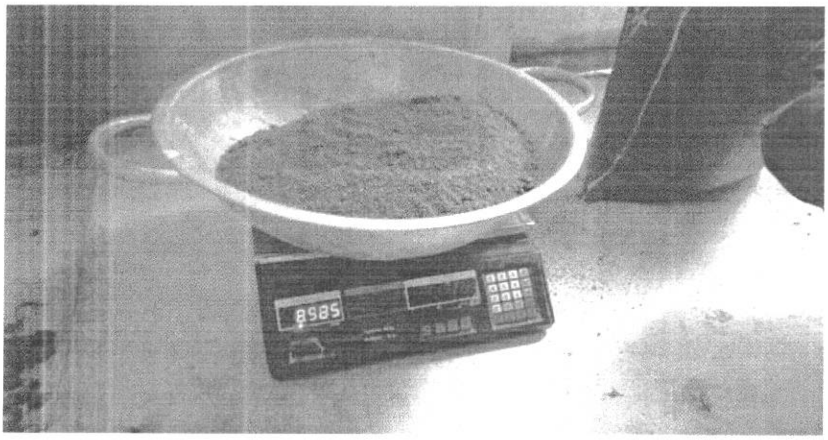

Plate 3.4: Fine aggregates

3.2.2.2 Coarse Aggregate

According to ASTM Standard C 33-03, Crushed hard stone and gravel are the common materials used as coarse aggregate for structural concrete. For this research the coarse aggregate used was granite as shown in Plate 3.5. Crushing granites, gneiss, crystalline limestone and good variety of sand stone, are also common examples of coarse aggregate. The material whose particles are of such size as are retained on a 3/16" in B.S. test sieve, is termed as coarse aggregate. The maximum size may be 20 cm (9") for mass concrete work, such as dams etc, and 62.5mm (2.5") for plain concrete work. For R.C.C. Construction, the maximum is (1") although 20mm (0.75") of aggregate is commonly adopted. The size of the coarse aggregate used was 20mm.

The coarse aggregate was of angular nature and with a nominal maximum aggregate sizes of 20mm and 25mmes.

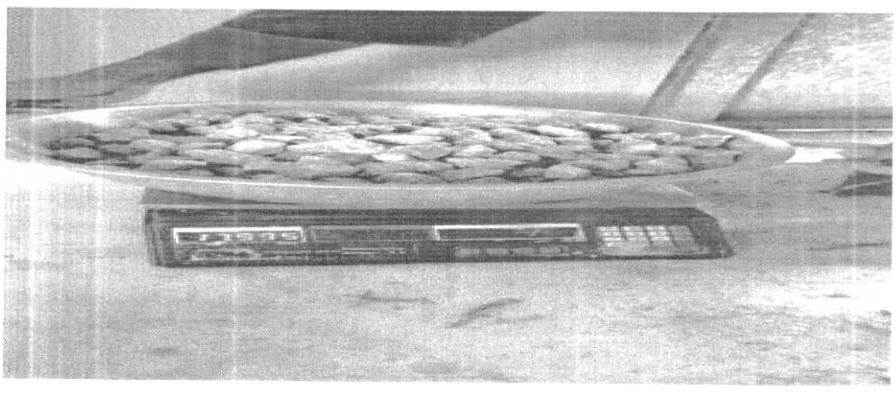

Plate 3.5: Course aggregates

3.2.3 Cement

The cement used for the project was a Portland cement manufactured in Nigeria, as in Plate 3.6. Ordinary Portland cement 53 grade (elephant cement) complying with IS 269, 1976. The cement was kept in an airtight container and stored in the humidity controlled room to prevent cement from being exposed to moisture.

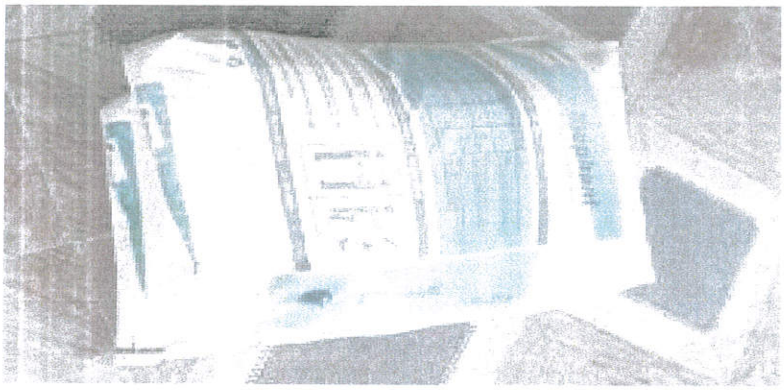

Plate 3.6: Ordinary Portland cement

3.2.4 Water

Portable water is used for mixing and curing. On addition of higher percentage of demolished waste the requirement of water increases for the same workability. Thus, a constant slump has been the criteria for water requirement but the specimens having 0% demolished waste, w/c of 0.50 has been used. Water supply would be gotten from the school water facilities, rain or nearby streams if the facilities would not be available for use.

3.2.5 Mould

The mould was built by a carpenter with dimensions 150 mm x 150 mm x 150 mm.as shown in Plate 3.7 and cylindrical pipe mould of dimension 300 mm x 150 mm, was bought for the purpose of the experiment, as shown in Plate 3.8. The moulds were used for the casting of the concrete specimens on which the strength properties were carried out respectively was also used.

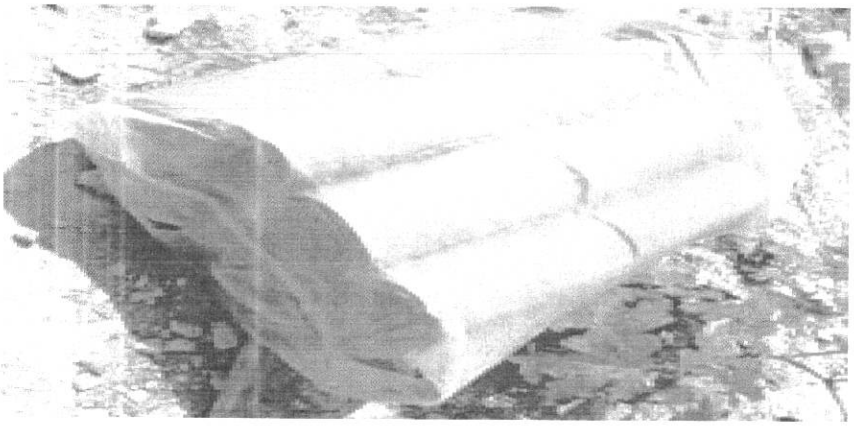

Plate 3.7: 150mmx300mm cylindrical pipes

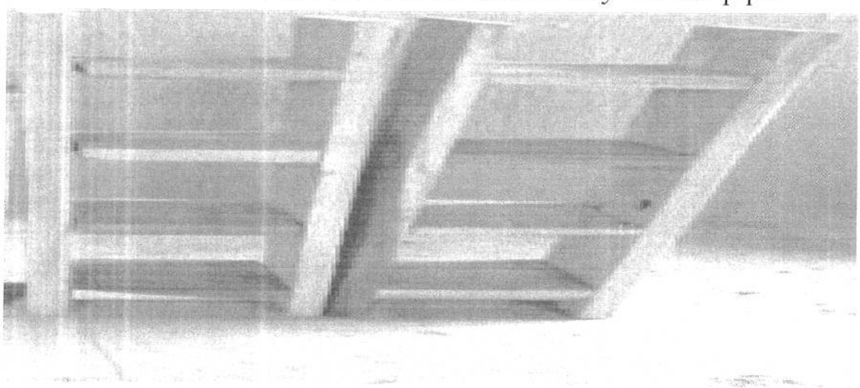

Plate 3.8: 150mm x 150mm x 150mm cube

3.3 Equipment

The equipment for the various tests include Slump cone, Compression testing machine, wooden moulds, rammer, weighing balance, Shovel and Head-pan.

3.4 Preliminary investigation

Tests were conducted to assess the mechanical and physical properties of the materials which include WGA, granite, sand at the soil mechanics laboratory of Federal Polytechnic Ado-Ekiti. The tests conducted include;

3.4.1 Specific gravity

Specific gravity also called relative density is the ratio of the density of aggregate to the density of distilled water at a standard temperature. The specific gravity of the aggregate samples were determined in accordance with Indian standard IS 2770: Part3: 1963, Method of test for soil. Pycnometer method for specific gravity was used as in Plate

3.9.The sample was dried in an oven for 16 hours at a temperature of 115°c as shown in Plate 3.10. The pycnometer was dried and weighed with its cap, and was filled to about two-third with the oven dried specimen and the pycnometer was weighed again. Water was added to cover the specimen and the cap was screwed, entrapped air were removed by shaking the pycnometer. The pycnometer was then filled with water and weighed after air has been removed. The pycnometer was cleaned completely with water and the cap was screwed. The outside of the pycnometer was dried and weighed. The specific gravity was determined from the ratio of the weight of the aggregate to the weight of equal volume of water.

Plate 3.9: Specific gravity test set-up (weighing balance, samples, Pycnometer)

3.4.2 Moisture content

The moisture content of the aggregate samples were determined in accordance with BS812: Part 109: 1990. The oven drying method (Definitive method) was adopted for the test. The oven-drying method provides a measure of the total water present in a sample of aggregate, the method comprises placing a test portion in a container and heating it in an oven until it reaches constant dry mass, as shown in Plate 3.10. Moisture content is then determined by the difference in mass and expressed as a percentage of dry mass.

A clean container, dried was weighed and aggregate sample was placed in the container and then re-weighed. The container containing the aggregate sample was placed in the oven and was dried at a constant temperature of 105°c. The container was removed from the oven and cooled in an air tight container for one hour and was weighed again. The moisture content was determined as a percentage of the dry mass.

Plate 3.10: Drying the aggregate samples in a controllable oven

3.4.3 Bulk density

Bulk density is the weight of material in a given volume. It is expressed in kg/m^3. The bulk density (unit weight) of an aggregate gives valuable information regarding the shape and grading of the aggregate. The bulk density was determined in accordance with provisions in BS 812: Part 2: 1995.

A cylindrical container was filled with the aggregate sample to about one-third the container. Then compactive blows were given to the aggregate sample, with each blow been given by allowing the tamping rod to fall freely from 5mm above the surface of the aggregate. Similar quantity of aggregate was added and same number of blows was given. Container was filled till it overflowed and it was tampered with the same number of blows. Excess aggregate was removed by rolling the tamping rod across the top of the container. The mass of the aggregate in the container was determined.

3.5. Mixing and Proportioning of Concrete

A mix ratio of 1:1:2 by weight (cement: fine aggregate: coarse aggregate) was adopted to achieve a concrete cube strength of $25N/mm^2$ and cylindrical strength of $25N/mm^2$. While the water – cement ratio of 0.5 was used. Waste Glass at 0%, 10% 20% and 30% replacement level would replace coarse aggregate.

3.5.1 Preliminary Information

Mix ratio - 1:1:2

Concrete Grade - M-25

Water-Cement ratio - 0.5

No of cubes per sample = 1

No of curing Days = 5 (i.e. 7, 14, 28, 56, and 90 days)

No of proportioning = 2 (i.e. 1 for WGA, 1 WGA and 1 control. i.e. 0%, 10%, 20%, 30%)

Total number of cubes = 40 cubes (15 containing WGA, 15 containing WGA and 10 control)

3.5.2 Mix Design Calculations

Volume of a cube = (0.15) × (0.15)× (0.15) = 0.003375m^3

Concrete Density = 2400 $^{kg}/_{m3}$

Density = ($^{mass}/_{volume}$)

Mass = Density × Volume = 2400× 0.003375= 8.1kg

Total Mass = 8.1 × 40 = 324 Kg

Weight of each concrete constituent

Table 3.1: Mix design schedule for 150mm × 150mm cubes

Proportion of WGA	Coarse Aggregate (kg)		Fine Aggregate (kg)	cement	Water (kg)	Number of cubes
	WGA	25mm granite				
0%	0	4.05	2.05	2.05	1.025	20
10%	0.405	3.645	2.05	2.05	1.025	20
20%	0.810	3.240	2.05	2.05	1.025	20
30%	1.215	2.835	2.05	2.05	1.025	20

Table 3.2: Mix design schedule for 300mm × 100mm cylinder

Proportion of WGA	Coarse Aggregate (kg)		Fine Aggregate (kg)	cement	Water (kg)	Number of cubes
	WGA	25mm granite				
0%	0	4.05	3.18	3.18	1.59	
10%	0.405	3.645	3.18	3.18	1.59	
20%	0.810	3.240	3.18	3.18	1.59	
30%	1.215	2.835	3.18	3.18	1.59	

3.6 Fresh State Properties

3.6.1 Workability (Slump Test)

The workability of cement can be tested by carrying out the slump test. The slump test is a means of assessing the consistency of fresh concrete. It is used, as a means of checking that the proportioning of water in the concrete mix is correct. The test was carried out in accordance with BS EN 12350-2. The test is popular due to the simplicity of apparatus used and simple procedure.

Procedure

The test was carried out using a metal mould in the shape of a conical frustum known as a slump cone which is opened at both ends and has an attached handle. The tool typically has an internal diameter of 100mm at the top and 200mm at the bottom with a height of 300mm, as shown in Plate 3.13.The cone was filled with fresh concrete in three stages. Each time, each layer was tamped 25 times with a 600 mm long bullet-nosed metal rod measuring 16mm in diameter At the end of the third stage, the concrete was struck off flush with the top of the cone. The cone was carefully lifted vertically upwards with twisting motion so as not to disturb the concrete cone. The upturned slump cone was placed on the base to act as a reference, and the difference in level between its top and the top of the concrete was measured and recorded to the nearest 5 mm to give the slump of the concrete. When the cone was removed, the slump may take one of three forms. In a true slump the concrete simply subsides, keeping more or less to shape. In a shear slump the top portion of the concrete shears off and slips sideways.

Apparatus used;

i. Slump cone

ii. Tamping rod

iii. Concrete

iv. Hand Trowel

v. Measuring Tape

Plate 3.11 workability of concrete using slump cone

3.7 Casting of Specimens

The moulds as shown Plate 3.7 and Plate 3.8 was used. Brush was used to apply engine oil on the inner surface of the mould so as to give a lubricating effect between the mould and the concrete after it has harden for easy removal. The mould was put at a levelled and smooth surface so as to give the cubes a smooth base. The weight of each of the constituents were taken, as shown in Plate 3.12 .and the constituents were carefully mixed, using shovel as shown Plate 3.13

Plate 3.12: weighing of cement

Plate 3.13 Mixing of Concrete

Concrete was poured into the moulds in three layers in such a way that each pouring was approximately equivalent with the height of the mould divided into three. Each layer poured was compacted using a tamping rod so as to give proper locking of the concrete and also to reduce the honeycomb due to improper compaction, each layer was tamped 25 times, equally distributed throughout the surface of the layer. At the last layer the concrete was poured above the height of the mould before compacting it so as to provide a sufficient level of concrete, excess concrete was then scraped off from the surface using a hand trowel, so as to give a proper levelling with the top of the mould. The surface of the cast cube was smoothening to provide a smooth surface. The proportion of the WGA present in the concrete and the date of casting was inscribed on the concrete cubes. and the resulting concrete specimen were removed from their respective moulds after 24 hours as shown in Plate 3.14.

Plate 3.14: Demoulded concrete cubes

3.8 curing of concrete specimen

Specimen were then de-moulded and totally immersed in fresh water in a curing tank to ensure complete hydration as shown in Pllate3.15. (Zawde 1983) Stated that no part of the process of making a good concrete is more important than through curing. On the testing day, the specimen was removed from the water and excess moisture was wiped from the surfaces of the cube specimens, it was allowed to air dry for 30 minutes prior testing (Clvilolgy 2017)

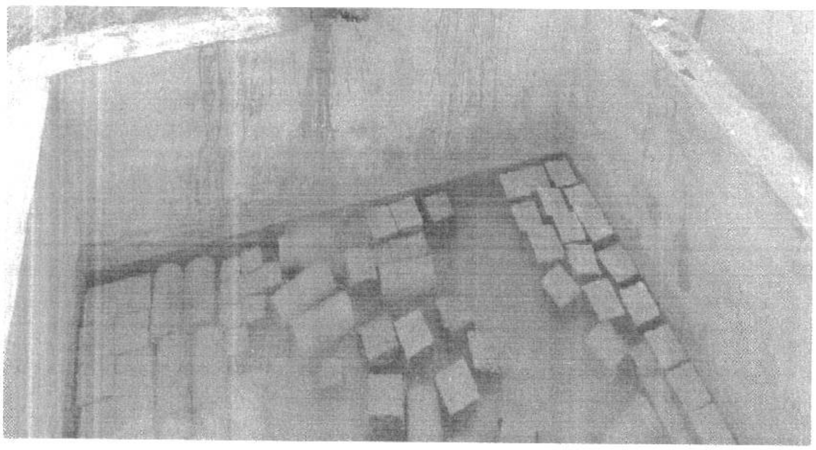

Plate 3.15: Curing the concrete cubes in the curing tank

3.9 Main Investigation

3.9.1 Compressive strength test

The term compressive strength is the capacity of material or structure to withstand axially directed forces. This is a test in which a batch of concrete will be tested for strength and durability. The course of the project focuses on the determination of the strength of the concrete cubes and the variation in the strength properties of the cubes by partial replacement with waste glass using different coarse aggregate grading (25mm and 20mm).

The specimens were tested by compression testing machine after 7 days, 14 days, 28days, 56days and 90 days curing. Load was applied gradually till the Specimens fails. The compressive strength of the concrete will be determined using the formulae below.

$$\text{Compressive strength (N/mm}^2\text{)} = \frac{\text{Ultimate compressive load (N)}}{\text{Area of cross section of specimen (mm2)}}$$

Procedure

The crushing procedures are shown in Plate 3.16 to Plate 3.18.

i. The specimens were removed from water after specified curing time and wiped off of excess water from the surface.

ii. The weight of each of the specimen was taken using weighing balance.

iii. The bearing surface of the testing machine was cleaned.

iv. The specimen were placed in the machine such that the load was applied to the opposite side of the cube cast.

v. The specimen were aligned centrally on the base plate of the machine.

vi. Load was applied gradually till the specimen fails.

vii. The maximum load was recorded as at when failure occurred to the specimen.

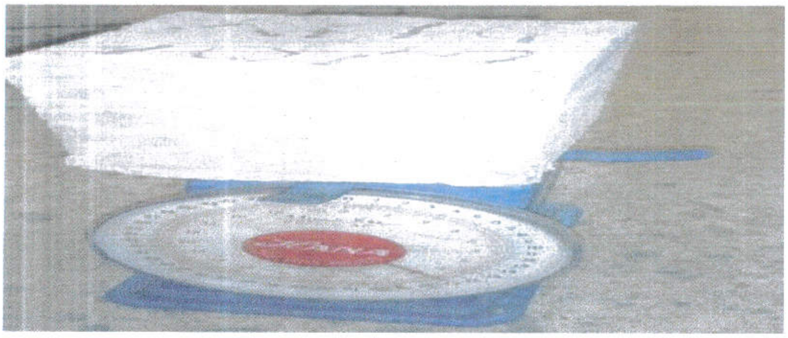

Plate 3.16 Weighing of Concrete cube

Plate 3.17 Crushing of cube

Plate 3.18 Failure occurring to cube during Crushing

3.9.2 TENSILE STRENGTH: The capacity of a material or structure to withstand loads tending to elongate; resist tension (being pulled apart); measured by the maximum stress that a material can withstand while being stretched or pulled before breaking.

Split-Cylinder Test

It is the standard test, to determine the tensile strength of concrete in an indirect way. This test could be performed in accordance with IS: 5816-1970.

A standard test cylinder of concrete specimen (300 mm X 150mm diameter) is placed horizontally between the loading surfaces of Compression Testing Machine Plate 3.19.The compression load is applied diametrically and uniformly along the length of cylinder until the failure of the cylinder along the vertical diameter. To allow the uniform distribution of this applied load and to reduce the magnitude of the high compressive stresses near the points of application of this load, strips of plywood are placed between the specimen and loading platens of the testing machine. Concrete cylinders split into two halves along this vertical plane due to indirect tensile stress generated by poison's effect as shown in Plate 3.20.

Plate 3.19: cylindrical specimen under the application of load for tensile strength

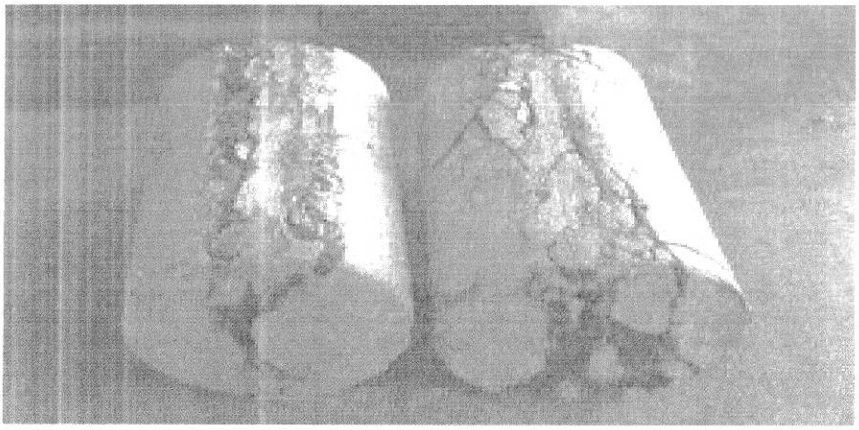

Plate 3.20 Failure occurring to cylindrical specimen during loading

Due to this compressive loading, an element lying along the vertical diameter of the cylinder is subjected to a vertical compressive stress and a horizontal stress Plate 3.17 The loading condition produces a high compressive stress immediately below the loading points. But the larger portion of cylinder, corresponding to its depth is subjected to uniform tensile stress acting horizontally Assuming concrete specimen behaves as an elastic body, a uniform lateral tensile stress of Ft acting along the vertical plane causes the failure of the specimen, which can be calculated from the formula as,

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

P=compressive load failure

L=length of cylinder

D=diameter of cylinder

The above test result represents the "Splitting Tensile Strength" of concrete that varies between 1/8 to 1/12 of the cube compressive strength.

Procedure

The crushing procedures are shown in Plate 3.19 to Plate 3.20.

i. The specimens were removed from water after specified curing time and wiped off of excess water from the surface.
ii. The weight of each of the specimen was taken using weighing balance.
iii. The bearing surface of the testing machine was cleaned.

iv. The specimen were placed in the machine such that the load was applied on the horizontal plane of the cylindrical specimen
v. The specimen were aligned centrally on the base plate of the machine.
vi. Load was applied gradually till the specimen fails.
vii. The maximum load was recorded as at when failure occurred to the specimen.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 General

The results from the tests are discussed in this chapter. The results from the preliminary tests which include specific gravity, chemical composition, fineness, moisture content, as well as the concrete strength tests (Density, Compressive strength and tensile strength test) are discussed in this chapter. The tables and figures in this chapter shows the results of the preliminary and main tests. The details of the results are discussed below.

4.2 Chemical Analysis

4.2.1 Procedures

Sample digestion

One gram of pulverised sample was weighed into a conical flask and moistened with distilled water.100ml aqua regia was added to it and boiled steadily to almost dryness. The sample was then cooled and leached with 5ml of 6M H_2SO_4.5ml of distilled water was added and boiled for 10 minutes. The Sample was then cooled and filtered. The filtrate was made up to 100ml and presented for mineral analysis.

Mineral analysis

The mineral content of the digested sample were analyzed using Atomic Absorption Spectrophotometer (Buck Scientific 210 VGP), flame photometer (FP 902 PG) and their oxides were calculated using a conversion table.

Sulfite Determination

One gram of the sample is measured accurately and transferred into a flask with a ground-glass stopper, containing 50 ml of 0.05 mol/l iodine solution exactly measured, and dissolved. It was allowed to stand for 5 minutes, and 2 ml of diluted hydrochloric acid was added. Then, the excess iodine was titrated with 0.1 mol/l sodium thiosulfate solution (indicator: starch TS).

Loss on ignition

Loss on ignition is determined using the standard method (ASTM D7348) Samples are placed in weighed crucible and weighed .weight loss is measured after heating the samples overnight at 100°C to remove water, at 550°C for four hours to remove organic matter, and at 1000°C for two hours to remove carbonates. After each heating step, the firebrick holding crucibles is allowed to cool completely in the oven or furnace before weighing, or placed in a dedicator if crucibles cannot be weighed immediately. The weight loss of the sample due to heating is then determined, the constant weight obtained is then measured as loss on ignition. (ASTM D7348)

The result of the chemical analysis summarized from the procedures above are given in Table 4.1 and Figure: 4.1

Table 4.1: Chemical composition of constituent elements

S/N	Chemical Composition	Portland Cement	Glass	Granite	Sand
1	Na_2O	0.51	9.609	5.194	0.356
2	CaO	62.60	21	7.114	0.223
3	K_2O	0.29	2.176	8.208	1.091
4	MgO	1.74	0.719	0.609	2.271
5	Al_2O_3	5.09	3.017	9.670	12.104
6	Mn_2O_3	0.007	0.072	0.275	0.030
7	Fe_2O_3	3.20	0.746	4.817	0.497
8	SiO_2	20.34	94.23	75.830	81.484
9	SO_3	2.19	0.012	3.701	2.130
10	LOI	0	0.023	2.096	0.697

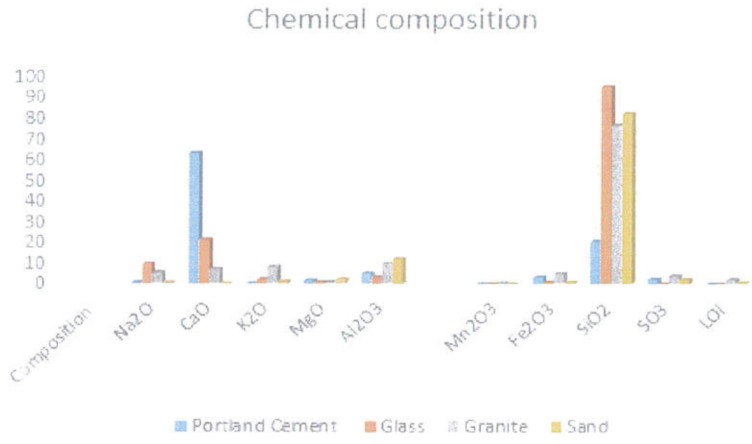

Figure: 4.1: Chemical composition of the constituent

4.3 Specific Gravity

The specific gravity obtained for the granite, sand, and WGA aggregates were 2.75, 2.64, and 2.70 respectively as shown in Table 4.1. According to British Standard BS 812: Part 2: 1995, the majority of natural aggregate have specific gravity between 2.60 and 2.70. Aggregates with specific gravity less than about 2.4 are classified as lightweight while normal weight concrete aggregates have specific gravity around 2.6 (Popovics, 1992)

4.4 Moisture Content

The moisture content obtained for the sand, WGA and granite aggregate are 0.6%, 0% 0.009% respectively. Table 4.1 shows the moisture content result of the aggregate samples. It is observed that fine aggregate (sand) had the highest moisture content, while WGA had the lowest moisture content. The rate at which aggregate absorb certain quantity of water depends on the porosity of the aggregate sample. Moisture content is important in the control of the nature of cement especially in terms of workability and quality. Abrams law stated that, all other things been equal, compressive strength of concrete is dependent on the ratio of mass of water to cement.

It should be noted that if the aggregates are dry they absorb water from the mixing water and thereby affect the concrete's workability and, on the other hand, if the aggregate contains moisture they contribute extra water to the mix and thereby increase the water/cement ratio. Both conditions are harmful to the quality of concrete, in making quality concrete it's necessary that measures should be taken for free moisture (Moisture content) so that the water/cement ratio is kept exactly as per the design.

4.5 Bulk Density

The value of bulk density of granite, sand and WGA aggregate were 1660 kg/m^3, 1786 kg/m^3 and 1364 kg/m^3 respectively. Bulk density shows how densely the aggregate is packed when filled in a standard manner. The bulk density depends on the particle size distribution and shape of the particles. Table 4.1 shows the bulk density of the aggregate samples.

It should be noted that the higher the bulk density the lower the void content to be filled by sand and cement. Since sand aggregate had maximum bulk it alludes that it has minimum voids and it's the right aggregate sample for making economical mix. WGA had the lowest bulk density and the result shows that it had about less weight compared to both the fine and coarse aggregate making it a light weight aggregate.

Table 4.1: Physical Properties of aggregate

Properties	WGA	Granite	Sand
Specific gravity	2.70	2.75	2.64
Moisture content	0.60	0.01	1.14
Bulk density	1364	1660	1786

4.6 Workability Test

The workability result of the fresh concrete mix using 20mm and 25mm WGA are given in Table 4.2 and Table 4.3 respectively, while Figure 4.2 represents the variation in the workability of the WGA mix at varying replacements.

Table 4.2 Effect of WGA on workability of Concrete (20mm)

Proportion (%)	(0%) Control	(10%) replacement	(20%) replacement	(30%) replacement
Slump Value (mm)	20	35	85	92

Table 4.3 Effect of WGA on workability of Concrete (25mm)

Proportion (%)	(0%) Control	(10%) Replacement	(20%) replacement	(30%) replacement
Slump Value (mm)	0	70	86	160

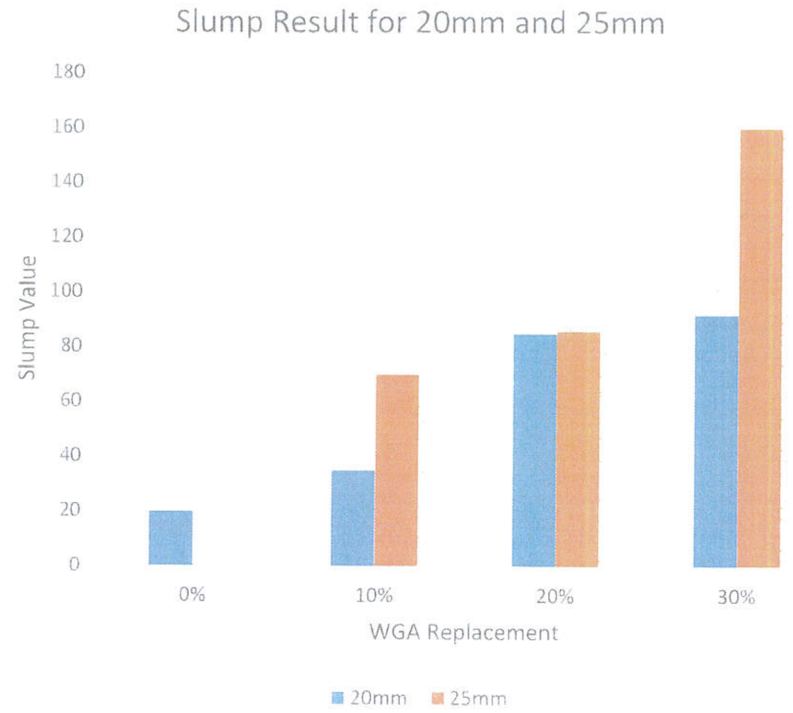

Figure: 4.2: Workability of 20mm and 25mm WGA replacement.

4.7 Compressive Strength

The compressive strength result for the 20mm and 25mm WGA replacement for all the curing ages are given in Table 4.4 and Table 4.5 respectively,

Table 4.4: Compressive Strength for 20mm WGA replacement

WGA %	Average Compressive Strength Of Concrete (N/Mm^2)				
	7 Days	14 Days	28 Days	56 Days	90 Days
0%	30.05	28.94	35.05	40.10	42.60
10%	30.10	27.98	33.62	39.82	40.20
20%	31.60	32.05	38.85	43.70	43.99
30%	32.14	32.91	39.02	44.62	45.70

Table 4.5: Compressive Strength for 25mm WGA replacement

WGA %	Average Compressive Strength Of Concrete (N/Mm^2)				
	7 Days	14 Days	28 Days	56 Days	90 Days
0%	29.74	30.57	34.02	42.60	49.80
10%	38.12	31.06	32.51	43.80	49.70
20%	31.18	31.85	38.02	44,04	49.74
30%	28.71	30.16	32.83	42,26	45.50

The change in the compressive strength for concrete with different proportion of WGA at different percentages (0%, 10%, 20&, 30&).for the 20mm granite replacement, the compressive strength was found to decrease at 10% WGA glass replacement and then increased progressively as the percentage of the glass increases from 20% to 30%, as shown in Figure 4.3.The maximum strength of the concrete cube was found at 30% replacement at 90 days which gave a compressive strength of 45.70 N/mm^2, while the lowest strength of the concrete cubes was found to be 27.98 N/mm^2 at 10% replacement of WGA at 14 days. The compressive strength of the concrete cubes with the different WGA was also found to increase as the curing ages of the cubes increased.

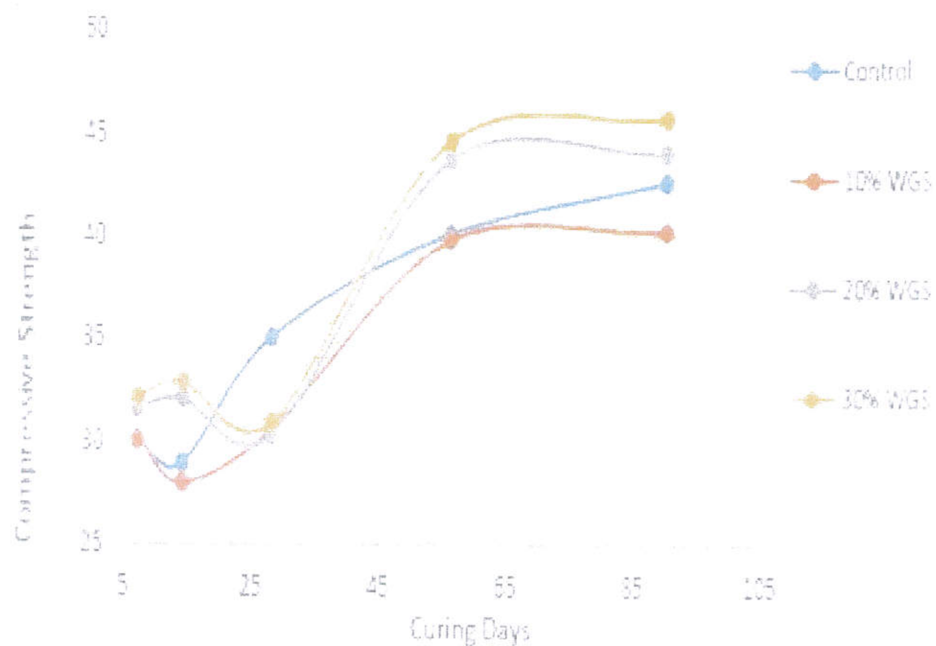

Figure 4.3: Compressive strength of concrete at 20mm WGA replaement at different proportion

The compressive strength for concrete with different proportion of WGA at different percentages (0%, 10%, 20%, 30%) for the 25mm granite replacement, the compressive strength was found to increase progressively at replacement from 0% to 20% and then continue to decrease at 30% replacement For all ages except for 7days and 28 days which does not increase progressively from 0% to 20% , before it later decreased at 30 % like the other ages, as shown in Figure 4.4. The maximum strength of the concrete cube was found at 0% replacement at 90 days which gave a compressive strength of 49.80 N/mm^2 while the lowest strength of the concrete cubes was found to be 28.71 N/mm^2 at 30% replacement of WGA at 7 days. The compressive strength of the concrete cubes with the different WGA was also found to increase as the curing ages of the cubes increased.

Figure 4.4: Compressive strength of concrete at 25mm WGA replaement at different proportion

4.8 Tensile Strength

The tensile strength result with varying percentage of 20mm WGA across the different curing ages are given in table 4.6

Table 4.6: Result of the tensile strength of concrete at 28days, 56days and 90days using 20mm WGA

WGA % In Concrete	Average Tensile Strength Of Concrete (N/Mm^2)		
	28 Days	56 Days	90 Days
0%	2.86	3.05	3.1
10%	2.90	3.26	2.97
20%	2.84	3.14	2.26
30%	2.84	3.12	1.98

The tensile strength for all the ages reached it maximum at 10% and graually began to fall as the percentages of the WGA increases except for the 90days result which strength decreases as the WGA increases from 0% to 30 %, as shown in Figure 4.5. The maximum strength was found to be 3.26 N/mm^2 at 10% WGA at 56 days curing age. and the minimum tensile strength es found to be 1.98 N/mm^2 30% WGA at 90days curing age.

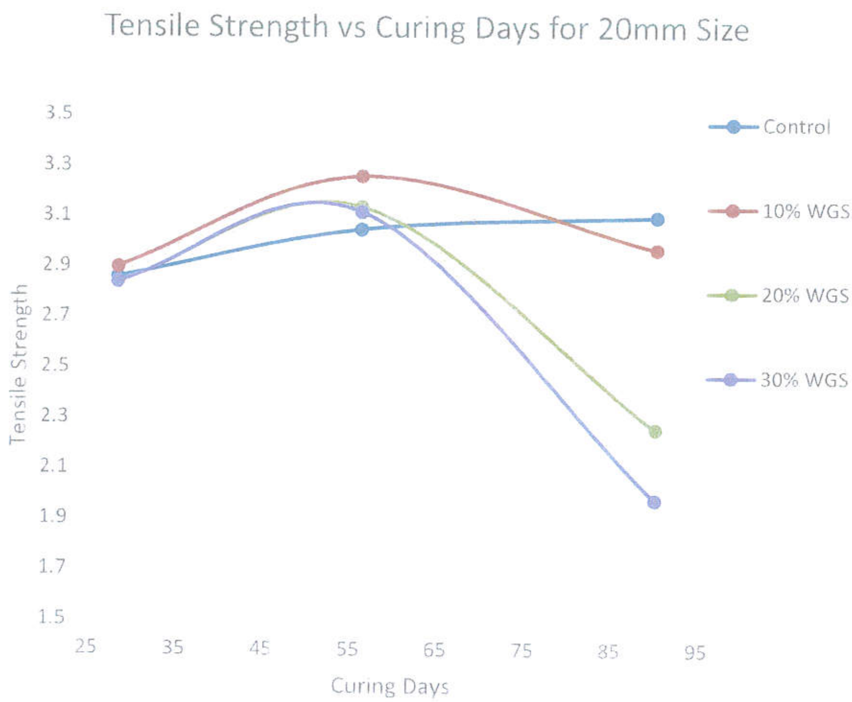

Figure 4.5: Variation in the tensile strength of the cylinderical concrete samples

The tensile strength result with varying percentage of 25mm WGA across the different curing ages are given in table 4.7

Table 4.7: Result of the tensile strength of concrete at 28days, 56days and 90days using 25mm WGA

WGA % In Concrete	Average Tensile Strength Of Concrete (N/Mm^2)		
	28 Days	56 Days	90 Days
0%	3.11	2.96	3.98
10%	2.55	3.09	4.27
20%	3.04	2.83	3.57
30%	2.76	2.71	2.75

The tensile strength for all the ages reached it maximum strength at 10% and graually began to fall as the percentages of the WGA increases except for the 28days result whose tensile strength decreases as the WGA increases in a non linear manner from 0% to 30%, as shown in Figure 4..6. The maximum strength for the 25mm WGA replacement was found to be 4.27N/mm^2 at 10% WGA at 90 days curing age. and the minimum tensile strength was found to be 2.55N/mm^2 10% WGA at 28days curing age.

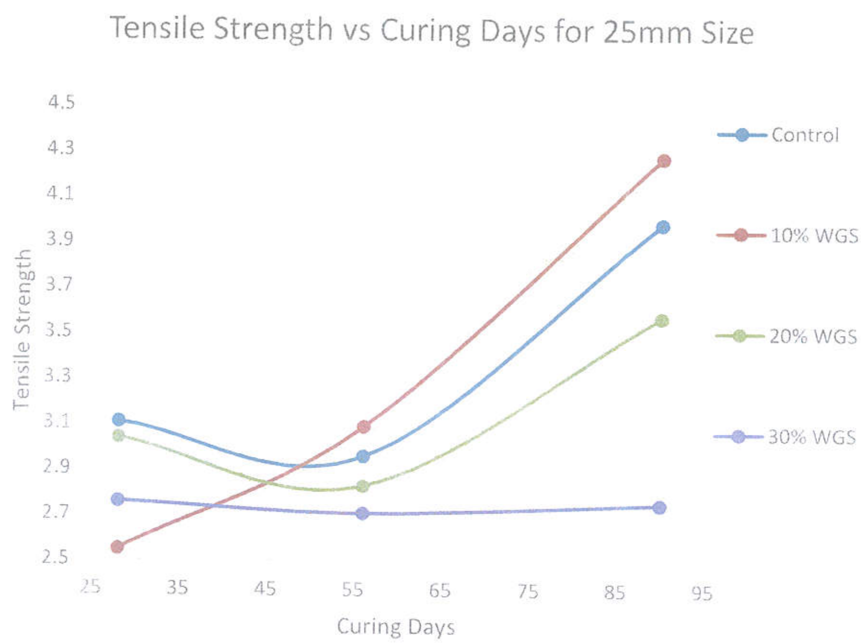

Figure 4.6: Tensile strength of concrete at 25mm WGA replaement at different proportion

4.9 Density of Concrete Specimens with 20mm & 25mm

Density of concrete with different proportion of WGA using 20mmes coarse aggregate considered at different curing age is shown in Table 4.8 and it can be shown from the table that the density reduces as the percentage of the WGA increases, the lowest density for the 20mm was discovered to be 2325.93 Kg/m^3 of 20% WGA at 7days and the highest was discovered to be 2681.48 Kg/m^3 of 0% WGA at 90days

Table 4.8: Density of concrete with different proportion of WGA at various ages for 20mm and 25mm

Curing Age (days)	Proportion 20mm	Density (Kg/m^3)	Proportion 25mm	Density (Kg/m^3)
7	0	2370.37	0	2672.59
	10	2370.37	10	2672.59
	20	2325.93	20	2542.22
	30	2340.74	30	2382.22
14	0	2340.74	0	2400.00
	10	2346.66	10	2400.00
	20	2385.19	20	2355.56
	30	2370.37	30	2420.74
28	0	2376.30	0	2459.30
	10	2367.41	10	2444,44
	20	2370.37	20	2367.41
	30	2364.44	30	2340.74
56	0	2488.88	0	2672.60
	10	2488.88	10	2503.70
	20	2370.37	20	2441.48
	30	2503.70	30	2382.22
90	0	2681.48	0	2663.70
	10	2503.70	10	2545.19
	20	2367.41	20	2311.11
	30	2367.41	30	2370.37

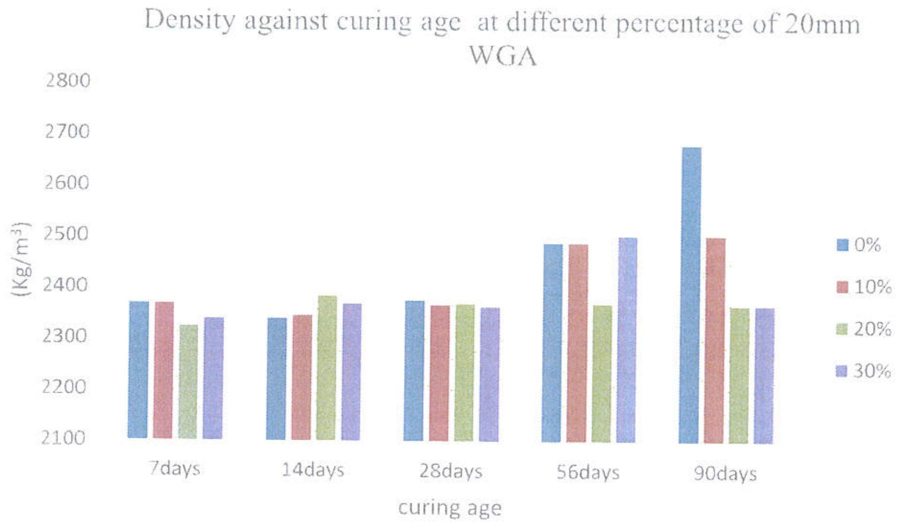

Figure 4.7: Density against curing age at different percentage of 20mm WGA

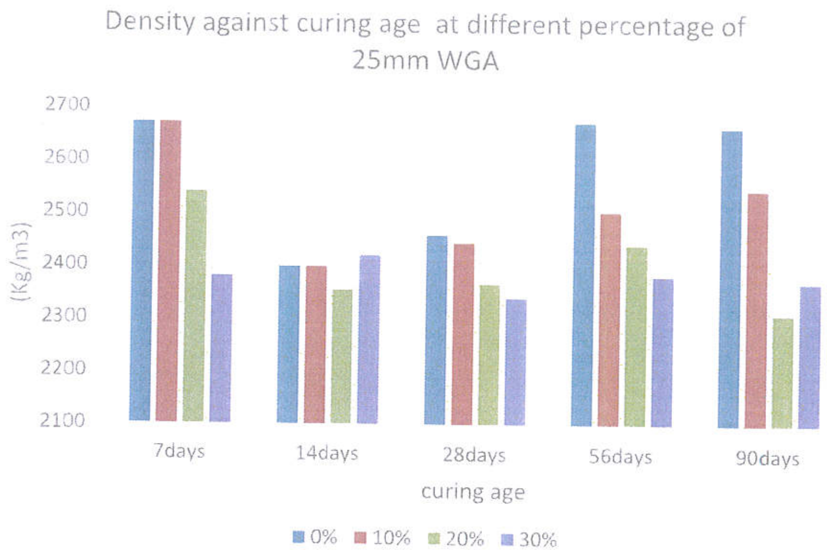

Figure 4.8: Density against curing age at different percentage of 25mm WGA

Also, considering the three types of concrete based on density which are: Lightweight, Normal weight and Heavy Weight Concrete, from the knowledge that concrete having densities in the range of 300 – 1950kg/m^3 are classified as lightweight concrete; those in the range of 2200 – 2400kg/m^3 as normal weight concrete, and concrete with densities greater than 2500 kg/m^3 are regarded as heavyweight concrete (Falade et al., 2011), and since all the concrete with different proportion percentage with different curing age ranges in densities between 2325.93 and 2681.48kg/m^3, the concrete are classified as a Normal weight concrete an heavy weight concrete, and this helps in the optimization of concrete density to improve structural efficiency (the strength to density ratio) & reduce transportation costs.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

This research studied the variation in the strength properties of concrete using waste glass as partial replacement for different coarse aggregates grading (20mm and 25mm) during the course of this study, preliminary investigations including chemical analysis, specific gravity moisture content and bulk density were carried out. In addition to these, major investigations including compressive strength, tensile strength, and density were also carried out.

Based on the above findings of this study, the following conclusions were drawn;

i. The physical and mechanical properties of the WGA are satisfactory, based on BS 882 (1992). Mechanical properties such as specific gravity and bulk density values are found to be lower than corresponding values for the coarse aggregates, (granite). Waste glass aggregates WGA possess a low moisture content which affect the workability of the concrete at the mixing stage with subsequent effect on the hydration of the cement. Based on the physical properties of waste aggregate, WGA is a potential replacement for granite in regard with its different grading.

ii. For the 20mm WGA replacement, the compressive strength at 10% was found to be lesser than that of the control (i.e. 0%) and the strength started increasing as the WGA increases progressively from 20% to30% increment and the maximum compressive strength was at 30% for the 20mm WGA. The compressive strengths also increased as the curing age increased from 7days to 90days

iii. Likewise, for the 25mm WGA replacement, the compressive strength of concrete at 10% was found to be lesser than that of the control (i.e. 0%) and the strength was at it maximum at 20% 25mm WGA replacement and the strength fell at further increment (i.e. 30%) .

iv. The compressive strength of concrete with both 20mm and 25mm WGA increases as the curing age of the concrete increases progressively from 7days up to 90days as shown in figure 4.3 and 4.4.

v. Result shows that the tensile strength for all the ages reached it maximum strength at 10% and graually began to fall as the percentages of the WGA increasesfor both 20mm and 25mm WGA replacement except for the 28days and 90days result whose tensile strength decreases as the WGA increases in a non linear manner from 0% to 30%. for the 25mm rand 20mm eplacement respectively The workability of the concrete increased progressively as the addition of the WGA increases for both 20mm and 25mm coarse aggregate

vi. The workability in the concrete mix with the 25mm WGA was found to be greater than that of the 20mm WGA because the 25mm WGA provides a greater void in the concrete mix, allowing for more air and water in the concrete mix which in turn result to the concrete mix of 25mm being more workable than the 20mm WGA

vii. The test result shows that the tensile strength for all the ages reached it maximum strength at 10% for 20mm and 25mm WGA and graually began to fall as the percentages of the WGA increases except for the 20mm 90days curing age and the 29days curing age for 25mm WGA replacement.

viii. The densities of concrete with different proportion of WGA for the 20mm and 25mm coarse aggregate replacement ranges from densities of 2240 and 2400kg/m^3 and are classified as a Normal weight concrete and this helps in the optimization of concrete density to improve structural efficiency (the strength to density ratio), reduce transportation costs, and also enhance the hydration of high cementations concrete mixtures with low water-binder ratios.

ix. The mix design used for this work. That is, M25 was found suitable for the WGA replacement as the resulting compressive strengths for all the ages did not fall below 25N/mm^2 which was the minimum compressive strength of concrete of ratio 1:1:2is suitable for standard construction

x. WGA is suitable in Civil Engineering construction with design mix M 25 up to 30% replacement without compromising the strength of the concrete

Recommendations

i. Waste glass aggregate (WGA) is a potential construction material suitable for use with ready and cheap availability which will help in making the natural aggregates sustainable and help to reduce the environmental and disposal problems in countries with inadequate disposal facilities

ii. More investigative studies should be done using M25 mix with 20mm & 25mm WGA replacement to see the percentage at which the replacement will become unsafe for use
iii. Countries' with depleting natural aggregates should begin to consider WGA as an alternative to avoid further depletion which might cause an adverse effect on the environment
iv. WGA has a very low porosity which allows no or little water to be absorbed or retained on it. Care must be taken in the water content chosen while using WGA as an aggregate so as not to encounter unsuitable working conditions with the material.

REFERENCES

Abdulwahab, R., and Ajamu, S.O., (2016). Effect of broken glass as a partial replacement for granite in the production of concrete research journal of civil engineering Vol. 1, No .2 November (2015)

Agama. T., Durga S., and Chandrakala. B. 2016 "Partial Replacement of coarse Aggregate With Waste Glass Pieces and Steel Waste" International Journal of Engineering Science and Computing

Agamuthu, P., Fauziah, S.H., and Kahlil, K., (2009). Evolution of solid waste Management in Malaysia: impacts and implications of the solid waste bill. J Mater Cycles Waste Manage (Oxford); 11: 96–103.

Agarwal, S. K. (2006). Pozzolanic activity of various siliceous materials. Cement and Concrete Research, 36(9), 1735-1739.

Alex, A., (2015). Shear Strength Properties of Structural Lightweight Reinforced Concrete Beams And Two-Way Slabs Using Palm Kernel Shell coarse Aggregates. Kumasi: Kwame Nkrumah University of Science and Technology.

Ali, E. E., & Al-Tersawy, S. H. (2012). Recycled glass as a partial replacement for fine aggregate in self-compacting concrete. Construction and Building Materials, 35, 785-791.

Ashok. H., (2010), Use of aggregate screening as a substitute for silica sand Portland cement (PCC), Technical Report, 1-149,

American Standard of Testing Materials C125-07, (2007). Standard Terminology Relating to Concrete and Concrete Aggregates. West Conshohocken, PA www.astm.org.

American Standard of Testing Materials C330. (1999.) Standard Specification for Lightweight Aggregates for Structural Concrete, .West Conshohocken, PA: American Standard for Testing Materials (ASTM) International,

Batayneh. M., Iqbal. M., and Ibrahim. A (2007). "Use of selected waste materials In concrete mixes. "Waste management 27.12: 1870-1876.

Bates, R. L., and J. A. Jackson. (1980)."Glossary of Geology, 2nd." American Geological nstitute 751

Begum, R. A., Siwar, C., Pereira, J. J., & Jaafar, A. H. (2007). Implementation of waste management and minimization in the construction industry of Malaysia. Resources, conservation and Recycling, 51(1), 190-202.

Boopath. P, Dinesh P., Krishnan. B., Karthi T., Kokila. S., (2017) Experimental Investigation on Partial Replacement of Coarse Aggregate by Recycled Concrete Aggregate and Crushed Waste Glass in Concrete SSRG International Journal of Civil Engineering.

BS 1881: Part 102. (1983) Testing concrete: Part 102. Method for determination of slump. 2 Park Street London Wl A 2BS: British Standards Institution,

BS 8110. (1997) Structural use of concrete. 389 Chiswick High Road London W4 4AL: BSI Publications,

BS 812. Testing Aggregate (1985) - Methods for determination of particle size distribution BS 812: Part 103. 389 Chiswick High Road London W4 4AL. British Standards Institution, BSI Publication,.

BS 812. Testing Aggregate (1990) - Methods for determination of the aggregate impact value (AIV) BS 812: Part 112. 389 Chiswick High Road London W4 4AL. British Standards Institution, BSI Publications,

BS 812. Testing Aggregates (1995) - Method of determination of density BS 812: Part 2. 389 Chiswick High Road London W4 4AL: British Standards Institution, BSI Publication,

BS 812. Testing Aggregates (1990) - Methods for determination of aggregate abrasion value (AAV) BS 812: Part 113. 389 Chiswick High Road London W4 4AL. British Standards Institution, BSI Publication,

BS 812. Testing Aggregates (1990) - Methods for determination of aggregate crushing value (ACV) BS812: Part110. 389 Chiswick High Road London W4 4AL.British Standards Institution, BSI Publications,

BS 812. Testing Aggregates (1990) - Methods for determination of moisture content, BS 812: Part 109. 389 Chiswick High Road London W4 4AL: British Standards Institution, BSI Publication,

BS 812. Testing Aggregates (1995) - Methods of determination of density. 389 Chiswick High Road, London W4 4AL: British Standards Institution, BSI Publications, BS 882. (1992) Specification for Aggregates from Natural Sources for Concrete. Chiswick High Road London: BSI Publications,

BS1881: Part 116. (1992). Testing concrete. Method for determination of compressive strength of concrete cubes. 389 Chiswick High Road London.

Caijun, S. and Keren, Z., A., (2007). A review on the use of waste glasses in the Production of cement and concrete" The Journal of Resources, Conservation, and Recycling, Vol. 52, pp. 234–247.

Čechák, T., Kopecká, I., Trojek, T., Štanzel, T., & Bártová, H. (2015). Application of X-ray fluorescence in an investigation of photographic heritage. Radiation Physics and Chemistry.

Cecil. C., Handisyde, (1969). Building Materials Science and Practice. London, The Architect Press.

Clvilolgy. V., (2017.) Lab test; Compressive Strength of concrete cubes.. http://www.civilology.com/compressive strength of concrete cubes/.

Davorin, k., (2009.) "Experimental study of recycling lightweight concrete with aggregates containing expanded glass", Process Safety and Environmental Protection, Vol. 87, pp.267-273,

Dr. Andrew M., (2007).Characterization of Mineral Wastes, Resources and Processing technologies, Integrate waste management for the production of construction material, Case study 1-8,

Federico, L. and Chidiac, S., (2009.) Waste glass as a supplementary cementitious material in concrete: Critical review of treatment methods Cement & Concrete Composites, Vol.31, pp. 606–610,

Francis A.J. (1997). The Cement Industry 1796–1914: A History, David and Charles, England.

Golterman, P, Johansen, V. and Palbol. L. "Packing of Aggregates: An Alternative Tool to Determine the Optimal Aggregate Mix." Materials Journal of American Concrete institute. Vol. 94(5), 1997: 435.

Hong, L., Huiying, B., and Ewan, A., (2007) Use of waste glass as aggregate in concrete UK CARE Annual General Meeting, UK Chinese Association of Resources and Environment, Greenwich.

Idir, R., Cyr, M., and Tagnit. A., (2010). "Use of fine glass as ASR inhibitor in glass aggregate mortars" Construction and Building Materials, Vol. 24, pp. 1309–1312,

Ismail, Z. and Al-Hashmi, E., (2009). "Recycling of waste glass as a partial replacement for fine Aggregate in concrete", Journal of Waste Management, Vol. 29, pp. 655-659,

Karthik, O., Haejin, K. and Colin. L. (2007). Effect of Continuous (Well-Graded) Combined Aggregate Grading on Concrete Performance Phase A: Aggregate Voids Content (Packing Density). National Ready Mix Concrete Association (NRMCA),

Kara, P., Csetényi, L.J., and Borosnyói,A., (2016). Performance Characteristics of Waste Glass Powder substituting Portland cement in Mortar Mixtures, IOP Conf. Ser.: Material .Sci. Eng. 123.

Kaveh. A., and Prasadarao. R (2015). Influence of Fineness of Ground Recycled Glass On Mitigation of Alkali–Silica Reaction in Mortars, 257, 267, Construction and Building Materials – 81.

Kaveh, A., Prasada, R. R., (2016). Impact of Combined Use of Glass Powder and Crushed Glass Aggregate on Selected Properties of Portland cement concrete, 263, 272 Construction and Building Materials –117.

Khmiri, M., and Chaabouni, B. S., (2013). Chemical Behavior of Ground Waste Glass Powder when Used as Partial Cement Replacement in Mortars, 74, 80, Construction and building Materials – 44.

Kou, S. and Poon, C., (2009). Properties of self-compacting concrete prepared with recycled glass aggregate, Cement and Concrete Composites Journal, Vol. 31, pp. 107 – 113.

Lee, M., Ko, C., Chang, F., Lo, L., Lin, J., Shan, M., and Lee, J., "Artificial stone slab Production using waste glass, stone fragments, and vacuum vibratory compaction", Cement and Concrete Composites, Vol. 30, pp. 583-587, April 2008.

Mannesh. J., (2010).Use of Crushed Granite Fine as Replacement to River Sand in Concrete Production, Leonardo Electronic Journal of Practices and Technologies, 9(17),

Mehta, P. K., and. Monteiro. P. J (1993) Concrete: Structure, Properties, and Materials.

New ersey: Prentice-Hall,

Meyer, C., Egosi, N., and Andela, C., (2001). "Concrete with Waste Glass as Aggregate" International Symposium Concrete Technology Unit of ASCE and University of Dundee,

Mageswari1, M. and Dr. Vidivelli, B., ,(2010).The Use of Sheet Glass Powder as Fine Aggregate Replacement in Concrete, The Open Civil Engineering Journal, 4,65-71

NarasinhaRaju1 V.R.K. and Reddy, T. A (2009), Workability and Strength characteristics of Cement Concrete with Partial Replacement of River Sand by Manufactured Fine aggregate, International Journal of Mechanics and Solids,4, (1), 95-104

ShahulHameed M. and Sekar, A. S. S. (2009) Properties of Green Concrete Containing Quarry Rock Dust and Marble Sludge Powder as Fine Aggregate, ARPN Journal of Engineering and Applied Sciences,4(4), 83-89,

Palmquist, S., (2003) "Compressive behavior of concrete with recycled aggregates", Ph.D. Thesis, TUFTS University,

Park, S .Lee, B., and Kim, J., (2004). Studies on mechanical properties of concrete containing waste glass aggregate", Cement and Concrete Research, Vol. 34, pp. 2181-2189,

Pereira L. A. and Oliveira 1 J.P. (2008). Castro-Gomes 2P. Santos 3 Mechanical and Durability Properties of Concrete with Ground Waste Glass Sand, International Conference on Durability of Building Materials and Components Istanbul, 11 -14

Popovics, S. (1992) Concrete Materials Properties, Specifications and Testing, 2nd Edition. New Jersey, USA: Noyes Publication.

Quiroga, P. N., and W. D. Fowler. (2004). The effects of aggregates characteristics on the performance of Portland cement concrete. Austin, USA

Rached, M., Moya, D. M. and Fowler. D.W. (2009). Utilizing Aggregates Characteristics to Minimize Cement Content in Portland cement Concrete. Austin USA: International Center for Aggregates Research (ICAR 401). Report by ACI Committee (1999). 549, 594.1R 93 Guide for the Design, Construction &Repair of Ferro cement, Reapproved.

Saccani, A. and Bignozzi, M., (2010). ASR expansion behavior of recycled glass fine aggregates in Concrete. Cement and Concrete Research, Vol. 40, pp. 531 – 536,

Shalini. S., (2017). Partial replacement of coarse aggregate with waste glass in concrete International journal of innovative research in science engineering and technology Vol. 6. Issue April.

Schuura, H.M.L. (2007). Calcium silicate products with crushed building and demolition waste, Journal of Materials Civil Engineering, Vol.12, special issue: eco-cementitious materials, 282–287.

Schott. G, (2007). Physical and Technical Properties of Glasses, Technical Report, Mainz Germany.

Keerthinarayana, S., and Srinivasan, R., (2010). Study on Strength and Durability of Concrete by Partial Replacement of-63.

Shi, C. and Zheng, K., A review on the use of waste glasses in the production of cement andconcrete, Resources, Conservation, and Recycling, Vol.52, pp. 234-247, 2007

Topçu, I. and Canbaz, M., (2004). Properties of concrete containing waste glass, Cement and Concrete Research Journal, Vol. 34, pp. 267 – 274,

Topçu, I, Boga, A., and Bilir, T., (2007). Alkali-silica reactions of mortars produced by using waste glasses fine aggregate and admixtures such as fly ash and Li_2CO_3, Waste Management, Vol.28, pp. 878 – 884.

Veera. R. and Shinkul M, (2010). Investigations on stone dust and ceramic scrap as aggregate replacement in Concrete, International Journal Of Civil And Structural Engineering, Vol.1, No.3, 661-666.

Yaqub, M., and Bukhari. I. (2006). Effect of size of coarse aggregate on compressive strength of high strength concretes. Our world in Concrete and Structures. Singapore: Available online: http://cipremier.com/100031052,

Zawde, B., (1983). Compressive strength of mortar in hot-humid environment. Strength, Mortars, Hot-Climate, High Humidity Vol.13, No.2, 1983: 225-232.