Civil Engineering Department
Wolkite university, College of Engineering and Technology

Use of Waste Glass as a Partial Replacement of Coarse Aggregate and Decorative Tile

Aregahngn Achayehu[1], Masresha Abebe[2], Muluken wolde[3], Frezer Eshetu[4], Meskerm Zerihun[5], Selamnesh Asegd[6]

Advisor/s

Aliyu Nursefa & Misganaw B

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[1] Wolkite University, Civil Engineering Department, ID Number Engr117/08
[2] Wolkite University, Civil Engineering Department, ID Number Engr562/08
[3] Wolkite University, Civil Engineering Department, ID Number Engr668/08
[4] Wolkite University, Civil Engineering Department, ID Number Engr1054/08
[5] Wolkite University, Civil Engineering Department, ID Number Engr1049/08
[6] Wolkite University, Civil Engineering Department, ID Number Engr979/08

Wolkite University, College of Engineering and Technology

Civil Engineering Department

As members of the examining board of the final B.Sc. open defense, we verify that we have read and evaluated the final BSc thesis prepared by Aregahngn Achayehu, Masresha Abebe, Muluken wolde, Frezer Eshetu, Meskerm Zerihun, and Selamnesh Asegd entitled Use of waste glass as a partial replacement of coarse aggregate and decorative tile, we recommended for acceptance as a fulfillment of the requirement of **B.Sc. in Civil Engineering**

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Internal Examiner	Signature	Date

Preface

This document is a report as a part of fulfilment for a Bachelor of Science in Civil Engineering. The study is conducted by Aregahngn Achayehu, Masresha Abebe, Muluken wolde, Frezer Eshetu, Meskerm Zerihun, and Selamnesh Asegd

Abstract

This research was carried out to investigate the use waste glass as partial replacement of coarse aggregate for structural concrete and decorative purpose for production of tiles. The study used laboratory test for concrete making material (fine aggregates, coarse aggregates and recycled crushed glass). Concrete mix design was prepared for C25 class of concrete using ACI mix design procedure. The coarse aggregate in each grade of concrete was replaced by recycled crushed glass a 5%, 15% and 30% by weight. The control mix without incorporation of recycled crushed glass was prepared which was used for reference for comparison of test result with those specimens produced by partial replacement. Generally 4 concrete mixes was prepared including the control mix for C25 class of concrete. Slump test was conducted for each grade of fresh concrete. The properties of hardened concrete were studied by conducting compressive strength. The compressive strength was carried out at the 3rd, 7thdays. Furthermore, terrazzo concrete was prepared by partial replacing coarse aggregates at 5% and 30% with recycled crushed glass. The test result obtained by partial replacement were compared with result of the control mix. In line with it the results obtained by concrete specimens produced by partial replacement were slightly greater than that of the control mix. The general results reveals that recycled crushed glass can be used for structural concrete and for decorative tile purpose.

KEYWORDS: Water, concrete, recycled crushed glass, aggregates, terrazzo, tiles.

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Above all, our special thanks go to the Almighty God.

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Acronyms

%-	Percent
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ASR	Alkali Silica Reaction
ASTM	American Society for Testing Materials
BS	British Standard
cm^3	centimeter cube
CPT	Concrete Prism Test
EBCS	Ethiopian Building Code Standard
ES	Ethiopian Standard
FM	Fineness Modulus
kg	Kilo gram
kg/m^3	Kilogram per meter cube
m	meter
m^3	meter cube
mm	millimeter
MPa	Mega Pascal
OPC	Ordinary Portland cement
PCA	Portland cement Association
PPC	Portland Pozzolanic cement
SCM	Supplementary Cementitious Material
SSD	Saturated surface dry
w/c	Water cement

1 Introduction

1.1 Background

Concrete is a composite material composed of aggregate, generally sand and gravel, chemically bound together by hydrated Portland cement. The aggregate generally is graded in size from sand to gravel; with the maximum aggregate size in structural concrete may be used (Liang et al., 2007).

Since aggregates make up about 60% - 75% of the total volume of concrete, their selection is important. Aggregates should consist of particles with adequate strength and resistance to exposure conditions and should not contain materials that will cause deterioration of the concrete. A continuous gradation of aggregate particle sizes is desirable for efficient use of the paste (Liang et al., 2007).

Glass is a non-crystalline amorphous solid that is often transparent and has wide spread practical, technological and decorative usage, for example, window panes, table ware, and optoelectronics. Scientifically the term glass is often defined in a broader sense, encompassing every solid that possesses a non-crystalline (that is amorphous) structure at the atomic scale and that exhibits a glass transition when heated towards the liquid state (Vijaya Sekhar et al., 2015).

Coloured recycled glass is a popular and environmentally friendly alternative to traditional stone and pebble based aggregate. The use of recycled glass as a concrete glass aggregate is sure to bring all of those that see it great visual appearance. 5-10mm glass is the most commonly used size grading in concrete aggregate and polished concrete applications.

The most familiar and historically the oldest type of glass are silicate glasses based on the chemical compound silica (silicon oxide or quartz), the primary constituent of sand. The term glass in popular usage is often used to refer only to this type of material, which is familiar from use as window glass and glass bottle

A very clear and durable quartz glass can be made from pure silica but the high melting point and very narrow glass transition of quartz make glass blowing and hot working difficult. In glasses like soda lime the compounds added to quartz are used to lower the melting temperature and improve workability at a cost in the toughness, thermal stability and optical transmittance .(Gautam et al., 2012)

Glass recycling is the process of using waste glass in to usable products. Glass waste should be separated by chemical composition and then depending on the end use and local processing capabilities might also have to be separated in to different colours .(Liang et al., 2007)

1.2 Statement of the problem

Crushed stone is the only sources of aggregate in our country, hence another additional sources should be arranged. Beside the most common color of concrete is grey hence this appearance of concrete should be amended by incorporating glass to produce decorative concrete. In addition Most of the time locally fabricated floor finish materials are common in esthetic appearance so there should be alternative material with unique appearance. Glass is one of the components of solid waste so alternative form of recycling should be devised to use it for useful purposes.

1.3 Objective of the study

1.3.1 General Objective

The general objective of the research is to utilize recycled crushed glass as partial replacement of coarse aggregates and its chips for production of decorative tile.

1.3.2 Specific Objectives

- To produce decorative concrete for floors, countertops, walls and pedestrian walkways from different types of recycled crushed glass.
- To study the properties of fresh and hardened concrete produced by partially replacing coarse aggregate with recycled crushed glass by conducting different types of concrete laboratory tests and to compare the result with the control mix.
- To suggest safe application area of decorative recycled crushed glass concrete.
- To make recommendations and conclusions based on the laboratory test results regarding decorative recycled glass concrete.

1.4 Significance of the Study

The study is believed to be beneficiary since it aims at providing concrete with unique aesthetic appearance where the coarse aggregate is partially replaced with recycled crushed glass. In addition, it plays great role in minimizing solid waste disposal and the related costs incurred for transportation of waste and it minimizes the space which would have been occupied by the waste glass.

The production process of crushed waste glass is environmentally friendly when compared with production of river sand and coarse aggregate where the later erodes river beds and the former emits high amount of dust. The study will provide concrete with unique appearance which will play significant role in the aesthetic of concrete.

1.5 Scope and Limitations of the Study

The scope of the study is limited to structural concrete and floor finish material (Terrazzo). The study doesn’t include high strength concrete. Due to the unavailability of testing equipment at Wolkite University material Laboratory test and the time frame used to do the research due to the outbreak of covid-19, tests like tensile strength of concrete, flexural strength of concrete, transverse strength, water absorption of terrazzo and flaky index of glass not included on the laboratory test.

For determination of its strength and durability of the concrete only the compressive strength of the concrete on 3rd and 7th days tested on the Laboratory due to the above reasons.

1.6 Possible Beneficiary of the Study

The possible beneficiary of the study will be the public and the construction society.

1.7 Organization of the Paper

This study organized into five chapters. The first chapter focused on the introductory part of the study, which includes background of the study, statement of the problem, objectives, significance, scope and limitation of the study. The second chapter contains literature review part of the study in which theoretical and empirical literatures related with the issue were incorporated. The third chapter deals about the research methodology: research design, approach and method; sampling design, sources of data, data collection methods, analysis and presentation were incorporated. The fourth chapter is all about the data analysis and interpretation, and finally the fifth chapter winds up by conclusion and gives recommendations to the problem related with building collapse. The following figure (Fig. 1) shows the organization and structure of the paper

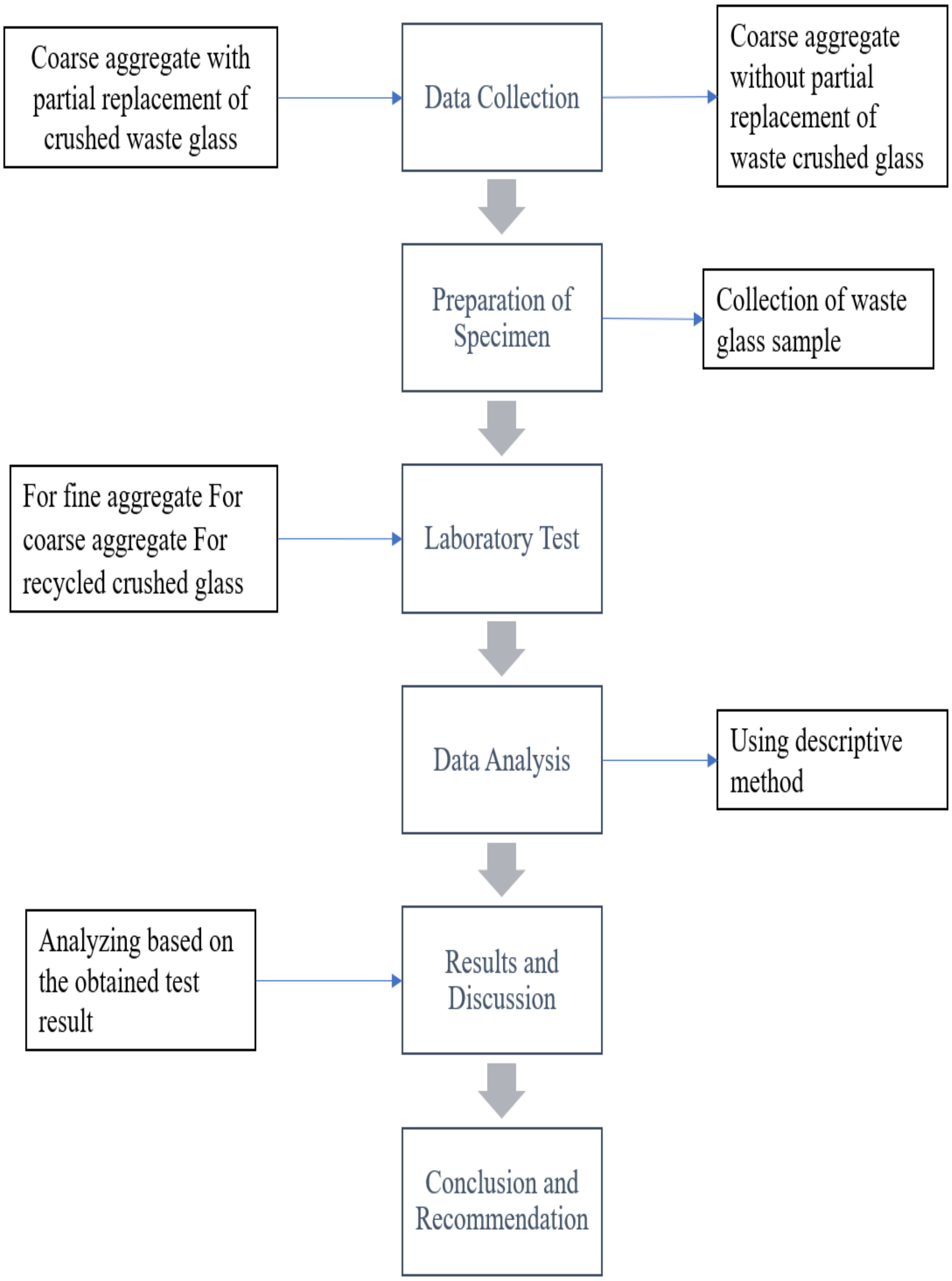

Figure 1flow chart of the thesis

2 Literature Review

2.1 Introduction

Concrete is basically a mixture of two components: aggregates and cement paste. The paste, comprised of Portland cement and water, binds the aggregates (usually sand and gravel or crushed stone) into a rock like mass as the paste hardens because of the chemical reaction of the cement and water. Supplementary cementations materials and chemical admixtures may also be included in the paste. (Steven H. et al., 2003)

Aggregates are generally divided into two groups; fine and Coarse. Fine aggregates consist of natural or manufactured sand with particle sizes ranging up to 9.5 mm; coarse aggregates are particles retained on the 1.18 mm sieve and ranging up to 37.5mm in size. The maximum size of coarse aggregate is typically 19 mm or 25 mm. An intermediate-sized aggregate, around 9.5 mm, is sometimes added to improve the overall aggregate gradation. An increase in the cement content in the mix and the use of well graded aggregate increases the strength of concrete.

2.2 Constituents of Concrete

Concrete consists of coarse and fine aggregate, cement water and in many cases different type of admixture. The materials are mixed together until a cement paste is developed, filling most of the voids in the aggregates and producing a uniform dense concrete. The plastic concrete is then placed in a mould and left to set, harden, and develop adequate strength .(Neville, 2013)

a) Aggregate

Since approximately three quarters of volume of concrete is occupied by aggregate, its quality is of considerable importance. Not only may the aggregate limit the strength of concrete but the aggregate properties greatly affect the durability and structural performance of concrete(Steven H. et al., 2003)

The strength of concrete is affected by the strength of the aggregate, its surface texture, its grading, and, to a lesser extent, by the maximum size of the aggregate. Strong aggregates, such as felsite, trap rock, or quartzite, are needed to make very-high strength concretes. Weak aggregates include sandstone, marble, and some metamorphic rocks, while limestone and granite aggregates have intermediate strength. Normal-strength concrete made with high-strength aggregates fails due to mortar cracking, with very little aggregate failure. The stress–strain curves of such concretes tend to have an appreciable declining branch after reaching the maximum stress (Steven H. et al., 2003).

On the other hand, if aggregate failure precedes mortar cracking, failure tends to occur abruptly with a very steep declining branch. This occurs in very-high-strength concretes and in some lightweight concretes. Concrete strength is affected by the bond between the aggregate and the cement paste. The bond tends to be better with crushed, angular pieces of aggregate. A well-graded aggregate produces a concrete that is less porous. Such a concrete tends to be stronger. The strength of concrete tends to decrease as the maximum aggregate size increases. This appears to result from higher stresses at the paste–aggregate interface.(Liang et al., 2007)

Aggregate was originally viewed as an inert, inexpensive material dispersed throughout the cement paste so as to produce a large volume of concrete. In fact aggregate is not truly inert because it’s physical, thermal, and sometimes, chemical properties influence the performance of concrete. It is advantageous to use a mix with as much aggregate and as little cement as possible, but the cost benefit has to be balanced against the desired properties of concrete in its fresh and hardened state.

Natural aggregates are formed by the process of weathering and abrasion, or by artificially crushing a larger parent mass. Thus many properties of the aggregate depend on the property of the parent rock, e.g. mineral and chemical composition, petrographic classification, specific gravity, hardness, strength, physical and chemical stability, pore structure, colour, etc. In addition, there are other properties of the aggregate which are absent in the parent rock:-particle shape and size, surface texture and absorption. All these properties may have a considerable influence on the quality of fresh and hardened concrete (Steven H. et al., 2003).

a) Size classification

Concrete is made with aggregate particles covering a range of sizes up to a maximum size which usually lies between 10mm and 50mm; 20mm is typical. The particle size distribution is called grading. The alternative, very much more common, and always used in the manufacture of good quality concrete; is to obtain the aggregate in at least two separate lots, the main division being at a size of 5mm or no. 4 ASTM sieve. This divides fine aggregate from coarse aggregate.

Grading is the particle-size distribution of an aggregate as determined by a sieve analysis (ASTM C 136 or AASHTO T 27). The aggregate particle size is determined by using wire- mesh sieves with square openings. The seven standard ASTM C 33 (AASHTO M 6/M 80) sieves for fine aggregate have openings ranging from 150µm to 9.5 mm (Steven H. et al., 2003).

The grading and grading limits are usually expressed as the percentage of material passing each sieve. There are several reasons for specifying grading limits and nominal maximum aggregate size; they affect relative aggregate proportions as well as cement and water requirements, workability, pump ability, economy, porosity, shrinkage, and durability of concrete. Variations in grading can seriously affect the uniformity of concrete from batch to batch. Very fine sands are often uneconomical; very coarse sands and coarse aggregate can produce harsh, unworkable mixtures. In general, aggregates that do not have a large deficiency or excess of any size and give a smooth grading curve will produce the most satisfactory results.

b) Fine Aggregate Grading

Fine aggregates generally consist of natural sand or crushed stone with most particles smaller than 5 mm. Table 2.1 below shows grading limit of fine aggregate with different opening size of sieve

Table 1 fine aggregate grading limit (Steven H. kosmatka, 2003)

Sieve Size	**Percent passing by mass**
9.5mm	100
4.75mm (No. 4)	95 to 100
2.36mm(No. 8)	80 to 100
1.18mm(No. 16)	50 to 85
600 μ m(No. 30)	25 to 60
300 μ m(No. 50)	5 to 30 (AASHTO 10 to 30)
150 μ m(No. 100)	0 to 10 (AASHTO 2 to 10)

2.2.3 Coarse-Aggregate Grading

The coarse aggregate grading requirements of ASTM C 33 (AASHTO M 80) permit a wide range in grading and a variety of grading sizes. The grading for a given maximum-size coarse aggregate can be varied over a moderate range without appreciable effect on cement and water requirement of a mixture if the proportion of fine aggregate to total aggregate produces concrete of good workability. Mixture proportions should be changed to produce workable concrete if wide variations occur in the coarse-aggregate grading. Since variations are difficult to anticipate, it is often more economical to maintain uniformity in manufacturing and handling coarse aggregate than to reduce variations in gradation. The maximum size of coarse aggregate used in concrete has a bearing on the economy of concrete. Usually more water and cement is required for small-size aggregates than for large sizes, due to an increase in total aggregate surface area.

a) Shape and texture classification

The external characteristics of the aggregate, in particular the particle shape and surface texture, are important with regard to the properties of fresh and hardened concrete. The shape of three dimensional bodies is difficult to describe, and it is convenient to define criteria geometrical characteristics of such bodies.

Roundness measures the relative sharpness or angularity of the edges and corners of particle, the actual roundness is a consequence of the strength and abrasion resistance of the parent Rock and of the amount of wear to which the particle has been subjected. In the case of crushed aggregate, the shape depends on the nature of the parent material and on the type of crushes and its reduction ratio, i.e. the ratio of initial size to that of the crushed product. A convenient classification of particle shape is given in Table 2.2 below.

Table 2 particle shape classification of coarse aggregates

Classification	**Description**	**Examples**
Rounded	Fully water worn or completely shaped by attrition	River or seashore gravel; desert, sea shore and windblown sand
Irregular	Naturally irregular, or partly shaped by attrition and having rounded edges	Other gravels; land or dug Flint
Flaky	Material of which the thickness is small relative to other two dimensions	Laminated rock
Angular	Possessing well defined edges formed at the intersection of roughly planar faces	Crushed rock of all types; talus; crushed slag
Elongated	Material usually angular, in which the length is considerably larger than the other two Dimensions	
Flaky and Elongated	Material having the length considerably larger than the width, and width considerably larger than thickness	

Another aspect of the shape of coarse aggregate is its spherecity, defined as a function of the ratio of surface area of particle to its volume. Sphercity is related to the bedding and cleavage of the parent rock, and is influenced by the type of crushing equipment when the size of particle has been artificially reduced. Particles with high ratio of surface area to volume are of particular interest as they lower workability of the mix.

2.2.1 Mechanical properties

It is not possible to relate the potential strength development of concrete to the properties of the aggregate, and indeed it is not possible to translate the aggregate properties into its concrete making properties (Neville, 2013).

a. Bond

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

The determination of the quality of bond is rather difficult and no accepted test exists. Generally, when bond is good, a crushed concrete specimen should contain some aggregate particles broken right through; in addition to the more numerous ones separated by the paste matrix. However, an excess of fractured particles suggests that the aggregate is too weak(Neville, 2013).

b. Strength

Clearly the compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained therein, although it is not easy to determine the crushing strength of the aggregate itself. A few weak particles can certainly be tolerated; after all, air voids can be viewed as aggregate particles of zero strength.

The required information about aggregate particles has to be obtained from indirect tests; crushing strength of prepared rock samples, crushing value of bulk aggregate, and performance of aggregate in concrete. Testes on prepared rock samples are little used, but we may note that a good average value of crushing strength of such samples is about 200MPa, although many excellent aggregates range in strength down to 80MPa. It should be observed that the required aggregate strength is considerably higher than the normal Range of concrete strength because the actual stress at points of contact of individual particles may be for in excess of the nominal applied compressive stress (Neville, 2013).

2.2.2 Physical properties

Several common physical properties of aggregate are relevant to the behaviour of aggregate in concrete and to the properties of concrete made with the given aggregate.

a) Specific gravity

Since aggregate generally contains pores, both permeable and impermeable, the meaning of the term specific gravity has to be carefully defined, and there are indeed several types of this measure. According to ASTM C 127-04, specific gravity is defined as the ratio of the density of a material to the density of distilled water at stated temperature; hence, specific gravity is dimensionless.

The absolute specific gravity and the particle density refers to the volume of the solid material excluding all pores, whilst the apparent specific gravity and the apparent particle density refers to the volume of solid material including the impermeable pores, but not the capillary ones. It is the apparent specific gravity or the apparent particle density which is normally required in concrete technology, the actual definition being the ratio of the mass of aggregate dried in an oven at 100 to 110 ˚c for 24 hrs. To the mass of water occupying a volume equal to that of the solid including the impermeable pores.

The bulk specific gravity (SSD) and the bulk particle density are most frequently and easily determined, and are necessary for calculations of yield of concrete or the quantity of aggregate required for given volume of concrete.

The majority of natural aggregates have an apparent specific gravity of between 2.6 and 2.7, whilst the values for light weight and artificial aggregates extend considerably from below to very much above this range. Since the actual value of specific gravity or particle density is not a measure of the quality of the aggregate, it should not be specified unless we are dealing with a material of a given petrologic character when a variation in specific gravity or particle density would reflect a change in the porosity of the particles.

b) Bulk density

It is well-known that in the metric system the density of a material is numerically equal to the specific gravity although, of course, the latter is a ratio of while density is expressed in kilograms per litter. The absolute density refers to the volume of individual particles only, and of course it is not physically possible to pack these particles so that there are no voids between them, thus, when aggregate is to be batch by volume it is necessary to know the bulk density which is the actual mass that would fill a container of unit volume, and this density is used to convert quantities by volume. The bulk density depends on how densely the aggregate is packed and, consequently on the size distribution and shape of the particles. Thus the degree of compaction has to be specified.

As mentioned earlier, the bulk density depends on the size distribution of the aggregate particles all of one size can be packed to a limited extent but smaller particles can be added in the voids between the larger ones thus increasing the bulk density, in fact the maximum bulk density of a mixture of fine and coarse aggregates is achieved when the mass of the fine aggregate is approximately 35 to 40 percent of the total mass of aggregate. Consequently, the minimum remaining volume of voids determines the minimum cement paste content and therefore, the minimum cement content; this latter is, of course, of economic importance.

c) Fineness Modulus

The fineness modulus (FM) of either fine or coarse aggregate according to ASTM C 125 is calculated by adding the cumulative percentages by mass retained on each of a specified series of sieves and dividing the sum by 100. The specified sieves for determining FM are: 150 µm (No. 100), 300 µm (No. 50), 600 µm (No. 30), 1.18 mm (No. 16), 2.36 mm (No. 8),

4.75 mm (No. 4), 9.5 mm , 19.0 mm, 37.5 mm , 75 mm and 150 mm. FM is an index of the fineness of an aggregate—the higher the FM, the coarser the aggregate. Different aggregate grading may have the same FM. FM of fine aggregate is useful in estimating proportions of fine and coarse aggregates in concrete mixtures.(Neville, 2013).

d) Absorption and Surface Moisture

The absorption and surface moisture of aggregates should be determined according to ASTM C 70, C 127, C 128, and C 566 (AASHTO T 255) so that the total water content of the concrete can be controlled and correct batch weights determined. The internal structure of an aggregate particle is made up of solid matter and voids that may or may not contain water. Coarse and fine aggregate will generally have absorption levels (moisture contents at SSD) in the range of 0.2% to 4% and 0.2% to 2%, respectively. Free-water contents will usually range from 0.5% to 2% for coarse aggregate and 2% to 6% for fine aggregate. The maximum water content of drained coarse aggregate is usually less than that of fine aggregate. Most fine aggregates can maintain maximum drained moisture content of about 3% to 8% whereas coarse aggregates can maintain only about 1% to 6%.(Steven H. et al., 2003).

2.2.3 Cement

Portland cements are hydraulic cements composed primarily of hydraulic calcium silicates. Hydraulic cements set and harden by reacting chemically with water. During this reaction, called hydration, cement combines with water to form a stone like mass, called paste. When the paste (cement and water) is added to aggregates it acts as an adhesive and binds the aggregates together to from concrete, the world's most versatile and most widely used construction material.

Portland cement is produced by pulverizing clinker which consists primarily of hydraulic calcium silicates. Clinker also contains some calcium aluminates and calcium alumina ferrites and one or more forms of calcium sulphate (gypsum) is interact with the clinker to make the finished product. Materials used in the manufacture of Portland cement must contain appropriate amounts of calcium, silica, alumina, and iron components. During manufacture, chemical analyses of all materials are made frequently to ensure uniformly high quality cement.

a) Water

The quality of water is important because impurities in it may interfere with the setting of the cement, may adversely affect the strength of the concrete or cause staining of its surface and also may lead to corrosion of the reinforcement. For these reasons, the suitability of water for mixing and curing purposes should be considered

Mixing water - Water that is suitable for drinking and that has no pronounced taste or odour may be used. It is generally thought that the PH of the water should be between 6.0 and 8.0.

Salt water must not be used as mixing water, because chlorides and other salts in such water will attack the structure of the concrete and may lead to corrosion of pre stressing tendons.(Liang et al., 2007)

2.3 Properties and proportions of concrete Constituents

Concrete is a mixture of cement, aggregate and water. An increase in the cement content in the mix and use of well graded aggregate increases the strength of concrete.

2.3.1 Properties of fresh concrete

When concrete is freshly produced, it is plastic in behaviour and is often called plastic concrete. The requirements for fresh concrete include the time available for placing it into formwork and workability. Workability is often referred to as the ease with which a concrete can be transported, placed and consolidated without excessive bleeding or segregation.

In everyday practice, slump is the most common test for workability. The main purpose of this test is intended to detect the change in water content as indicated by a change in slump. Before the age of chemical admixtures, a higher slump is deemed to indicate higher water content and may result in lower strength due to the likely higher water/cement ratio.

The use of mechanical concrete mixers and the proper time of mixing both have favourable effects on strength of concrete. Also the use of vibrators produces dense concrete with a minimum percentage of voids. A void ratio of 5% may reduce the concrete strength by 30%.(Nadim M, 2008).

2.3.1 Properties of hardened concrete

Generally, the term concrete strength is taken to refer to the uniaxial compressive strength as measured by a compression test of a standard test cylinder or cube, because this test is used to monitor the concrete strength for quality control or acceptance purposes. For convenience, other strength parameters, such as tensile or bond strength, are expressed relative to the compressive strength.(Liang et al., 2007)

a) Compressive Strength

Among the large number of factors affecting the compressive strength of concrete, the following are probably the most important for concretes used in structures. These are; water cement ratio, type of cement, supplementary cementitious material, aggregate type, mixing.

Water, moisture condition during curing, temperature condition during curing, age of concrete, maturity of concrete and rate of loading.

The curing conditions exercise an important influence on the strength of concrete. Both moisture and temperature have a direct effect on the hydration of cement. The longer the period of moisture storage; the greater the strength of concrete.(Nadim M, 2008)

a) Age of Concrete

The strength of concrete increases appreciably with age, and hydration of cement continues for months. In practice the strength of concrete is determined from cylinders or cubes tested at the age of 7 days and 28 days. As a practical assumption concrete at 28 days is 1.5 times as strong as at 7 days. The range varies b/n 1.3 and 1.7. The British Code of Practice accepts concrete if the strength at 7 days is not less than two thirds of the required 28 days strength. For a normal Portland cement, the increase of strength with time, relative to 28 days strength, may be assumed as follows:

Table 3 age of concrete

Age	7 days	14 days	28 days	3 months	6 months	1 year	2 years	5 years
Strength ratio	0.67	0.86	1	1.17	1.23	1.27	1.31	1.35

2.4 The use of recycled crushed glass in concrete construction

2.4.1 Introduction

Glass is a transparent material produced by melting a mixture of materials such as silica, soda ash, and $CaCO_3$ at high temperature followed by cooling where solidification occurs without crystallization. Glass is widely used in our lives through manufactured products such as sheet glass, bottles, glassware, and vacuum tube. Glass is an ideal material for recycling.

It is a 100% recyclable material with high performances and unique aesthetic properties which make it suitable for wide-spread uses. The use of recycled glass saves lot of energy. One of its significant contributions is in the construction field where the waste glass was reused for concrete production.(Gautam et al., 2012)

Several studies have shown that waste glass that is crushed and screened is a strong, safe and economical alternative to sand used in concrete. During the last decade, it has been recognized that sheet glass waste is of large volume and is increasing year by year in the shops, construction areas and factories.(Vijaya Sekhar et al., 2015)

Waste glass is a major component of the solid waste stream in many countries. It can be found in many forms, including container glass, flat glass such as windows, bulb glass and cathode ray tube glass. Although a small proportion of the post-consumer glass has been recycled and reused, a significant proportion, which is about 84% of the waste glass generated in UK, is sent to landfill.(Gautam et al., 2012)

The amount of waste glass produced has gradually increased over the recent years due to an ever growing use of glass products. Most of the waste glass is being dumped into landfill sites. The land filling of waste glass is undesirable because waste glass is non-biodegradable which makes them environmentally less friendly. There is huge potential for using waste glass in the concrete construction sector. When waste glasses are reused in making concrete products, the production cost of concrete will go down. This move will serve two purposes; first, it will be environment friendly, second, it will utilize waste in place of precious and relatively costlier natural resources.

When used in construction applications, waste glass must be crushed and screened to produce an appropriate design gradation. Glass crushing equipment normally used to produce a cullet is similar to rock crushing equipment. Because glass crushing equipment in glass sector has been primarily designed to reduce the size of the cullet for transportation purpose, the crushing equipment used is typically smaller and use less energy than conventional aggregate or rock crushing equipment. Waste glasses are used as aggregates for concrete. However, the applications are limited due to the damaging expansion in the concrete caused by ASR between high-alkali in cement paste and reactive silica in the waste glasses.

The chemical reaction between the alkali in Portland cement and the silica in aggregates forms silica gel that not only causes crack upon expansion, but also weaken the concrete and shortens its life.(Vijaya Sekhar et al., 2015)

The common form of silica is sand, but also occurs in nature in crystalline form known as quartz. Pure silica can produce an excellent glass, but it is very high melting (1,723^{o}c) and the melt is so extremely viscous that is difficult to handle. All common glasses contain other ingredients that make the silica easier to melt and the hot liquid easier to handle.

2.4.2 Chemical composition and constituents of glass

Glass is a fused mixture of the silicates of alkali's, alkaline earths and of more common metals. Usually the alkaline bases are sodium and potassium; the alkaline earth is calcium, and the common metallic element is lead. All of these are used in the form of salts. In melting together the various ingredients employed in the batch or mixture it appears that silica in the influence of heat in the presence of a flux forms silicates with sodium or potassium, and calcium, lead, etc. and the alkaline silicate then dissolves the remaining silicates. It is this solution that solidifies in to glass on cooling.

Sand is therefore the major constituent of glass, constituting from 52 to 65 percent of the mass of the original mixture, or from 60 to 75 percent of the finished product after melting has driven off carbon dioxide, sulphur dioxide and other volatile materials. Table 2.3 below shows chemical composition of glass.

Table 4 chemical composition of glass

Description	Composition (% by mass)
Silica (SiO_2)	72.5
Alumina (Al_2O_3)	0.4
Iron oxide (Fe_2O_3)	0.2
Calcium oxide (CaO)	9.7
Magnesium oxide (MgO)	3.3
Sodium oxide	13.7
Potassium oxide	0.1
Loss on ignition	0.36

The raw materials used in manufacturing glass are sand, lime (chalks) and soda or potash which are fused over 1000°C. Oxides of iron, lead and borax are added to modify hardness, brilliance and colour.

2.4.3 Products of recycled crushed glass

Glass concrete products can be categorized as commodity products and value-added products. For simple commodity products, the primary objective is to utilize as much waste glass as possible. For value-added products, on the other hand, the aesthetic potential of the glass is utilized, because glass can be very attractive.

Commercial production of both commodity and value-added products requires a reliable supply of glass that is cleaned, crushed, and graded according to specifications. The crushing and grading operations ought to be coordinated such as to result in preferably zero wastage.(Aswathy et al., 2015)

The crushing operation can be quite dusty. But collection of the dust is not mandated by air pollution control. The glass powder turns out to be the most valuable product of the crushing operation, both because of its pozzolanic potential and filler effect. Special aesthetic effects can be achieved with colour-sorted glass. Architects or designers can help coordinate the colours of glass aggregate and cement matrix. Also the choice of surface texture and treatment may benefit from specialists trained in the visual arts.

The development of an appropriate production technology should recognize the differences between glass and natural aggregates. For example, the basically zero water absorption of glass improves the mix rheology and calls for quite different mix designs, including the choice of admixtures, which also depends on whether a dry or wet technology is used. Since plain glass concrete is quite brittle, just like conventional concrete, it is advantageous to reinforce glass concrete products with either randomly distributed short fibers or, in the case of thin sheets or panels, with fibers mesh or textile reinforcement.

The following are types of products which are produced using glass:

a) Concrete Masonry Block Unit

The first product to be developed for commercial production was a concrete masonry block unit. Because of the uncertainty at the time of project conception whether the solution of the ASR problem would be possible, a rather modest goal was set to replace just 10% of the fine aggregate with finely ground glass. The economics of concrete masonry block production is promising, but depends strongly on a reliable supply of glass, that is cleaned, crushed, and graded according to specifications. Whereas replacing just the sand by finely ground glass may be of modest economic benefit, replacing also part of the cement by glass powder, which is obtained during crushing process, improves the economic outlook.

b) Paving Stone

The next product of glass is a paving stone, which contains up to 100% glass aggregate. The idea was to create a paver with novel colours and surface texture effects, such as special light reflections, that cannot be obtained with regular natural aggregate. Other advantages are the greatly reduced water absorption and excellent abrasion resistance due to the high hardness of glass

As an option, the paving stone may be reinforced with randomly distributed short fibers to offset the inherent brittleness of concrete in general and glass concrete in particular. Fiber reinforcement improves the paver's mechanical properties, especially its energy absorption capacity or fracture toughness. A fiber-reinforced paver will also crack like any other paver under impact loading. However, fibers will keep such cracks so small as to be basically invisible. Initial tests have shown that the freeze-thaw cycle resistance is excellent. An initial batch of samples survived 300 cycles with about one quarter of a percent weight loss.

c) Architectural and Decorative Applications

Decorative concrete is the use of concrete as not simply a utilitarian medium for construction but as an aesthetic enhancement to a structure, while still serving its function as an integral part of the building itself such as floors, walls, and driveways. The transformation of concrete into decorative concrete is achieved through the use of a variety of materials that may be applied during the pouring process or after the concrete is cured. 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 is to the construction field where the waste glass was reused for value-added concrete production.(Aswathy et al., 2015) The most exciting applications appear to be in the architectural and decorative fields. Not only can we engineer the material's mechanical and other properties to about any reasonable specifications. We also can create surface textures and appearances using techniques well known in the field of architectural concrete, while fully utilizing the aesthetic potential of Coloured glass. The results can be stunning, and the numbers of potential applications are limited only by one's imagination. To name just a few building façade elements, precast wall panels, partition walls, floor tiles, wall tiles and panels, elevator panelling, table top counters, park benches, planters, trash receptacles and ashtrays.

2.4.4 How to use Glass Chips in Decorative Concrete

Unlike water and oil, glass and concrete do mix well under the right circumstances. The quantities of glass used and the mixes of colour chosen can provide a unique and signature decorative concrete product.

The most common applications of glass in decorative concrete are seeding and integral mixing.

a) Seeding**:** means sprinkling, broadcasting or spreading glass on to the surface of a concrete floor, slab or other surface. The advantage of seeding glass is that the quantity of glass used is reduced relative to other methods.

b) Integral Mixing**:** the second most common application is integral mixing. It means replacing all or a portion of the aggregate in a concrete mixture with recycled glass chips. If you have your own proprietary mixture, simply subtract your original aggregate amount by weight by the amount of glass added to your mixture. The advantage of mixing integrally is that the glass aggregate mixes uniformly in the batch of concrete and obviously uniformly distributed in the finished concrete product. The disadvantage is that much more glass is needed in a batch of concrete relative to seeding.

Add fine glass to make silica in the fine glass chemically reacts well with the cement to better bond the concrete mixture to the glass.

2.4.2 The effect of alkali silica reaction and prevention methods

Alkali silica reaction is a chemical reaction between certain reactive minerals in some aggregate and alkali's in the pore solution of concrete. This reaction can result in expansion

And cracking of the concrete leading to shortened service life. It is well documented fact that combining glass aggregate with Portland cement may trigger ASR. What happens is the silica in the glass reacts with calcium hydroxide (a powerful alkali with PH of 12) in the Portland cement and forms siliceous gel. This gel with in the cement paste absorbs water and swells. If the swelling is sufficient the pressure can cause micro cracking, expansion and ultimately the deterioration of the surrounding concrete. Sometimes this happens early on, other times it can take years. The amount of damage inflicted by ASR on concrete depends on the volume and the particle size.

According to a report issued by the Clean Washington Centre (CWC) increasing the surface area to ratio of glass (using smaller shards) will reduce the effect of reaction. Using smaller pieces of glass tends to speed up ASR, which gives the gel time to swell before the concrete hardens, and limiting potential damage. Powdered glass will be consumed by the process to the degree that it causes no ASR at all.(PCA Durability Sub committe, 2011)

According to multiple research results, the alkali silica reactions start when specific reactive aggregate types are mixed with cement. The white gel formed as a by-product of the ASR expands when it reacts with moisture within the concrete.

To determine whether an aggregate is potentially reactive, ASTM C1260, Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method) is often used as a screening test. A similar test, ASTM C1567, Standard Test Method for

Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method), is used to evaluate the efficacy of mitigation using hydraulic cement and supplementary cementitious materials (SCM) combinations.

In the ASTM C1260/C1567/accelerated mortar bar test (AMBT), aggregate with a specified gradation is used in making 25 mm × 25 mm × 285 mm mortar bars that are cured for 48 hours, and then stored in NaOH solution at 80°C .(PCA Durability Sub committe, 2011)

In ASTM C1260 testing, bars that expand in harsh environment by more than 0.20% after 14 days of soaking are considered to be made with aggregates that are potentially ASR- reactive. Bars that expand between 0.10% and 0.20% include aggregates that are known to be both innocuous and deleterious in field performance. In both of these cases, supplemental information should be developed. Such supplemental information might include petrographic analyses to confirm that the expansion is due to ASR, as well as a review of service history records. However in the absence of further information, the aggregate should conservatively be considered reactive and mitigate measures should be taken. Expansions of less than 0.10% at 14 days are generally indicative of innocuous aggregate, using ASTM C1260, or of effective mitigation using ASTM C1567. ASTM C1260 is a screening test and is known to provide both false positives (that is, classifying an aggregate as reactive when it is not) and false negatives (classifying reactive aggregates as innocuous). (PCA Durability Subcommitte, 2011)

Many consider ASTM C1293, Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction (also known as the concrete prism test or CPT), to be the best test method for evaluating deleterious ASR potential in terms of providing the strongest correlation to field performance. However, ASTM C1293 takes 1 year to perform when evaluating aggregate reactivity, or 2 years when evaluating the efficacy of SCMs to mitigate deleterious expansion.

Therefore ASTM C1260/C1567/AMBT has a significant practical advantage in its speed. The relatively high correlation between AMBT and CPT is coincidental, as the different specimen sizes, materials, proportioning, curing and exposure conditions all lead to different

Mechanisms dominating the rate and extent of the ASR distress observed. Changing one of the parameters, like test duration, may easily reduce the correlation between them [6].

It is found that expansion due to ASR can be reduced or eliminated by the addition to the mix of reactive silica in a finely powdered form. This apparent paradox can be explained by the relation between the expansion of a mortar bar and the content of reactive silica between 850 and 300μm (No 20 and No 50 ASTM) sieves i.e. not in a powdered form.(Neville, 2013)

There are a number of measures to avoid ASR or to mitigate its damaging effects.

a) Grinding the glass to pass at least U.S. standard mesh size no 50;

b) Adding mineral admixtures that can effectively suppress the reaction;

c) Making the glass alkali-resistant, for example, by coating it with zirconium (a solution chosen by the glass fiber industry, but impractical for post-consumer waste glass);

d) Modifying the glass chemistry, if that is an option, e.g. for specialty glasses;

e) Sealing the concrete to protect it from moisture, either on a micro- or component level, because ASR needs three factors to thrive: alkali, silica, and moisture;

f) Using a low-alkali cement, which is likely to be less effective, unless alkalis from the environment can be kept away;

g) Developing special ASR-resistant cements, some of which are already being offered commercially.

h) ASR problems can be overcome with the right mix design. Using extremely low alkali cement, a lithium based admixture or a pozzolanic that reacts with calcium hydroxide will keep ASR in check. The pozzolanic transforms calcium hydroxide so there is none left to react with the glass aggregate. If you decide to go to low alkali cement route ASTM defines this kind of cement as consisting of less than 0.6 percent by weight of alkalis.

2.4.3 Previous studies on glass as partial replacement of concrete making materials

In order to make concrete industry sustainable, the use of waste materials in place of natural resources is one of the best approaches. An enormous quantity of waste glass is generated all around the world. It was estimated that the global disposed solid waste was 200 million tons in 2004, 7% of which was glass products. In 2013, 11.54 million tons of waste glass was generated in United States and only 27.3% was reused. In India, 0.7% of total urban waste generated comprises of glass. UK produces over three million tons of waste glass annually.(Iqbal & Muzafar, 2013)

Waste glasses were normally disposed into landfills if not recycled. Previous studies indicated the potential use of waste glass as constituent in concrete, such as in the form of aggregates, filler, alkali activated binder, and SCM. Waste glass is crushed into specified sizes for use as aggregate in various applications such as water filtration, grit plastering, sand cover for sport turf and sand replacement in concrete.

The use of waste glass as aggregate for concrete has been attempted decades ago. Those early efforts were thwarted by the problem of alkali-silica reaction (ASR), which was not well understood then. It was also expected that the glass aggregate would affect the mechanical properties of the concrete.

For example, it is known that the concrete strength is typically controlled by the bond strength between cement matrix and aggregate. If natural aggregate with relatively rough surfaces is replaced by crushed glass particles with relatively smooth surfaces, one would expect a drop in strength and in particular a reduction of an already low ductility. Finally, it was recognized early on that glass concrete is basically a new material that requires the development of appropriate production technologies, as well as answers to other questions that need to be addressed by basic research.

In spite of its potential reactivity in an alkaline environment, glass has a number of properties that make it a very attractive aggregate for a variety of concrete products. The following are the major advantages of glass for concrete production:

Because it has basically zero water absorption, it is one of the most durable materials known to man. With the current emphasis on durability of high- performance concrete, it is only natural to rely on extremely durable ingredients.

The excellent hardness of glass gives the concrete an abrasion resistance that can be reached only with few natural stone aggregates or the addition of metallic fines typical of special floor toppings.

For a number of reasons, glass aggregate improves the flow properties of fresh concrete so that very high strengths can be obtained even without the use of super plasticizers.

The esthetic potential of color-sorted glass, not to mention specialty glass, has barely been explored at all and offers numerous novel applications.

Very finely ground glass has pozzolanic properties and therefore can serve both as partial cement replacement and filler.

a) Previous studies about utilization of recycled crushed glass as partial replacement of fine aggregate

The use of river sand as fine aggregate leads to exploitation of natural resources, lowering of water table, sinking of bridge piers and erosion of river bed. If fine aggregate is replaced by waste glass by specific percentage and in specific size range, it will decrease fine aggregate content and thereby reducing the ill effects of river dredging and thus making concrete manufacturing industry sustainable. The amount of waste glass produced has gradually increased over the recent years due to an ever growing use of glass products. Most waste glass has and is being dumped into landfill sites. This move will serve two purposes; first, it will be environment friendly; second, it will utilize waste in place of precious and relatively costlier natural resources.(Iqbal & Muzafar, 2013)

Ground waste glass was used as fine aggregate in concrete and no reaction was detected with fine particle size, thus indicating the feasibility of the waste glass reuse as fine aggregate in concrete. In addition, waste glass seemed to positively contribute to the mortar

Micro-structural properties resulting in an evident improvement of its mechanical performance. Larger the particle size of waste glass more is the chance of ASR occurrence. It is reported that fine glass powder for incorporation into concrete up to 30% as a pozzolanic material suppressed the ASR. Hence the size of waste glass used in the range 0- 1.18mm show no effect of ASR.(Adaway & Wang)

Fine aggregates were partially replaced by waste glass at 10%, 20%, 30% and 40% by weight. Concrete specimens were tested for compressive strength, splitting tensile strength, durability (water absorption) and light weight nature for different waste glass percentages. The results obtained were compared with results of normal C-25 concrete mix and it was found that maximum increase in compressive strength occurred for the concrete mix containing 20% waste glass as fine aggregate. With increase in waste glass content, water absorption decreased indicating increase in durability.(Iqbal & Muzafar, 2013)

The study summarized the behaviour of concrete involving replacement of fine aggregates by waste glass at 10%, 20%, 30% and 40 % by weight which may help to reduce the disposal problems of waste glass and enhance properties of concrete. Compressive strength tests and splitting tensile strength tests were carried out at 7 and 28 days. An increase in compressive strength was observed up to 30% replacement of fine aggregates by waste glass and there after decreasing. The maximum compressive strength measured was 25% more than that of reference mix at 28 days corresponding to concrete mix containing 20% waste glass in place of fine aggregates. Compressive strength for concrete mix with 40% waste glass content was found to be less than that of reference mix. Splitting tensile strength decreased with increasing waste glass content.

Recent studies which have focused on the suitability of using waste glass as a partial replacement for fine aggregate have found good results. One crucial finding from this research has been that glass colour has no influence on concrete properties, eliminating the need to sort postconsumer glass by colour, and thus making this an attractive form of recycling [7].

b) Previous studies about utilization of recycled crushed glass as partial replacement of cement

Supplementary cementitious materials (SCMs) have been used widely to partially replace Portland cement in concrete. For instance, the cement manufacturers in Europe have substituted 25% of cement clinkers with other SCMs, in the past 20 years. Utilization of SCMs such as fly ash from coal combustion, or silica fume from silicon and ferrosilicon alloy production, or blast furnace slag from pig iron production, as cement replacement represents a value-added approach to address the environmental concerns. As such, not only the energy consumption and carbon dioxide emission could be reduced during the cement manufacturing process, environmental advantages could also be obtained with respect to reduction in solid waste disposal and landfills. Compared to those SCMs from industrial by- products, calcined clay is believed to have even greater potential to address the environmental impact of cement and concrete in the future, considering its availability on the earth.

On the other hand, another form of SCM, glass powder, should not be ignored due to its silica rich nature and huge amount of disposal globally. It was reported that glass powder could exhibit pozzolanic activity if finely grounded to below 38 mm.

Concrete with 30% glass powder as SCM showed lower compressive strength before 28 days but increased strength at 90 days, attributed to the pozzolanic reaction of glass powder. Similar to other SCM, pozzolanic activity of glass powder increases with decreasing particle size and higher curing temperature. Dyer and Dhir found that the cement hydration was accelerated by the replacement of glass powder, due to the dissolution of alkalis from the glass particle. However, the amount of released alkalis is insufficient to compensate the hydration and early age strength reduction caused by the cement dilution. Similar findings were reported by Du and Tan [29]. Schwarz et al investigated the durability characteristics of concrete containing 10% glass powder as cement replacement and revealed that the chloride ingress and water intake were both reduced. However, its compressive strength was lower than plain cement concrete at each testing age up to 90 days Matos and Sousa-Coutinho examined the durability characteristics of mortar with cement substituted by glass powder by 10% and 20% and found that water sorptivity was not affected and carbonation resistance decreased with glass powder inclusion, while the chloride diffusion was lowered. At a high content of 30%, it was reported that the long term pozzolanic activity of glass powder, up to 7 years, was superior to natural pozzolans and similar to fly ash (Adaway & Wang, n.d.).

It is noted that the use of glass powder in mortar or concrete is still limited to 30% replacement of cement content. Recently, some previous studies have started to examine the use of glass powder as SCMs in high volume (up to 60% by weight of Portland cement) in concrete. Both fresh and hardened properties were determined for such concretes. Although the early age strength (less than 7 days) was reduced continuously with glass powder content, the 28-day strength was found to increase, particularly for 30% replacement. Furthermore, the microstructure at the interfacial transition zone (ITZ) resulted in a denser and more compact concrete. Therefore, great improvements in the durability properties have been observed. However, with high cement substitution by silica-rich glass, the Ca/Si ratio in the formed calcium-silicate-hydrates (CSH) was lower and relatively more alkalis were bonded in the CSH phase. As a result, the PH value in the pore solution would decrease while the porosity might increase with higher glass powder substitution because of the higher effective water-cement (w/c) ratio, as reported by Du and Tan. However, it remains unclear as to the porosity and performance of high volume glass powder concrete after a longer curing age.

The advantages of high volume glass powder concrete can be seen by the compressive strength development history, up to one year, whereas plain cement concrete exhibited high strength at 7 days, it had the lowest strength at 365 days. Due to the slow rate of glass powder pozzolanic reaction, the replacement of cement would reduce the early age strength. With longer curing age, the amorphous silica in glass powder slowly dissolved under the alkaline environment and reacted with Ca^{2+} to form C-S-H gels(Adaway & Wang, n.d.).

With this process, concrete porosity would decrease and strength could increase. At the age of one year, mixes with 15% and 30% glass powder exhibited the highest compressive strength, about 27% higher than the reference plain concrete mix. Concrete with 60% glass powder, which gained only 65% of that of the plain concrete mix at 7 days, exceeded the reference mix by 12% at 365 days. A more compact microstructure of the paste matrix, especially at the ITZ, contributed to the enhanced mechanical strength. It should be noted that the pozzolanic reactivity of glass powder is directly related to its particle size. Smaller particle size would yield higher pozzolanic reactivity. Hence, the strength development rate would also be influenced by the particle size distribution of glass powder, which is worthy of further investigation, especially when early age strength is critical.

The observations on compressive strength correlate well with the reduced porosity of concrete. Mixes with 15% and 45% glass powder showed the highest strength and at the same time exhibited the lowest porosity. With respect to 28-day or later strengths, the optimum glass powder replacement rate seems to be in the range of 15% and 45% (Adaway & Wang, n.d.).

Research has been conducted at Addis Ababa University Institute of Technology by undergraduate students regarding utilization of waste glass powder as partial replacement of cement for concrete production.

The experimental study showed that the chemical composition of glass powder can be assigned as class N Pozzolans. According to the study the replacement of ordinary Portland cement by glass powder 5% to 10% results in a better compressive strength than that of control mix with 100% ordinary Portland cement. The study also recommended that glass powders have potential to replace cement and promotion should be made about its standardized production and usage(ASTM International standards, 2003).

c) Previous studies about utilization of recycled crushed glass as partial replacement of coarse aggregate

Experimental studies were conducted about the effect of replacement of coarse aggregates with recycled glass on the fresh and hardened properties of Portland cement concrete at Ambient and elevated temperatures.

Terro experiments indicated that the compressive strength of concrete made with recycled glasses decrease up to 20% of its original value. Shi and Kerens expressed that concretes made with 10% glass coarse aggregates replacement to natural coarse aggregate replacement, had better properties in the fresh and hardened concrete states at ambient and high temperatures than those with larger replacement. Based on the studies conducted on strength characteristics of concrete made with utilizing waste materials by Sekar et al, found that the compressive strength of concrete cubes made with glass concrete were found to be 16% lesser than that of conventional concrete. It was also found that the flexural strength and splitting tensile strength results were similar to that of compressive strength test results.

The study conducted by Vikas Srivastava et al shows that when coarse aggregate is replaced by 10% glass waste, the compressive strength at 7 days is found to increase by about 14.63% on average. However, it is evident that increase in compressive strength at 28 days is only 4.49% at same replacement level. It is observed that on replacing coarse aggregate by 20% glass waste on average there is an increase in compressive strength at 7 days by 3.24% however, at 28 days, compressive strength is same as that of referral concrete. It is seen that there is an increase in compressive strength at 7 days by about 12.17% whereas at 28 days compressive strength is decreased marginally at 30% and 40% replacement level(Vikas, 2014).

2.5 Terrazzo

2.5.1 Introduction

Terrazzo is a floor finish material consisting of concrete with an aggregate of marble chips selected for size and colour, which is ground and polished smooth after curing. It is concrete that is cast in place or precast and ground smooth; used as a decorative surfacing on floors and walls.

Terrazzo is exceptionally durable flooring material. It may be formed in place or installed as factory made tiles. For stair treads, window sills, and other large components, terrazzo is often precast. Because of its endless variety of colours and textures, terrazzo is often used in decorative flooring patterns.

The colours are separated from one another by divider strips of metal, plastic, or marble. The divider strips are installed in the under bed prior to placing the terrazzo, and are ground and polished flush in the same operation as the terrazzo itself.(Duggal, 2008)

a) Materials for Terrazzo manufacturing

Cement

The cement shall be ordinary, white or Coloured Portland cement complying with the requirements.

Aggregate Facing layer

The aggregate shall consist of good quality marble, or other natural stone of similar characteristics, of adequate hardness, angular in shape as distinct from elongated and flaky. Aggregate shall not contain clay, iron oxide, pyrites or other harmful foreign matter in such a form or in sufficient quantity to affect adversely the bond or strength, or cause surface failure. Aggregate should preferably be graded and it is important to avoid high fines or dust content.

Base layer

The aggregate shall consist of naturally occurring materials complying with the requirements of BS882, such as crushed or uncrushed gravel, or crushed stone, with natural sand, crushed stone sand or crushed gravel sand(British Standard, 1999)

a) Manufacture of Terrazzo

Terrazzo is made by grinding and polishing a concrete that consists of marble or granite chips selected for size and colour in a matrix of Coloured Portland cement or another binding agent. The polishing brings out the pattern and colour of the stone chips. A sealer is usually applied to further enhance the appearance of the floor.

The tile shall be vibrated to an extent which allows the entrapped air to escape to the surface and compacts the aggregate at the wearing face and it shall be hydraulically pressed with a pressure depending on the area of the tile but sufficient to mould the facing to the backing and to enable the tile to meet the performance tests specified in this standard(Duggal, 2008).

The facing layer shall be such as to provide a minimum wearing thickness of 6mm after grinding. The period between pressing and grinding shall be sufficient to enable the tile to meet the performance requirements specified in the standard. The surface treatment shall be by grinding. Any slight surface imperfections shall be filled by grouting with a neat cement paste Coloured to match the original mix and well worked into the surface(British Standard, 1999).

a) Tests for terrazzo

The following test shall be carried out to confirm the quality of terrazzo:

Water absorption test

When tested the tiles shall comply with the following requirements:

a) Water absorption by tile-face: No single result shall be more than0.4grams/cm^2.

b) Total absorption: No single result shall be more than 8%.

Age at testing

The minimum age at testing shall be28 days.

2.6 Literature Summary

Concrete is basically a mixture of two components: aggregates and paste. The paste, comprised of Portland cement and water, binds the aggregates (usually sand and gravel or crushed stone) into a rocklike mass as the paste hardens because of the chemical reaction of the cement and water. Supplementary cementitious materials and chemical admixtures may also be included in the paste(Steven H. et al., 2003).

Generally, the term concrete strength is taken to refer to the uniaxial compressive strength as measured by a compression test of a standard test cylinder, because this test is used to monitor the concrete strength for quality control or acceptance purposes. For convenience, other strength parameters, such as tensile or bond strength, are expressed relative to the compressive strength.

Among the large number of factors affecting the compressive strength of concrete, the following are the most important for concretes used in structures. These are; water cement ratio, type of cement, supplementary cementitious material, aggregate type, mixing water, moisture condition during curing, temperature condition during curing, age of concrete, maturity of concrete and rate of loading(Liang et al., 2007).

Glass is a transparent material produced by melting a mixture of materials such as silica, soda ash, and $CaCO_3$ at high temperature followed by cooling where solidification occurs without crystallization. Sand is major constituent of glass, constituting from 52 to 65 percent of the mass of the original mixture, or from 60 to 75 percent of the finished product after melting has driven off carbon dioxide, sulphur dioxide and other volatile materials. Waste glass is a major component of the solid waste stream in many countries. Glass is a 100% recyclable material with high performances and unique aesthetic properties which make it suitable for wide-spread uses. When used in construction applications, waste glass must be crushed and screened to produce an appropriate design gradation (Vijaya Sekhar et al., 2015).

Glass has a number of advantages for production of concrete; some of them are listed as follows:

a) Since it has basically zero water absorption, it is one of the most durable materials.
b) The excellent hardness of glass gives the concrete an abrasion resistance property
c) Glass aggregate improves the flow properties of fresh concrete.
d) Glass has pleasant esthetic appearance.
e) Very finely ground glass has pozzolanic properties and therefore can serve both as partial cement replacement and filler.

Different types of products can be made from recycled crushed glass, which are categorized as commodity products and value added products. Among them concrete masonry block units, paving stones and architectural concrete can be mentioned (Aswathy et al., 2015).

Previous studies show that recycled crushed glass can be used for partial replacement of cement, fine aggregate and coarse aggregate.

Partial replacement of fine aggregate at 10%, 20%, 30% and 40% by weight shows satisfactory results for structural concrete. An increase in compressive strength was observed up to 30% replacement of fine aggregates by waste glass and there after decreasing. The maximum compressive strength measured was 25% more than that of reference mix at 28 days corresponding to concrete mix containing 20% waste glass in place of fine aggregates. Compressive strength for concrete mix with 40% waste glass content was found to be less than that of reference mix(Iqbal & Muzafar, 2013).

Ground waste glass was used as fine aggregate in concrete and no reaction was detected with fine particle size, thus indicating the feasibility of the waste glass reuse as fine aggregate in concrete. In the research, fine aggregates were partially replaced by waste glass at 10%, 20%, 30% and 40% by weight. Concrete specimens were tested for compressive strength, splitting tensile strength, durability (water absorption) and light weight nature for different waste glass percentages. The results obtained were compared with results of normal C-25 concrete mix and it was found that maximum increase in compressive strength occurred for the concrete mix containing 20% waste glass as fine aggregate. With increase in waste glass content, water absorption

decreased indicating increase in durability. The paper summarized the behaviour of concrete involving replacement of fine aggregates by waste glass at 10%, 20%, 30% and 40 % by weight which may help to reduce the disposal problems of waste glass and enhance properties of concrete.

On the other hand, another form of SCM, glass powder, should not be ignored due to its silica rich nature and huge amount of disposal globally. Concrete with 30% glass powder as SCM showed lower compressive strength before 28 days but increased strength at 90 days, attributed to the pozzolanic reaction of glass powder. Similar to other SCM, pozzolanic activity of glass powder increases with decreasing particle size and higher curing temperature. It was reported that glass powder could exhibit pozzolanic activity if finely grounded to below 38 mm. Concrete with 30% glass powder as SCM showed lower compressive strength before 28 days but increased strength at 90 days, attributed to the pozzolanic reaction of glass powder. Similar to other SCM, pozzolanic activity of glass powder increases with decreasing particle size and higher curing temperature. It is noted that the use of glass powder in mortar or concrete is still limited to 30% replacement of cement content. Recently, some previous studies have started to examine the use of glass powder as SCMs in high volume (up to 60% by weight of Portland cement) in concrete. Both fresh and hardened properties were determined for such concretes. Although the early age strength (less than 7 days) was reduced continuously with glass powder content, the 28-day strength was found to increase, particularly for 30% replacement.

It is observed that when coarse aggregate is replaced by 10% glass waste, the compressive strength at 7 days is found to increase by about 14.63% on average.

However, it is evident that increase in compressive strength at 28 days is only 4.49% at same replacement level. It is observed that on replacing coarse aggregate by 20% glass waste on average there is an increase in compressive strength at 7 days by 3.24% however, at 28 days, compressive strength is same as that of referral concrete. It is seen that there is an increase in compressive strength at 7 days by about 12.17% whereas at 28 days compressive strength is decreased marginally at 30% and 40% replacement level(Vikas, 2014).

2.7 Ethiopian Experience

According to the information from different construction stakeholders, there is no Construction Company, business centre, or institution who utilized recycled crushed glass for conventional or decorative concrete construction. Most of the time waste glasses are dumped as garbage material despite their precious value for partial replacement of concrete making

Materials. The only organizations in our country where waste glasses are recycled and reused are glass factories. But when we see the construction industry where there is huge opportunity to use crushed glass for concrete making materials no effort is made to do so. Hence it is mandatory to conduct study on how and where to utilize recycled crushed glass for value added purpose.

2.7.1 Gap identification

It has been attempted to find out the utilization of recycled crushed glass for partial replacement of concrete making materials and for production of decorated concrete purpose in our country, but according to our findings there is no practice in using recycled crushed glass for the purpose of concrete work.

Accordingly, there is gap in utilization of this material for the purpose of value added concrete work. Hence it is valuable to conduct experimental study to fill the currently existing gap regarding utilization of crushed glass for concrete making materials in specified percentage.

Almost all broken (waste) glasses are dumped as waste material rather than recycling them for valuable purpose in our country. But in the construction industry the practice of using waste glass for concrete work is not observed. In my opinion it may be due to lack of awareness and inadequate experimental study to utilize waste glass for the purpose of concrete making material. The only fate of broken (waste) glass if not recycled by glass factories is dumping it as waste material.

Hence the study is intended to be conducted to use this valuable material which is regarded as waste for the purpose of decorated concrete production.

3 Research Methodology

3.1 Introduction

Concrete mixture with replacement of coarse aggregate with recycled crushed glass will be prepare. Maximum aggregate size of 12.5mm will be taken because the study will be planned to prepare terrazzo with 40mm thickness accordingly the preferable maximum size of aggregate should be 12.5mm. The materials utilize for the test are coarse aggregate with maximum size 12.5mm, recycled crushed glass with maximum size of 12.5mm, fine aggregate, cement(Dangote OPC) and water.

3.2 Research Design

There are two types of research approaches, namely: quantitative, qualitative. Quantitative study is a study where purely quantitative data and analysis techniques are adopted while qualitative approach makes use of purely qualitative data and analysis.

3.3 Study Area

This research is going to taste if recycled waste glass will replace coarse aggregate, the test will be done in Wolkite university construction and material Laboratory Located in western party of Ethiopia (Figure 2).

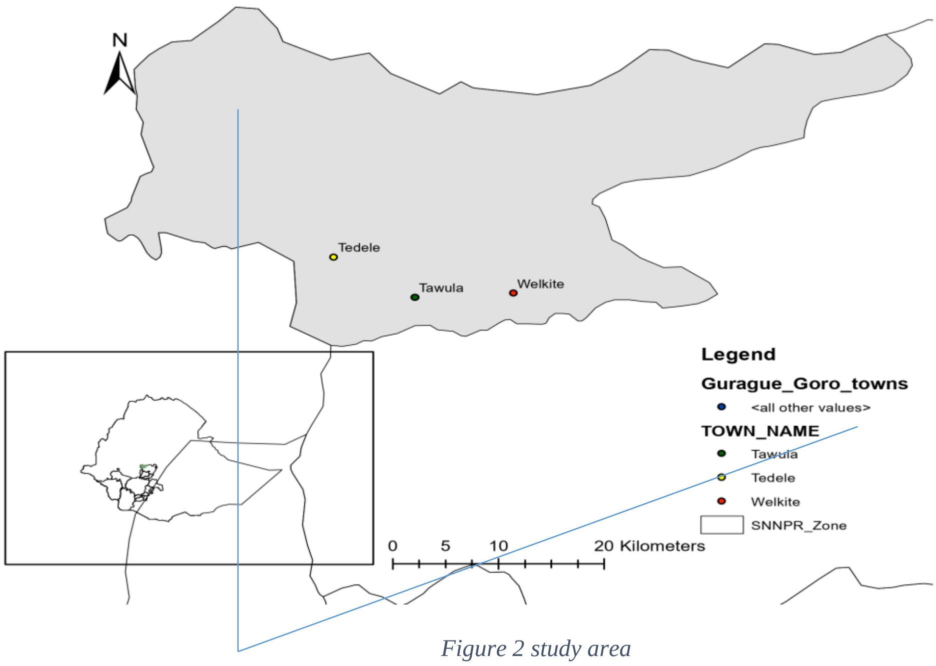

Figure 2 study area

3.4 Sample

3.4.1 Sample Size

Considering Limitations of resources, time, and availability of equipment on the laboratory test, we are obligated to reduce our sample size. Our sample size was eight, four each from C25 and C30 concrete types, due to the fact that we mentioned above we used one of them only C25 concert type. The reason we choose C25 is both of them common types of concrete for preparation of terrazzo but due to its curing time, C25 needs 21 days for full strength whereas C30 needs 28 days.

Mix design

The amount of recycled crushed glass that will replace the coarse aggregate will be quarter of the weight of the aggregate (25% by the weight of aggregate) and 50% by the weight of aggregate. Then we will determined the slump test and compressive strength of the concrete compared to the control mix design (concrete without recycled crushed glass).

Tests

Test on Sample

Types of test on the fine, coarse aggregate and recycled crushed glass without mix and with mix.

a) Sieve analysis of coarse and fine aggregate
Purpose; to determine fines modulus and grade of fine and coarse aggregate
Standard Reference**;** ASTM C136
Significanc**e;** it serves the purpose of comparing one aggregate with another in respect of fineness or coarseness. Aggregates should be proportional on the mix design for filling the most of the voids in the aggregate and producing a uniform dense concrete.

b) Specific gravity and water absorption of fine aggregates
Purpose; to determine specific gravity and water absorption of fine aggregates
Standard reference; ASTM C 127-04.
Significanc**e**; all rocks contain some small amount of void and the apparent specific gravity includes this voids. The specific gravity of aggregates is an indirect measure of materials density and its quality. A low specific gravity may indicate high porosity and therefore poor durability and low strength.

c) Specific gravity and water absorption of coarse aggregates
Purpose; to determine the specific gravity and water absorption of coarse aggregates
Standard reference; ASTM C 127.
Significanc**e**; for design of concrete mix, information about the specific gravity and water absorption of the coarse aggregates are required. Specific gravity of aggregates provides valuable information on its quality and properties. If the specific gravity is above or below than the value of normal assigned to particular type of aggregate; it may indicate that shape and grading of aggregates has altered.

Test on Mix

Type of tests on mix;

a) Measurement of workability of concrete by slump cone test
Purpose; to determine the workability of fresh concrete by the use of slump test
Standard reference; IS: 7320-1974, IS; 1199-1959, SP; 23-1982
Significanc**e**; unsupported fresh concrete flows to the side and a sinking in height takes place. This vertical settlement is known as slump. The slump is the measure indicating the consistency or workability of cement concrete. It gives an idea of water content needed for concrete to be used for different works.

b) Test for determination of compressive strength of concrete
Purpose; to determine the cube strength of the concrete of a given properties
Standard reference; ASTM C39
Significance; the strength in compression has a definite relationship with all other properties of concrete i.e these properties improved with the improvement in compressive strength.

3.5 Method of Data Analysis

The research was conducted using descriptive data analysis method.

4 Result

4.1 Introduction

The glasses were collected from waste material dumping area and they were thoroughly washed with tap water so as to remove the dirt and debris on them. The collected glasses were used as container for beer, wine and hard drinks. According to their chemical constituents they are categorized as soda lime glasses. The crushing activity was carried out manually with hammer to get the required size and it was sieved with series of sieves in laboratory. Those crushed glass particles which pass through 12.5mm sieve and which retained on 4.75mm sieve was used for the study. Figure 3 below shows waste glasses which are collected from waste dumping areas and ready for recycling, whereas Figure 4 shows cleaning of waste glass with tap water.

Figure 3 waste glass collected from waste dumping areas

Figure 4 cleaning waste glass manually

Figure 5 cleaned glass

Concrete grades of C 25 were prepared because it is the commonly used classes of concrete in most of building projects in our country. Concrete mix was prepared by partially replacing coarse aggregate with recycled crushed glass at 30% by weight. In addition, concrete mix without replacement of the coarse aggregate with recycled crushed glass was prepared as control (reference) mix. Generally 2 concrete mix designs were prepared for C 25 grades of concrete and laboratory tests were conducted on the fresh and hardened concrete. The workability of the fresh concrete was measured with slump test. The properties of the hardened concrete were conducted with compressive strength test at the age of 3rd, 7th.

Finally with 30% partial replacement of the coarse aggregate with recycled crushed glass terrazzo concrete has been prepared. The mix proportion was initially placed in the mold and it was vibrated. Finally the backing layer was added and it was hydraulically pressed with the pressing machine. Then it was polished at the 7th day. The surface water absorption, full water absorption and transverse strength test has been conducted at the 7th day.

4.2 Laboratory result of samples

a) Fine aggregate

The fine aggregate was thoroughly washed with tap water so as to remove the silt and debris on it. The conducted laboratory physical tests were sieve analysis (gradation), fineness modulus, unit weight, specific gravity (bulk, apparent and SSD), moisture content, water absorption and silt content.

Sieve analysis is used to determine the particle size distribution of the aggregate. The results are tabulated in Table 5 and the graphical representation is shown in Figure 6 below.

Table 5 sieve analysis test result of fine aggregates

Weight of fine aggregate taken (W_f): _500_ g						
SI No.	Sieve Size (mm)	Wt. of Retained (gm)	%ge Retained ($\frac{C_3}{W_f}$ x 100)	Cumul. %age retained	Percentage passed (100-C_5)	Standard Limit (%)
C1	C2	C3	C4	C5	C6	
						100
1	4.75	11	2.2	2.2	97.8	95-100
2	2.36	23	4.6	6.8	93.2	80-100
3	1.18	81	16.2	23	77	50-85
4	600 μm	189	37.8	60.8	39.2	25-60
5	300 μm	145	29	89.80	10.2	10 -30
6	150 μm	29	7.8	97.6	2.4	2 – 10
7	Pan	12	2.4			
	Total	500		280.2		

Fineness Modulus FM = cumulative coarser %

100

FM=280.2/100 =2.8

From the above Table 4.1we can see that the sieve analysis test result shows that the cumulative percent passing is within the standard limit. The test result of each sieve number complies with the standard; hence the sand fulfills the requirements as per ASTM standard.

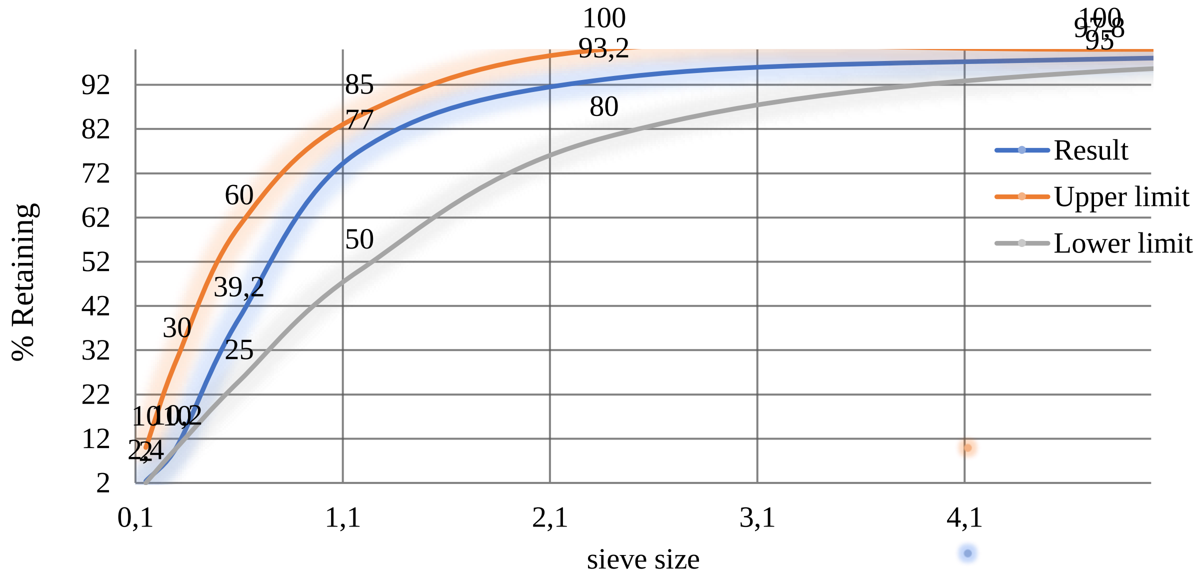

Figure 6 graphical representation of sieve analysis of fine aggregates

The test results of physical properties for fine aggregate are summarized in Table 4.2 below. As can be seen in the table the silt content of the sample is 2.4%, which is lower than the allowable limit 5% so it complies with the standard. The specific gravity test result reveals that the fine aggregate is medium weight material.

Table 6 laboratory test result sample of fine aggregates

Description	Test result
Bulk specific gravity (at SSD)	2.67
Moisture Content (%)	8.3
Water absorption (%)	1
Silt Content (%)	2.4
Fineness Modulus	2.8

a) Coarse aggregate; the maximum size of aggregate used for the study was 12.5mm, because the aim of the study is to produce terrazzo of thickness 40mm.

The types of the laboratory tests conducted for coarse aggregate were sieve analysis (gradation), unit weight, specific gravity (bulk, apparent and SSD), and moisture content and water absorption.

Table 7 sieve analysis test result of coarse aggregates

Weight of coarse aggregate taken (W_c): _2000_ g						
SI No.	Sieve Size (mm)	Wt. of Retained (gm)	%ge Retained ($\frac{C_3}{W_c}$ x 100)	Cumul. %age retained	Percentage passed (100-C_5)	Standard Limit (%)
C1	C2	C3	C4	C5	C6	
1	19					100
2	12.5	89	4.45	4.45	95.55	90-100
3	9.5	307	15.35	19.8	80.20	40-85
4	4.5	1598	79.9	100	0	0-10
		1994				

Table 7 above shows that sieve analysis test result of coarse aggregate is within the standard limit. The cumulative percent passing of each sieve number complies with ASTM standard

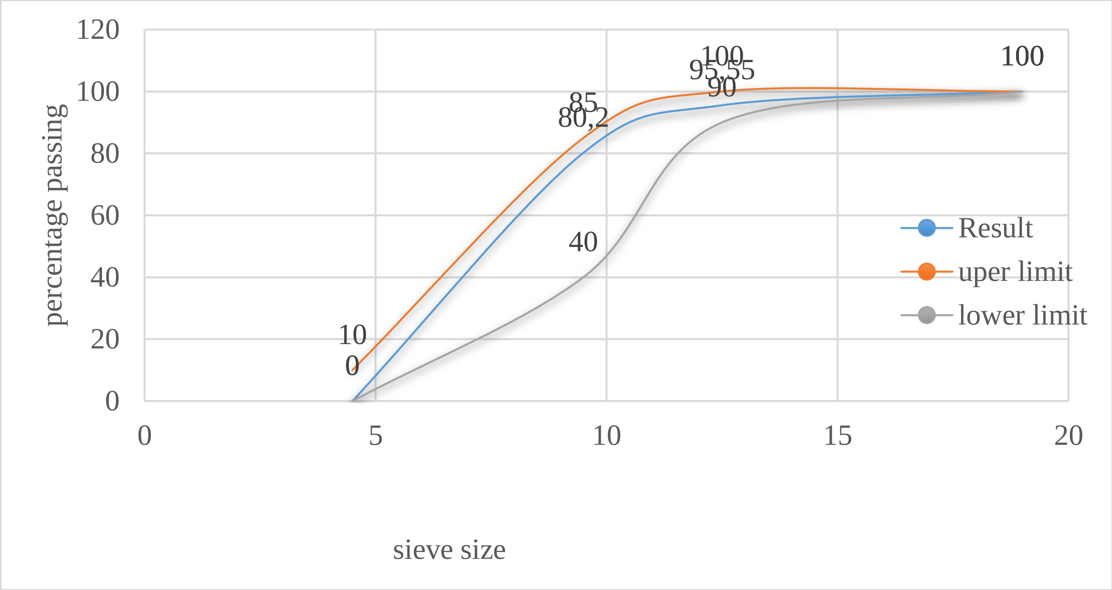

Figure 7 graphical representation of sieve analysis of coarse aggregates

The conducted physical property tests for coarse aggregate are summarized as follows in the Table 8 below. The water absorption test result complies with the requirements as per the standard. In addition the specific gravity test results also reveals that the material is medium weight accordingly it is preferable for production of structural concrete.

Table 8 laboratory test result sample of coarse aggregates

Description	Test result
Unit Weight (kg/m^3)	1,640.7
Bulk specific gravity	2.71
Bulk specific gravity (at SSD)	2.68
Apparent specific gravity	2.79
Moisture Content (%)	3.8
Water absorption (%)	0.83

a) Recycled Crushed glass

The recycled crushed glass used for the study was collected from waste dumping area around Woliso. The collected bottles were thoroughly washed with tap water to remove the debris and dirt. The maximum aggregate size of recycled crushed glass was 12.5mm which is the same as that of coarse aggregate. The sample of sieved recycled crushed glass is shown in Figure 8 below.

a) crushed bottles

b) Crushed bottles weighed

c) Preparation of samples

Figure 8 recycled crushed glass

The types of the tests conducted were: sieve analysis (gradation), unit weight, specific gravity (bulk, apparent and SSD), and moisture content and water absorption.

Table 9 sieve analysis test result of recycled crushed glass

Weight of recycled crushed glass taken (W_r): _2000_ g						
SI No.	Sieve Size (mm)	Wt. of Retained (gm)	%ge Retained ($\frac{C_3}{W_r}$ x 100)	Cumul. %age retained	Percentage passed (100-C_5)	Standard Limit (%)
C1	C2	C3	C4	C5	C6	
						100
1	19	6	1.20	1.20	98.80	95-100
2	12.5	15	3.00	4.20	95.80	80-100
3	9.5	72	14.40	18.60	81.40	50-85
4	4.5	206	41.20	59.80	40.20	25-60

The conducted laboratory tests for recycled crushed glass are summarized as follows in the Table 10 below. The test results of unit weight and specific gravity are greater than that of the coarse aggregate which shows that the crushed glass is denser than the coarse aggregate. Furthermore, the absorption capacity of glass is zero which in turn has the advantage of durability due to its low permeable property.

Table 10 laboratory test result sample of recycled crushed glass

Description	Test result
Unit Weight (kg/m^3)	1,685.2
Bulk specific gravity	2.79
Bulk specific gravity (at SSD)	2.80
Apparent specific gravity	2.84
Moisture Content (%)	4.2
Water absorption (%)	0

Sieve analysis test result of recycled crushed glass is shown in Table 9 above. The result shows that the cumulative percent passing on each sieve complies with ASTM standard. In addition Figure 9 shows the graphical representation of the sieve analysis test result of recycled crushed glass.

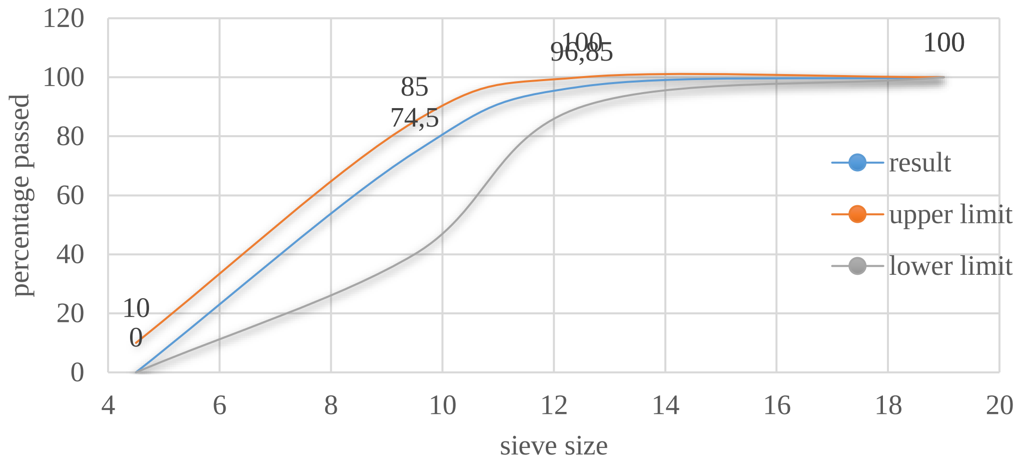

Figure 9 graphical representation of sieve analysis for recycled crushed glass

4.2.1 Laboratory test result for mix

a) Test for workability of concrete

The following procedure was followed to conduct slump test of concrete. The slump cone was cleaned with water. It was firmly held with feet on the steps and it was filled one third with concrete and it was compacted 25 times with tapping rod. Two further layers were added to a height of 100mm and each was compacted 25 times. The surplus concrete was strike off using steel float. The cone was carefully lifted vertically upwards, and then it was turned over and placed near the mold concrete, the tamping rod was placed over the empty cone and it reached over the slumped concrete. Measurement was taken from the underside of the rod to the surface of concrete.

The figure below shows slump test of concrete

a) Measuring result of slump test

b) Preparing slump for test

Figure 4-7 slump test

a) Test for compressive strength of concrete

Concrete mix was prepared with the calculated amount according to the mix design. Cubical molds were prepared and oiled properly in order to easily remove the concrete cubes from the mold. Concrete was filled in the cubic molds and it was vibrated with electric plate vibrator so as to remove the air bubbles. The surface was smoothed and excess concrete was removed using spatula, and casting date was written on it. The mold was removed after 24hours and it was placed in water for curing.

The concrete specimens were crushed at 3^{rd} and 7^{th} days. The concrete specimens were loaded to failure using concrete compressive strength testing machine and the failure load was recorded. The stress was calculated by dividing the load at failure by the contact area of the specimen. The figure below shows compressive strength test machine and cube which is going to be tested.

a) Checking perpendicularity of cube casted concrete

b) Preparing the concrete for testing

c) Preparing the machine

Figure 10 compressive strength test

4.1.3 Test for water Absorption of terrazzo

The test specimen were placed in an oven, it was dried until they attain constant weight. The removed tile was allowed to cool at a room temperature for 24 hours. The terrazzo was dried and it was weighed. Then it was immersed in water at a room temperature for 24hours. It was taken out of the water; the surface water was removed by dabbing using slightly dampened cloth. Then weight of the tile was measured and recorded. The recorded weights were used to compute the absorption of terrazzo. The figure below shows terrazzo produced by partial replacement of recycled crushed glass which ready for test.

a) Terrazzo made up of crushed glass before polish

b) Types of terrazzo made up of crushed class after polish

Figure 11 terrazzo ready for test

5 Discussion

5.1 Introduction

This section discuss about the laboratory results of the tests carried out to investigate the hardened and fresh properties of the concrete prepared by partially replacing coarse aggregate with recycled crushed glass and to compare the result with the control mix. In this part of the study, the results of slump, compressive strength test for C25 concrete are presented. In addition, analysis and discussion is also made based on the obtained test results.

5.2 Test Results of Concrete

5.2.1 Properties of Fresh Concrete

Since the long term properties of hardened concrete; strength, volume stability, and durability are seriously affected by its degree of compaction. It is vital that the consistence or workability of fresh concrete be such that the concrete can be properly compacted and also that it can be transported, placed and vibrated sufficiently easily without segregation, which would be detrimental to such compaction.

Workability is the amount of useful internal work necessary to produce full compaction. The useful internal work is a physical property of concrete alone and is the work or energy required to overcome the internal friction between the individual particles in the concrete.

a. Workability Test

Workability test was conducted and the result of the slump test was found as shown in Table 5.1 below. The test result revealed that as the percentage of recycled crushed glass increased the slump test result was also increased correspondingly. The increment of the slump test result is due to the zero water absorption property of the recycled crushed glass.

According to ACI, for the conducted mix design in this study, all the mixes were designed to have slump in range between 25mm to 50mm. The results of the slump test for both grades of concrete were greater than 25mm and less than 50mm, so it is with in the allowable range as per the standard.

Table 11 slump test result

No	Mix	Grade of Concrete (MPa)	% of glass	W/C ratio	Slump (mm)
1	C25g0	25	0	0.60	28
2	C25g5	25	10	0.60	39
3	C25g15	25	20	0.60	43
4	C25g30	25	30	0.60	46

5.2.2 Properties of Hardened Concrete

Different types of tests were conducted to investigate the hardened properties of concrete. The tests carried out are compressive strength, flexural strength and splitting tensile strength.

a. Compressive Strength Test Result

1. C25 Concrete

Compressive strength test was conducted at the 3rd, 7th days. The compressive strength test result at 3rd and 7thdays in Table 12 below shows that the compressive strength of concrete increased as the percentage of recycled crushed glass increased. The test result revealed that the incorporation of recycled crushed glass increased the compressive strength when compared with the control mix. The result shows that replacing coarse aggregate by 30% with recycled crushed glass attains the maximum compressive strength at the 3rd and 7th days.

Table 12 compressive strength test result

No	Mix	% glass	Compressive Strength (MPa)	
			3rd day	**7th day**
1	C25g0	0	14.66	20.56
2	C25g5	5	15.39	21.97
3	C25g15	15	16.47	22.9
4	C25g30	30	18.3	23.2

The test result which is graphically represented below on Figure 14 demonstrates that the compressive strength of the specimen increased as the percentage of partially replaced recycled crushed glass increased. The maximum percentage increment in strength is observed at the 30% partially replaced specimen. Concrete specimen at 5%, 15% and 30% partially replaced with crushed glass has 6.86%, 11.38% and 12.8% increment in compressive strength respectively, than the control mix at the 7th day. The highest strength increment is attained by concrete specimen produced at 30% partial replacement at 3rd and 7thday.

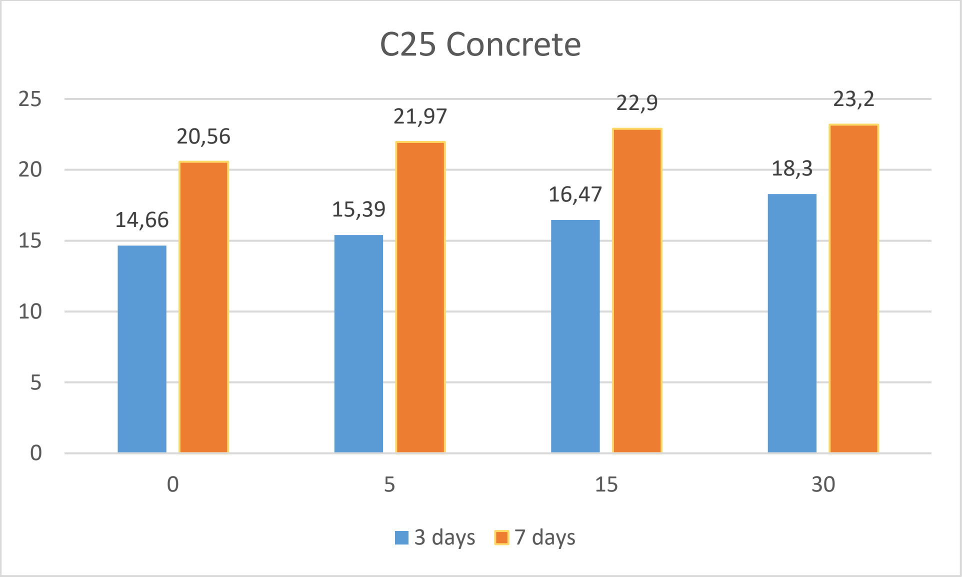

Figure 13 graphical representation of compressive strength test result for c25 concrete

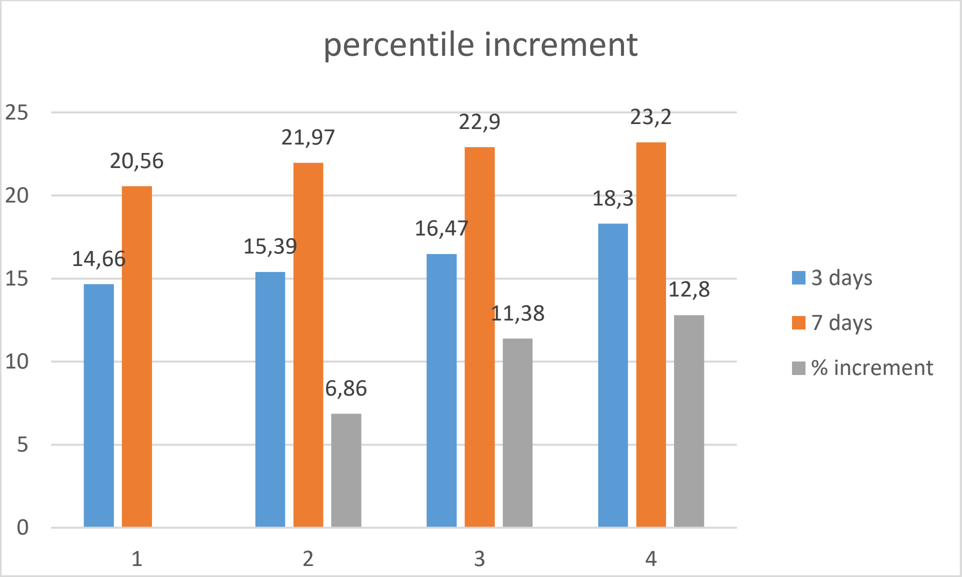

Figure 14 percentile increment compressive strength result

6 Conclusions and Recommendations

The general objective of this study is to analyze the fresh and hardened properties of concrete by partially replacing coarse aggregate with recycled crushed glass for production of decorated concrete. The results of the replacements were compared with the results of the control mix and the following conclusions are drawn and recommendations are forwarded:

6.1 Conclusions

The results of all the concrete mixes produced by partially replacing coarse aggregate with recycled crushed glass are within the acceptable range as per the standard. From the results it can be inferred that recycled crushed glass can partially replace coarse aggregate up to 30% by weight. Concrete specimen at 30% replacement attained the maximum value and the incorporation of recycled crushed glass in the concrete mix increased the slump test result and correspondingly the workability is also increased. In addition the replacement of coarse aggregate with recycled crushed glass increased the compressive strength test result of the concrete mix when compared with the control mix. As the percentage replacement of crushed glass increased the compressive strength test result is correspondingly increased. Furthermore Terrazzo produced by partially replacing coarse aggregate with recycled crushed glass has more pleasant aesthetics than the one produced without replacement.

Finally, from the conducted study it is concluded that recycled crushed glass can replace coarse aggregate up to 30 % by weight for structural concrete and for production of decorative concrete such as terrazzo, counter tops and window sills.

6.2 Recommendations

Based on results of this study, the paper recommends that glass is one of the common wastes from residential and commercial places, but this material which is regarded as waste can be used for value added purpose by incorporating it with in concrete as partial replacement of concrete making materials. In addition Waste glass can replace coarse aggregate for structural concrete and for decorative concrete as well. Therefore, the government (concerned government body) shall focus or device directives on the means of collecting waste glass and utilizing it for decorative concrete purpose. This paper is not enough, further intensive study should be carried out by academic institutions to investigate the long term properties and effects of concrete produced by partially replacing recycled crushed glass. Beside Research centers should be established which focus on the study of wastes which can be recycled and future focuses of study which should be continued as part of the extension of this study are listed as follows:

- The long term effects of concrete produced by partial replacement of coarse aggregate with recycled crushed glass need further study and investigation.
- The effect of alkali silica reaction is not included in this study so future study should be carried out.
- The effect of larger size (size greater than 12.5mm) recycled crushed glass on properties of fresh and hardened concrete should be studied.

Reference

Adaway, M., & Wang, Y. (n.d.). Recycled glass as a partial replacement for fine aggregate in structural concrete – Effects on compressive strength. *Australia, Deakin University, School of Engineering*, *14*(1).

ASTM International standards. (2003). Standard Specification for Concrete Aggregates. *ASTM International, United States*.

Aswathy, A. M., Prathibha, V., Rinu, I., & Rita Rose, J. (2015). Decorative Concrete Using Recycled Glass Aggregate. *International Journal of Civil and Structural Engineering Research*, *2*(2).

British Standard. (1999). Specification for Terrazzo tiles. *British Standard Institute*.

Duggal, S. K. (2008). Building Materials. *New Age International Ltd*, *3*.

Gautam, S. P., Vikas, S., & Agarwal, V. C. (2012). Use of glass wastes as fine aggregate in concrete, Journal of Academia and Industrial Research. *Journal of Academia and Industrial Research Journal of Academia and Industrial Research*, *1*(6).

Iqbal, M. M., & Muzafar, B. (2013). *Study of Concrete Involving Use of Waste Glass as Partial Replacement of Fine Aggregates*. *3*(7).

Liang, H., Zhu, H., & Byars, E. (2007). Use of Waste Glass as Aggregate in Concrete. *Greenwich,7th UK CARE Annual General Meeting*.

Nadim M, H. (2008). Structural concrete theory and design. *John Wiley and Sons, Inc*, *4*.

Neville, A. M. (2013). Properties of Concrete, Fifth edition. *Pearson Education Ltd*, *5*.

PCA Durability Subcommitte. (2011). Evaluation of Alkali Silica Reactivity Mortar Bar Testing (ASTM C1260 and C1567) at 14 days and 28 days. *Washington DC, Portland Cement Association*.

Steven H., K., Beatrix, K., & William, C. P. (2003). Design and Control of Concrete Mixtures. *Portland Cement Association*.

Vijaya Sekhar, R. M., Sumalatha, P., & Madhuri, M. (2015). Incorporation of Waste Glass Powder as Partial Replacement of Fine Aggregate. *International Journal of Scientific & Engineering Research*, *6*(12).

Vikas, S. (2014). Glass Wastes as Coarse Aggregate in Concrete. *India, Department of Civil Engineering, Journal of Environmental Nanotechnology, 3*.

Appendix:

Appendix A: Material properties

A1: Laboratory test result of fine aggregate

No	Description	Unit	Result
1	Moisture content	%	8.3
2	Bulk specific gravity (SSD)		2.67
3	Absorption capacity	%	1.0
4	Silt content	%	2.4
5	Fineness modulus		2.8

A2: laboratory test result of coarse aggregate

No	Description	Unit	Result
1	Moisture content	%	3.8
2	Absorption capacity	%	0.83
3	Rodded unit weight	kg/m^3	1640.7
4	Bulk specific gravity		2.71
5	Bulk specific gravity (SSD)		2.68
	Apparent specific gravity		2.79

A3: laboratory test result of recycled crushed glass

No	Description	Unit	Result
1	Moisture content	%	4.2
2	Absorption capacity	%	0
3	Rodded unit weight	kg/m^3	1685.2
4	Bulk specific gravity		2.79
5	Bulk specific gravity (SSD)		2.8
	Apparent specific gravity		2.84

Appendix B: Mix Design (ACI Method)

B1: C25 Mix Design

Mix Design Procedure

Concrete grade C25

Replacement of coarse aggregate with 0% crushed glass

Mix Design with ACI method Mix component properties:

Cement type: Dangote OPC

Specific gravity: 3.1

Concrete grade: C25

Characteristic strength: 25 MPa

Margin: 7 MPa For strength less than 26.25 MPa target strength=fc'+7

Target Strength: 32 MPa

MIX DESIGN PROCEDURE

Step 1

Choice of slump:

For pavements and slabs from Table A1.5.3.1 the required slump is 25-75mm.

Step 2

Choice of maximum size aggregate: 12.5mm

Step 3

Estimation of mixing water

For 25-50mm slump and 12.5mm nominal maximum size of aggregate mixing water should be 199 kg/m3.

Step 4

Selection of water cement ratio

From Table (a): the water cement ratio should be 0.6

Step 5

Calculation of cement content

332 kg/m^3 (199/0.6)

Step 6

Estimation of coarse aggregate content

For 2.71 fineness modulus and 12.5mm nominal maximum size of aggregate, volume of coarse aggregate is 0.56m^3/m^3.

Weight of coarse aggregate per cubic meter of concrete should be 931kg.

Replacement of 0% coarse aggregate with crushed glass.

Weight of crushed glass: 0.0*931 = 0 kg

Weight of coarse aggregate: 1.0*931 = 931 kg

Step 7

Estimation of fine aggregate content (mass basis

For 12.5mm nominal maximum size of coarse aggregate and non- air entrained concrete mass of 1 m^3 of concrete is 2310kg/m^3.

Weight of ingredients for 1 m^3 of fresh concrete:

Description	**Amount**	**Unit**
Water (net mixing)	199	kg
Cement	332	kg
Crushed glass	0	kg
Coarse aggregate	931	kg
Total	1462	kg

Mass of fine aggregate is computed by deducting mass of the ingredients in the table from the mass of fresh concrete, the result is 848 kg.

Step 8

Adjustment for aggregate moisture

Description	**Amount**		**Unit**
Coarse aggregate (wet)	931*1.044	972	kg
Fine aggregate (wet)	848*1.087	922	kg
Crushed glass (wet)	0*1.042	0	kg

Water absorption adjustment

Mixing water from coarse aggregate is 931*(0.044-0.009) = 33 kg

Mixing water from fine aggregate is 848*(0.087-0.01) = 65 kg

Mixing water from crushed glass is 0*(0.042-0.0) = 0 kg

Total mixing water from crushed glass, fine and coarse aggregate is 98 kg.

Estimated requirement of added water for mixing is 101 kg.

The estimated batch masses for a cubic meter of concrete are:

Description	**Amount**	**Unit**
Water (to be added)	101	kg
Cement	332	kg
Coarse aggregate (wet)	972	kg
Crushed glass (wet)	0	kg
Fine aggregate (wet)	922	kg
Total	2327	kg

Step 9 Trial Mix

For 0.02 m^3 of concrete the following amount is computed:

Description	Amount	Unit
Water (to be added)	2.02	kg
Cement	6.64	kg
Coarse aggregate (wet)	19.44	kg
Crushed glass (wet)	0	kg
Fine aggregate (wet)	18.44	kg
Total	46.54	kg

The concrete has a measured slump of 40mm and unit weight of 2336 kg/m3 in the trial to get the desired slump the actual volume of water added was 2.2 kg.

Description	Amount	Unit
Water (to be added)	2.2	kg
Cement	6.64	kg
Coarse aggregate (wet)	19.44	kg
Crushed glass (wet)	0	kg
Fine aggregate (wet)	18.44	kg
Total	46.72	kg

The concrete has a measured slump of 40 mm and unit mass of 2336 kg/m^3.

Step 9.1 Yield of trial batch

Mixing water content

Description	Amount	Unit
Water (to be added)	2.3	kg
On coarse aggregate	0.66	kg
On fine aggregate	1.3	kg
Total	4.26	kg

The mixing water required for a cubic meter of concrete with the same slump as a trial batch should be 213 kg.

Step 9.2 Adjustment for cement content

With change of water content cement amount should be adjusted to 355 kg.

Step 9.3

Since workability was found satisfactory, the quantity of coarse aggregate per unit volume of concrete will be maintained the same as in the trial batch. The amount of coarse aggregate per cubic meter of concrete becomes:

Description	Amount	Unit
Coarse aggregate (wet)	972	kg
Coarse aggregate (dry)	931	kg
Coarse aggregate (SSD)	939	kg

Step 9.4

The amount of fine aggregate required is:

Description	**Amount**	**Unit**
Fine aggregate (wet)	829	kg
Fine aggregate (dry)	821	kg
Fine aggregate (SSD)	922	kg

The adjusted basis batch masses per cubic meter of concrete are:

Description	**Amount**	**Unit**
Water (net mixing)	213	kg
Cement	355	kg
Coarse aggregate (dry)	931	kg
Fine aggregate (dry)	821	kg

Description	**Amount**	**Unit**
Water (net mixing)	213	kg
Cement	355	kg
Coarse aggregate (wet)	931	kg
Fine aggregate (wet)	821	kg

Appendix C: Compressive strength Test Result

C1: Compressive Strength Test Result for C25 Concrete with 0% Glass Replacement

Mix C25 g0

Grade of Concrete C25

Percent replacement of crushed glass 0%

No	Test age (days)	% Glass	Dimensions (cm)			Wt. (gm)	Volume (cm^3)	Failure Load (KN)	Comp. Strength (MPa)	Unit Wt. (gm/cm^3)
			L	W	H					
1	3	0	15	15	15.1	8139	3397.5	312.3	13.88	2.4
1	7	0	15	15	15.3	8074	3442.5	462.6	20.56	2.35

C2: Compressive Strength Test Result for C25 Concrete with 5% Glass Replacement

Mix

C25 g5

Grade of Concrete C25

Percent replacement of crushed glass 5%

No	Test age (days)	% Glass	Dimensions (cm)			Wt. (gm)	Volume (cm^3)	Failure Load (KN)	Comp. Strength (MPa)	Unit Wt. (gm/cm^3)
			L	W	H					
1	3	5	15	15	15.1	7885	3397.5	355.9	15.82	2.32
1	7	5	15	15	15.3	7928	3442.5	494.325	21.97	2.3

C3: 25 Concrete with 15% Glass Replacement

Mix C25 g15
Grade of Concrete C25
Percent replacement of crushed glass 15%

No	Test age (days)	% glass	Dimensions (cm)			Wt. (gm)	Volume (cm^3)	Failure Load (KN)	Comp. Strength (MPa)	Unit Wt. (gm/cm^3)
			L	W	H					
1	3	15	15	15	15.1	7951	3397.5	378.5	16.82	2.34
1	7	15	15	15	15.4	8060	3465	604.4	26.86	2.33

C4: 25 Concrete with 30% Glass Replacement

Mix C25 R30

Grade of Concrete C25

Percent replacement of crushed glass 30%

No	Test age (days)	% glass	Dimensions (cm)			Wt. (gm)	Volume (cm^3)	Failure Load (KN)	Comp. Strength (MPa)	Unit Wt. (gm/cm^3)
			L	W	H					
1	3	30	15	15	15	8015	3375	380.9	16.93	2.37
1	7	30	15	15	15.1	8053	3397.5	522.17	23.2	2.37

Appendix D: Pictures from Laboratory work

		
Checking perpendicularity of the cube casted concrete	Ordering sieves in size	Balancing aggregate
		
Sieved coarse aggregate	Preparing test equipment	Recording data