 

# A Study of Strength Characteristics of Recycled Glass (Cullets) in Concrete Floor Tiles Prodution

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**Abstract**
The utilization of recycled glass in construction, such as its application in highway pavement construction, concrete oversite and flooring has been occurring over the past couple of decades. In recent years, the discovery of several economic and environmental benefits has increased the use of recycled glass most especially in highway construction and precast concrete members such as wall panel, table tops and so many other concrete products, making the evaluation of the properties of glass and aggregate mixes necessary. The uses of recycled glass are varied depending on the specific application. Crushed recycled glass, or cullet, has been independently, and has also been blended with natural stone aggregate at different replacement rates. The research provides an evaluation of the potential use of glass cullet when used in combination with natural coarse aggregate for slab construction. This research studied the strength and the density characteristics of different glass-aggregate blend to examine the effects of blending glass cullet into concrete by partial replacement of the coarse aggregate. A source of natural aggregate was tested,' **GRANITE'** it being crusher run and very angular in nature. The glass was introduced into the concrete mix at the replacement rates of **20%, 40%, 60%, 80% and 100%** the maximum size of glass cullet is **20mm.**

## 1.0 INTRODUCTION

Concrete is a man-made composite. The major constituent of which is natural aggregate makes **70% - 80%** of total weight such as gravel and sand or crushed rock. Alternatively artificial aggregate such as blast furnace slag, broken bricks, iron shots maybe used where appropriate. The other principal constituent is its binding agent, cement which aids to form the hard composite medium in its hardened state, concrete is a hard like material with a high compressive strength; by virtue of ease to which fresh concrete in its plastic state can be moulded to any shape, it is used to advantage architecturally or solely for decorative purpose such as special surface finishes such as exposed aggregates, tooled surface finish and others .

Concrete is used structurally in buildings for foundations, columns, beams, slabs, shells, bridges, sewage treatment plants, railway sleepers, cooling towers, dams, harbors, offshore structure, coastal protection work and others.

The prevalence of discarded glass products is far becoming a nuisance thereby having significant socio-environmental and economical impact.

In a view to ameliorate the attendant effect of the product called waste glass, it was my aim in a view to recycling the product, to introduce it into concrete with a conviction that it would enhance the properties of the intended concrete, thereof utilizing to its maximum the potentials of glass due to its abundance and variation in its shades [colour].Of such properties includes its compressive strength and possible aesthetics quality of glass.

## 2.0 LITERATURE REVIEW

### AGGREGATES

Aggregates are much cheaper than cement and maximum economy is obtained by using as much aggregate as possible in concrete. Its use also considerably improves both the volume stability and the durability of the resulting concrete. The commonly held view that aggregate is a completely inert filler in concrete is not true, its physical characteristics and in some cases its chemical composition affect to a varying degree the property of concrete in both its plastic and hardened state. [**Shetty,** M. S. 2007]

The criterion for a good aggregate is that it should produce the desire properties in both the fresh and hardened concrete. In testing aggregate, it is important that a truly representative sample is used. The procedure for obtaining such a test sample is described in [**BS 812: part 102.]**

The properties of the aggregate known to have a significant effect on concrete behaviour are its strength, deformation, durability, toughness, hardness, volume change, porosity, relative density, and chemical reactivity.

The strength of an aggregate, limits the attainable strength of concrete only when the compressive strength is less than or of the same order as the design strength of concrete. The strength of concrete is therefore dependent upon the mechanical properties of the aggregate and the bond influence of the cement. It can therefore be concluded that while strong aggregates cannot make strong concretes, for making strong concrete, strong aggregates are required [**Shetty,** M. **S.** 2007] concrete.

The principal materials used in concrete are aggregates.Glass as an aggregate can be classified as a normal inorganic aggregate. The principal function of aggregates in concrete is to combine effectively with other components of the mix to develop strength, rigidity, and durability adequate for the service for which they are intended. These requirements largely define the properties that the material should possess and hence broadly determine the nature of test made on such material.

Glass, as a product of man's ingenuity, maybe as old as bronze, even older is the use of natural glass {obsidian} used for arrow head and artifacts. However, glass vases and glazes dates back **4500** years showing humans manipulating their resources for aesthetics desires. Glass has an unusual role in the world, it contains the most abundant elements on the earth: large quantities are made via mass production: although basically a ceramic product, glass is also an inorganic polymer. Its structure, properties and behaviour are related to both categories of material [ **Jastrzebski, Z.** 1977]**.**

## 3.0 MATERIALS AND METHODS

### 3.1 TEST MATERIALS AND EQUIPMENT

- Compressive testing machine.
- Measuring cylinder
- Concrete cube moulds **(150 × 150 mm )**
- BS Sieves
- Rammer
- Gauge box
- Steel plate
- Curing tank
- Flat steel slab mould **[ 35 × 450 × 450mm ]**
- Drying oven
- Riffle box
- Tamping rod
- Thermometer
- Pyncometer
- Sets of weights
- Semi – automatic balance
- Dial-o-Gram balance
- Stopwatch
- Vicat apparatus

**[***ELE International limited. Test Equipment manual*]

### 3.2 METHODOLOGY

This study presents the result of concrete mix batching and testing using glass aggregate. Crushed glass aggregate produced from recycling of useable glass gotten from broken bottles, glass panes, mirrors, mineral bottles, perfume bottles. This glass was incorporated in varying proportions of **20%, 40%, 60%, 80%** and **100%** into concrete mix with **20mm** maximum nominal aggregate size that is typical of concrete mix that is commonly used for commercial application. The purpose of this testing and evaluation is to compare the physical properties of the concrete mixture containing the glass aggregate component to a similar mix compose exclusively of locally available, naturally occurring aggregates. Strength, Water demand and Workability of the concrete mixture containing the glass aggregate were compared to the conventional concrete mix that used naturally occurring aggregate exclusively

### 3.3 MATERIALS DESCRIPTION

A **1 : 2 : 4** mix type, batching done by volume was chosen because it simulates similar concrete mixes used in general concrete work/construction. The mix components as listed on this design were used to perform the work. The following materials were used in designing and testing the concrete mixes:

**1. Cementitious Materials** Ordinary Portland Cement – Type 1- **Elephant®**
**2. Fine Aggregate** **Dug well sand** (light shade orange brown) Ilaro
**3. Coarse Aggregate** Igneous rock; **Granite**, **Glass cullet**.
**4. Water** Underground Water reservoir, Ilaro

The trial mixes were proportioned in accordance with **BS: 812,** "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete" using proportion b parts, **1 : 2 : 4** consisting of one part cement , two parts fine aggregate and four parts coarse aggregate of which the first two are held constant and the last was the independent variable [Coarse aggregate].

Early trial batching indicated that, because of the angular nature of the glass aggregate, replacing and varying coarse aggregate with glass aggregate produced a mix that had high water demand and was not workable [ **1 : 2 : 4 all glass aggregate** ]. To produce a more workable concrete, the water- cement ratio was increased to 0.65. The control mix a [ **I : 2 : 4 all coarse aggregate granite ].** Nine concrete cubes **150×150×150 mm** was cast along with two slabs of **450×450×25mm** on each trial batch.

The mixing procedures were as follows: Compaction was carried out by the means of a tamping rod allowing for minimum air void content. The specimen demoulded within **24hrs** and then cured by immersion in a curing tank.

## 4.0 RESULTS AND DISSCUSSION

Concrete materials and components were subjected to varying tests and the results obtained are presented below in Tables 4.1 through 4.6 as shown below.

**TABLE 4.2 INITIAL SETTING TIME OF CEMENT PASTE**

| NO. | DEPTH OF PENETRATION (MM) | TIME (MINUTES) |
|---|---|---|
| 1. | 1.0 | 5 |
| 2. | 1.8 | 15 |
| 3. | 2.6 | 20 |
| 4. | 3.5 | 25 |
| 5. | 4.3 | 30 |
| 6. | 4.9 | 35 |
| 7. | 5.0 | 37 |
| 8. | 5.4 | 40 |

**The initial setting time = 37mins**

**Inference** The quality of cement used is good**,** final setting time test was not observed on the basis of time. it was taken/assumed that as long initial setting time was within limits and cement product has been quality assured.

**TABLE 4.3 SPECIFIC GRAVITY ANALYSIS**
**SAMPLE : GLASS AGGREGATE**

| SPECIMEN NOS | 1 | 2 | 3 |
|---|---|---|---|
| BOTTLE NOS | 8 | 8 | 8 |
| WT. BOTTLE + WATER + GLASS $W_1$ [g] | 706.11 | 706.80 | 707.07 |
| TEMPERATURE. $T_1$ [C$^{\cdot}$] | 30.0 | 25.5 | 23.0 |
| WT. BOTTLE + WATER $W_2$ [g] | 673.67 | 679.28 | 679.57 |
| EVAPORATION DISH Nos | A-15 | A-15 | A-15 |
| WT DISH + GLASS [g] | 491.12 | 491.12 | 491.12 |
| WT OF DISH [g] | 438.92 | 438.92 | 438.92 |
| WT OF GLASS $W_S$ [g] | 52.20 | 52.20 | 52.20 |
| SPECIFIC GRAVITY OF WATER AT T, [$G_t$] | 0.996 | 0.997 | 0.998 |
| SPECIFIC GRAVITY OF GLASS AGGREGATE, [Gs] | 2.63 | 2.69 | 2.64 |

$$Gs = G_t \; W_s / Ws - W1 + W2$$

**Gs = 2.64**

**Inference:** The specific gravity of the glass cullet maximum size particle **20mm** is **2.64**

**TABLE 4.4 PARTICLE SIZE DISTRIBUTION FOR GLASS CULLET**

| BS SIEVE (mm) | Mass Retained (g) | Mass Passing (g) | Percentage Passing | Percentage Retained |
|---|---|---|---|---|
| 45.0 | - | 849.9 | - | 5.6 |
| 37.5 | 50.1 | 692.2 | 94.4 | 17.5 |
| 25.0 | 157.7 | 367.2 | 76.9 | 36.1 |
| 20.0 | 325.0 | 297.1 | 40.8 | 7.7 |
| 16.0 | 70.1 | 233.5 | 33.0 | 7.1 |
| 13.2 | 63.6 | 213.0 | 26.0 | 2.3 |
| 9.5 | 20.5 | 152.9 | 23.6 | 6.7 |
| 8.0 | 60.1 | 121.9 | 16.9 | 3.4 |
| 6.7 | 31.0 | 95.1 | 13.5 | 3.0 |
| 5.0 | 26.8 | 45.1 | 10.5 | 5.5 |
| 4.75 | 50.0 | - | 5.0 | 5.1 |
| TRAY | 45.0 | - | - | - |
| TOTAL | 900 | - | - | - |

**TABLE 4.5 PARTICLE SIZE DISTRIBUTION FOR SAND**

| BS SIEVE (mm) | Mass Retained (g) | Mass Passing (g) | Percentage Passing | Cumulative Percentage Retained | Cumulative Percentage Passing |
|---|---|---|---|---|---|
| 6.30 | - | 187.2 | 100 | - | - |
| 2.00 | 6.8 | 180.4 | 96.4 | 3.6 | 3.6 |
| 1.18 | 4.7 | 175.7 | 93.9 | 2.5 | 6.1 |
| 600 | 7.2 | 168.5 | 90.0 | 3.8 | 7.9 |
| 425 | 27.8 | 140.7 | 75.2 | 14.8 | 24.7 |
| 300 | 31.3 | 109.4 | 58.4 | 16.7 | 41.4 |
| 212 | 33.1 | 76.3 | 46.8 | 17.8 | 59.2 |
| 150 | 28.7 | 47.6 | 23.4 | 15.3 | 74.5 |
| 63 | 26.5 | 21.1 | 11.3 | 14.2 | 88.7 |
| Pan | 21.1 | - | - | 11.3 | 100 |
| Total | 187.2 | 100% | | | |

**TABLE 4.6 THE MIX PROPOTION AND SLUMP**

| | TYPE 1 | TYPE 2 | TYPE 3 | TYPE 4 | TYPE 5 |
|---|---|---|---|---|---|
| CEMENT | 1 | 1 | 1 | 1 | 1 |
| SAND | 2 | 2 | 2 | 2 | 2 |
| GRANITE | 4 | 3 | 2 | 1 | 0 |
| GLASS | 0 | 1 | 2 | 3 | 4 |
| WATER | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 |
| SLUMP | 3.75cm | 2.75cm | 2.50cm | 2.00cm | 1.5cm |

Trial batching was performed at the laboratory for each concrete mix .The concrete trial batch that exclusively used natural aggregates maximum size 20mm

**TABLE 4.7 MIX PROPERTIES**

| TYPES | | ONE | TWO | THREE | FOUR | FIVE |
|---|---|---|---|---|---|---|
| MIX RATIO | | 1 : 2 : 4$^{gl}$ : 0 | 1 : 2 : 3$^{gl}$ : 1 | 1 : 2 : 2$^{gl}$: 2 | I : 2: 1$^{gl}$:3 | 1 : 2 : 0$^{gl}$ : 4 |
| WATER/CEMENT | | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 |
| WEIGHT[ [kg] | | 7.82 | 8.00 | 9.56 | 8.11 | 8.52 |
| DENSITY [kgm$^{-3}$] | | 2250 | 2350 | 2510 | 2480 | 2450 |
| DAYS | 7 | 6 | 7 | 10 | 9 | 11 |
| AVERAGE COMPRESSIVE VALUE [N/mm$^2$] | 14 | 19 | 17 | 19 | 19 | 20 |
| | 28 | 24 | 27 | 30 | 31 | 33 |

**VOLUME OF CUBE MOULD 3.375x10 $^{-3}$ cm$^3$**

**CHART 4.0 TEST AGES OF MIXES AGAINST COMPRESSIVE STRENGTH VALUES**

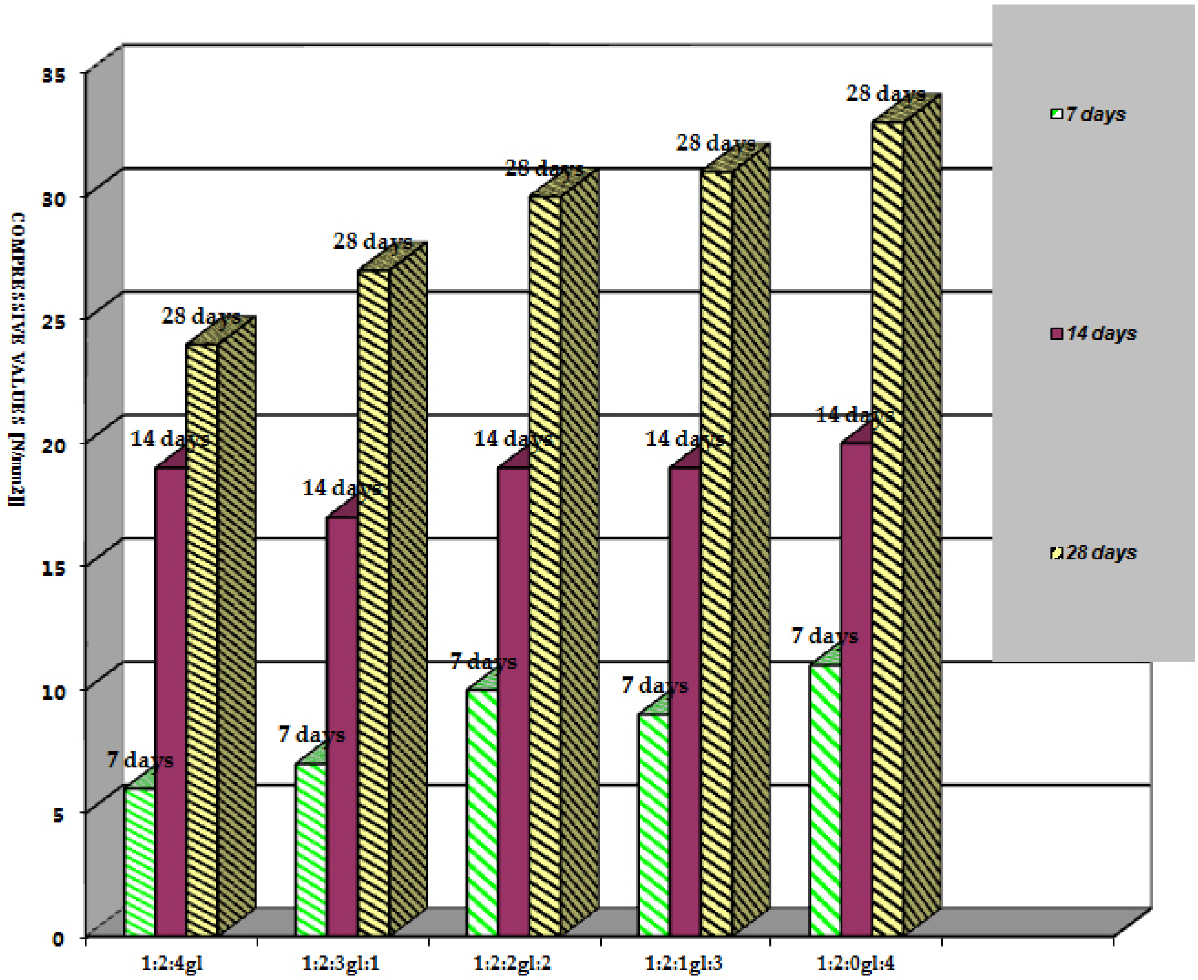
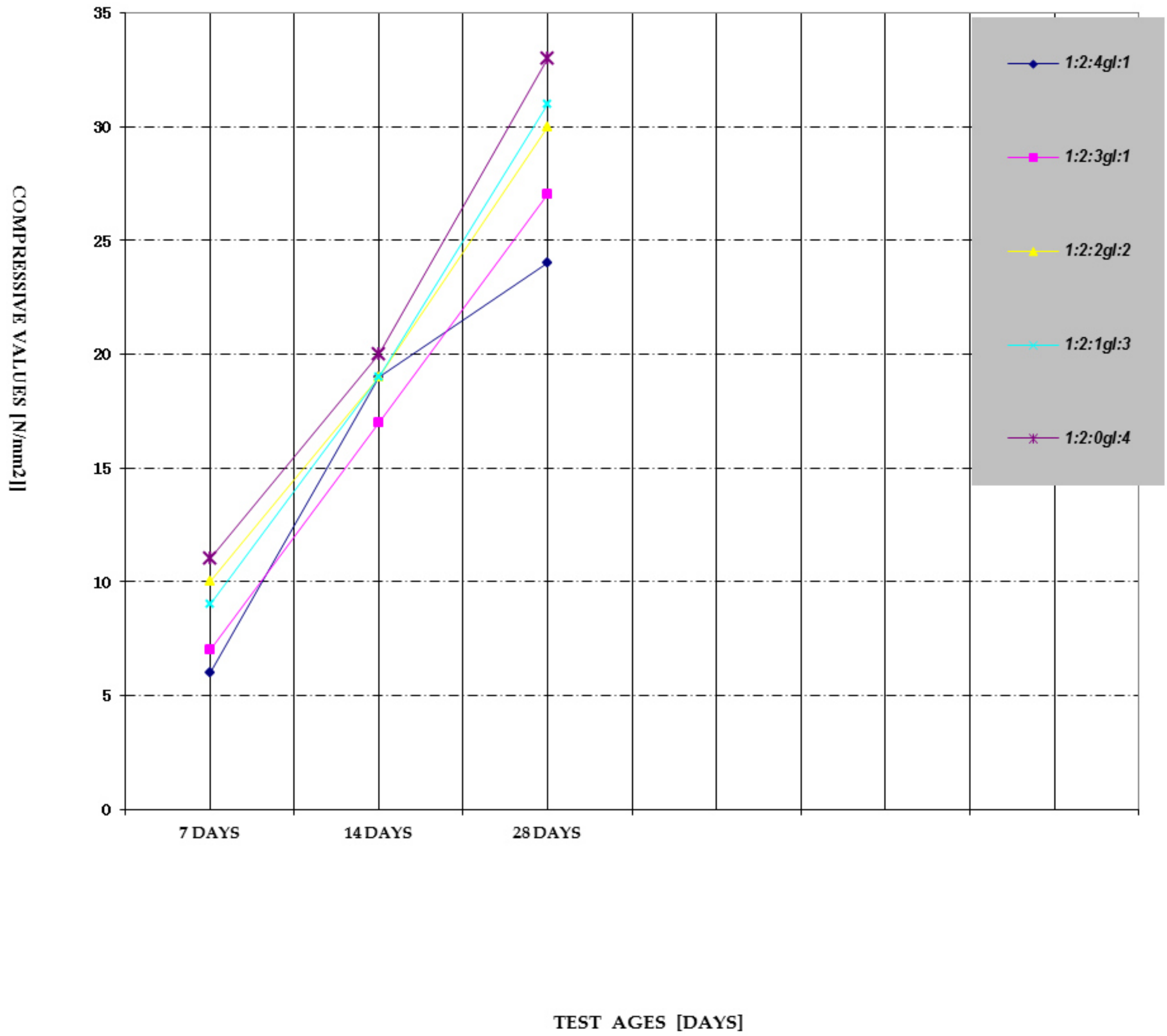


CHART 4.1 TEST AGES OF MIXES AGAINST COMPRESSIVE STRENGTH VALUES




Concrete strength is generally dependent on the water/cementitious materials ratio, age of the concrete, curing conditions, air content and the ability of the concrete paste to bond with the aggregates. Lower water/cementitious materials ratio will typically result in a greater concrete strength. Also, greater age and good curing conditions will affect the extent to which cement hydration has progressed and will result in higher strength. All other properties being equal, higher air content will result in lower concrete strength. However, higher air content may also reduce the amount of water needed to achieve the desired consistency, reducing the water cement ratio and offsetting some of the reduction in concrete. Good bonding of the cement paste with the aggregates will also result in a higher concrete strength. A good indication of the ability of the cement paste to bond with the aggregate is the amount of fractured coarse aggregate particles on the face of a fractured concrete strength test specimen. A high percentage of fractured coarse aggregate indicates that the cement sand matrix strength is at least as strong as the coarse aggregate and that there is a good bond between the coarse aggregates and cement/sand matrix.

The replacement in proportions of the natural coarse aggregate with the glass aggregate resulted to a decrease in compressive strength as the percentage of replacement with glass increased. It was notice that at a

replacement of **25%** and **50%** the strength was comparable to that observed using the control **[1:2:4 granite].** However, the workability result showed a dramatic change as the glass aggregate content increased slight decrease in workability and an increase water demand and, ultimately, the water/cement ratio. In my opinion, the increase in water/cement ratio and decrease in workability can be generally attributed to the angular nature of the glass aggregate. Because of the high degree of glass aggregate angularity, additional water was required in the mixture to maintain slump within desired range. It also my opinion that the decease in strength can be primarily attributed to the inability of the cement paste to adhere to the glass aggregate particles resulting to slip failure during compression and to a lesser extent, an increase in water/cement ratio.
These opinions are based on the following observations:

1. After performing strength testing of the mix containing the glass aggregate, I observed that the glass aggregate particles had pulled out cleanly away from the cement paste on the fractured surfaces of the test specimens.
2. Many exposed glass aggregate particles could be cleanly removed from the concrete specimen with fingers. Very little concrete cement paste residue was observed on the fractured surface of the test specimens.
3. Only approximately half of the coarse aggregate particles in the fractured face of the compressive test specimens were sheared.

## CONCLUSIONS

Based on the testing and finishing of cast slabs of the various mixes, it is my opinion that the glass aggregate in the concrete mixes could be used as an aggregate component in concrete mixes such that it would not be finished to expose the aggregates or subject the concrete to high loading, high traffic, or severe weathering conditions. If such, light coating of transparent enamel top is applied or an epoxy binders. The use of glass aggregate as special aggregate for decorative concrete is on the increase due to more colour possibilities. One might think this is a questionable practice in light of the potential for aggregate alkali - silica reaction [ASR] between the glass and the cement, but according to Lane Howell, a partner in American specialty Glass, Salt lake City, "We know there is the possibility for such a reaction but we have yet to hear a single case of ASR involving glass aggregates". http://www.concreteconstruction.net However, because of significant differences in compressive and flexural strength and the indication of poor bond between glass aggregate and cement paste , it is also my opinion that higher compressive results could be obtained only by decreasing the glass aggregate replacement percentage.

## RECOMMENDATIONS

Additional testing would be required to determine a percentage with a greater precision that could provide more comparable result with a normal concrete mix. It should also be noted that my testing only considered the properties of workability, compressive strength. Depending on the application of concrete mix, additional properties such as flexural strength, permeability, abrasion resistance, volume stability and durability may need to be investigated, also possible replacement of fine aggregates.

## REFERENCE

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