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Sustainable Concrete Blocks: Strength and Durability Assessment of 50% Waste Glass Bottle Powder Replacement

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ABSTRACT

The construction industry continuously seeks sustainable and eco-friendly alternatives to conventional materials to reduce environmental impact and enhance resource efficiency. This study explores the feasibility of utilizing waste glass bottle powder as a partial replacement for cement, fine aggregates, and coarse aggregates in concrete block production. The investigation focuses on the performance of M30-grade concrete, where 50% of the total volume of the concrete block is substituted with finely ground waste glass bottles. This research aims to evaluate the fresh and hardened properties of concrete with waste glass incorporation, including workability, compressive strength, flexural strength, and water absorption. A mix design with a maximum water-to-cement (w/c) ratio of 0.45 was adopted, and concrete cubes of 150mm × 150mm × 150mm and beams of 100mm × 100mm × 500mm were cast. A slump test was conducted to assess the workability of fresh concrete, while compressive strength, flexural strength, and water absorption tests were carried out at curing ages of 7, 14, and 28 days. The slump test results indicated a reduction in workability due to the incorporation of waste glass powder, which may be attributed to the angular particle shape and lower water absorption capacity of glass particles compared to conventional aggregates. The hardened properties of concrete showed a decrease in compressive strength and flexural strength with a 50% replacement of waste glass bottle powder compared to the control mix. However, the results remained within acceptable structural limits, suggesting that waste glass can be a viable alternative material in concrete production. Additionally, the percentage of water absorption was lower for the glass-modified concrete, indicating improved durability and reduced porosity.

Overall, the study demonstrates that replacing 50% of cement and aggregates with waste glass bottle powder in concrete blocks offers environmental benefits by reducing cement consumption and promoting waste recycling.

Keywords: Sustainable concrete, Waste glass powder , Partial replacement, Compressive strength.

1. INTRODUCTION

Modern construction industry calls for a more innovative comprehensive materials in line with the past developing hands of construction. The thought of all these creative ideas come up to challenge the spirit of young engineers to achieve a study that would possibly change the history. A wide variety of materials come from municipal and household garbage or waste glass from collapsed building caused by an earthquake. When considering a waste material referred to as broken glass as a substitute for coarse aggregate, there are three (3) major areas are relevant [1, 3]. First, are the economy, second, the compatibility with the other materials and last, the concrete properties. The economical use of waste materials depends on the quantity available. The amount of transportation required the extent beneficiation and the mix design requirements. Waste materials must not react adversely with other constituents of the mix. Most waste glass will readily take part in the alkali-aggregate reaction and possess a potential durability problem. The effect of waste materials such as waste glass, on concrete properties must be considered. For example, the lower modulus of elasticity glass compared to that of good-quality rock will lower the elastic modulus of concrete [2].

2. REVIEW OF LIETRATURE

Sustainable construction practice means creation and responsible management of a healthy built environment considering resource efficiency and ecology (Plessis, 2007). Being versatile and economical, concrete became prime construction material over the world, however, it has impacts on the environment (Naik, 2008). Manufacturing of cement (key ingredient used for the production of concrete) is a major source of greenhouse gas emissions (Imbabi et al., 2012).

Being non-biodegradable in nature, glass disposal on landfill sites has many severe environmental implications and could also be quite expensive. Sustainable construction practices mean creation and responsible management of a healthy built environment considering resource efficiency and ecology (Plessis, 2007). Manufacturing of cement (key ingredient used for the production of concrete) is a major source of greenhouse gas emissions (Imbabi et al., 2012). Waste glass when not properly disposed leads to environmental problems. Landfill is the conventional approach to solid waste management, but space for landfill is becoming scarce in many parts of Ghana as the need for land for other projects become imminent. Final disposal of waste glass in Ghana is normally on dump and landfill sites and on nearby undeveloped lands. These practices create problems for authorities where land scarcity exists. Using glass powder to replace cement in concrete production is advantageous by reducing waste glass that ends up on our landfill site thereby reducing construction cost. For instance, in brick manufacturing, substituting waste glass for clay in
red mixture reduces the heat required to fire the body to maturity (Diaz et al., 1982). Moreover, the substitute could result in about thirty percent (30%) increase in the quantity of red bricks produced without additional kiln capacity.

Many authors have worked on the use of glass material in concrete production in construction industry as a way of managing generated bulk waste glass in society. Their works established solid

grounds for further investigation into waste glass management (Bashar and Ghassan, 2009). In the late sixties, researchers devoted their study on the use of waste glass as coarse and fine aggregates in concrete production (Pike et al., 1960, Schmidt et al., 1963). Recent works by (Pike et al., 1960, Schmidt et al., 1963) rekindle the ideas but
concentrate on usage of glass material as either fine or coarse aggregate replacement in concrete, moulding of blocks and road construction material. It is against this background that investigations are ongoing to further exploit new ways of reusing glass waste for sustainable management of solid waste.

Research indicates that glass has a chemical composition and phase comparable to traditional supplementary cementitious materials (SCMs) (Ryou et al., 2006; Binici et al., 2007; Nassar and Soroushian, 2012). It is abundant, can be of low economic value and often landfilled (Byars et al., 2003). Milling of glass to micro-meter scale particle size, can enhance reactions between glass and cement hydrates, bring energy and offer environmental and economic benefits when cement is partially replaced with it for production of concrete (Rashed, 2014). Some studies also focused on the use of waste glass as aggregate in concrete production (Rashed, 2014; Taha and Nounu, 2009).

A study on durability of concrete with waste glass pointed to better performance against chloride permeability in the long term but there is concern about alkali-silica reaction (Rashed, 2014). The pozzolanic properties of glass were first notable at particle sizes below approximately 300 ml, and below 100 ml, glass can have a pozzolanic reactivity at low cement replacement levels after 90 days of curing (Shi et al., 2005). This size can be achieved by using a grinding operation with the help of ‘‘Ball Mill” which is generally used in cement industry to grind cement clinker. Several researches show that, at a higher age recycled glass concrete (15% to 20% of cement replaced) with milled waste glass powder provides compressive strengths exceeding those of control concrete (Nassar and Soroushian, 2011). However, review study by Rashed (2014) showed previous studies with glass addition
were not conclusive considering workability and strength while the chloride resistance of glass added concrete was found to be similar with control condition.

Moreover, glass waste generation have several environmental challenges. Disposal of glass waste bottles in landfills reduces their life span thus creating land use problems. Apart from limited space challenges, waste glass bottles found in the open gutters of our cities choke and clog gutters thereby causing perennial flooding in our cities amidst even light rains. This is the biggest environmental problem faced by managers of big cities in Ghana. Glass bottles and plastic polythene bags are major components of solid waste dump along the shores of beaches posing threat to users of the beaches and marine organisms across the country. Interestingly, waste glass has proven to be a good substitute for one or two ingredients of concrete in the construction industry for concrete production. Furthermore, cost of production of concrete for building infrastructure would decrease, and the industry would become more environmentally friendly. We can guarantee a cleaner and greener environment if we make reuse and recycling of waste glass a priority. This study examined the potential of replacing cement with waste glass powder for sustainable concrete technology.

Experimental work was carried out on the performance of glass in mortar and concrete. Concrete samples were prepared to evaluate strength properties.

3. PROPOSED SYSTEM

Concrete, is a homogeneous mixture of cement, fine aggregates and coarse aggregates derives its strength in the presence of water through hydration. The bonding strength of concrete mainly depends on the cement used and the compressive strength of concrete is derived from the coarse and fine aggregates used. In present experimental work the following ingredients are used.

3.1.1.2 Cement properties

The properties of Cement below tabe 4.1:

Table 3.1 Physical Properties of cement

Property	**Result**
Standard Consistency	32%
Initial Setting Time	38min
Final Setting Time	310min
Specific gravity	3.2

3.1.2 Fine aggregates

River sand passing through 4.75mm IS sieve and confirming to zone-II of IS:383 (1987a) was used. The specific gravity was found to be 2.52.

3.1.3 Coarse Aggregates

Coarse aggregates of nominal size 20mm and sub round in shape are used for the experimental work with specific gravity of 2.78.

3.1.4 Water

Distilled water for mixing chemicals and fresh potable water for the purpose of workable mix was used in the experimental work.

3.1.5 Specific gravity of materials used in concrete

The specific gravity of all the materials has been tested in the laboratory using specific gravity bottle for cement, Pycnometer for fine aggregate and coarse aggregate and the results are as follows:

Table 3.5: Specific Gravity of the Materials

Materials	**Specific Gravity**
Cement	3.14

Fine Aggregate	2.61
Coarse Aggregate	2.83

3.1.6 Glass powder

The collected waste glass bottles clean and dried under sunlight. After dring crushed the glass bottle by using loss angles abrasion testing machine. After 150 revolutions collected the glass powder from machine. The collected sample is sieved with IS Sieves.

From retained and passed sample from:

[a] 4.75 mm and passed from 20mm considered coarse aggregates replacement.

[b] 4.75mm to passed and 0.075mm retained sample considered as fine aggregates replacement.

[c] 0.075mm to passed and retained on pan considered that sample as cement replacement.

Figure.3.6 Waste glass bottles as collected before crushing and sieving

Figure 3.7: Very fine glass powder

Figure 3.8: Coarse glass aggregates

Figure 3.9: Fine glass aggregates

3.2 Methodology

LIETRATURE

↓

COLLECTING WASTE GLASS BOTTLES

↓

CRUSHING OF GLASS BOTTLES

↓

MIX DESIGN M30 (50% REPLACEMENT OF WASTE GLASS)

↓

TESTS ON FRESH AND HARDEN PROPERTIES OF CONCRETE

↓

RESULTS & DISCUSSIONS

3.3 Mix design

Following are the site considerations used for the mix design for nominal concrete in our experimental work

Concrete Grade : M30

Type of Cement : OPC 53

Type of aggregate : 20mm Sub rounded

Exposure Condition : Severe

Specific Gravity Of Cement : 3.14

Specific Gravity Of Fine Aggregate : 2.61

Specific Gravity Of Coarse Aggregate : 2.83

Zone Provision : Zone II

Workability : 75 mm (slump)

Table 3.3: Quantities of materials in cement concrete (M30)

Material	Quantity (Kg/m^3)
Cement (grade 53)	425.73
Water	191.58
Fine aggregate	649.63
Coarse aggregate	1199.92
Water: cement	0.45

4. RESULTS AND DISCUSSIONS

As per experimental programme results for different experiments were obtained. They are shown in table format or graph, which is to be presented in this chapter.

4.1 Workability Test

4.1.1 Slump Test

The Slump test was performed on the Waste glass based concrete to check the workability. The following results were obtained, according to which it can be concluded that with the decreases workability when waste glasses added to the concrete. The results obtained for Slump test are shown below in Table 7.1.

Table 4.1: Results of Slump test

Concrete	Slump value (mm)
50% replacement of glass in concrete	85
Conventional concrete	120

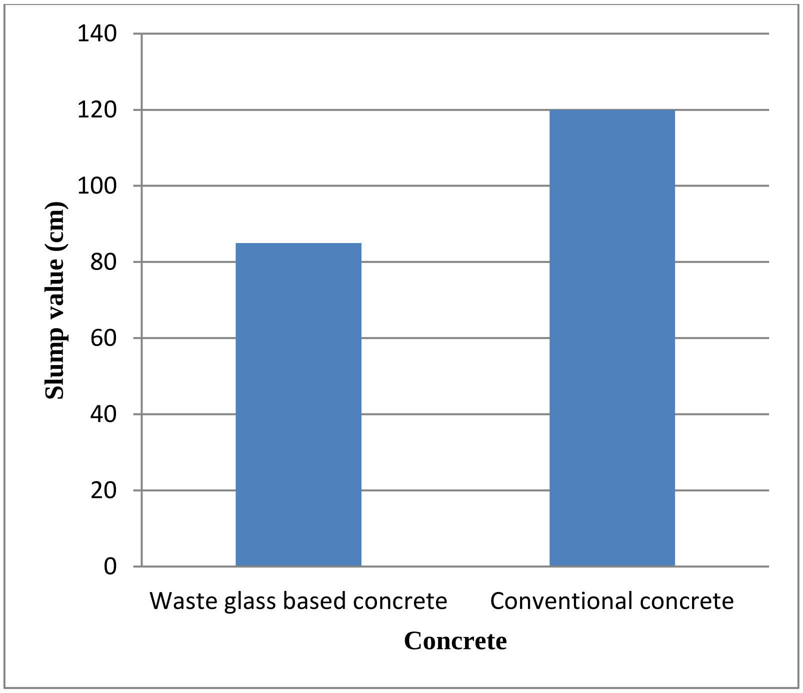

Fig 4.1 : Slump test results

The above figure 4.1 shows the slump results. It was observed that, the slumps was less than the control mix.

4.1.2 Compaction factor test

The compaction factor test was performed on the Waste glass based concrete to check the workability. The following results were obtained, according to which it can be concluded that with the decreses workability when waste glasses added to the concrete. Theoretical maximum value of compaction factor can be 0.96 to 1.0. The results obtained for Slump test are shown below in Table 7.2.

Table 4.2: Results of compaction factor test

Concrete	Compaction factor (%)
50% replacement of glass in concrete	0.80
Conventional concrete	0.87

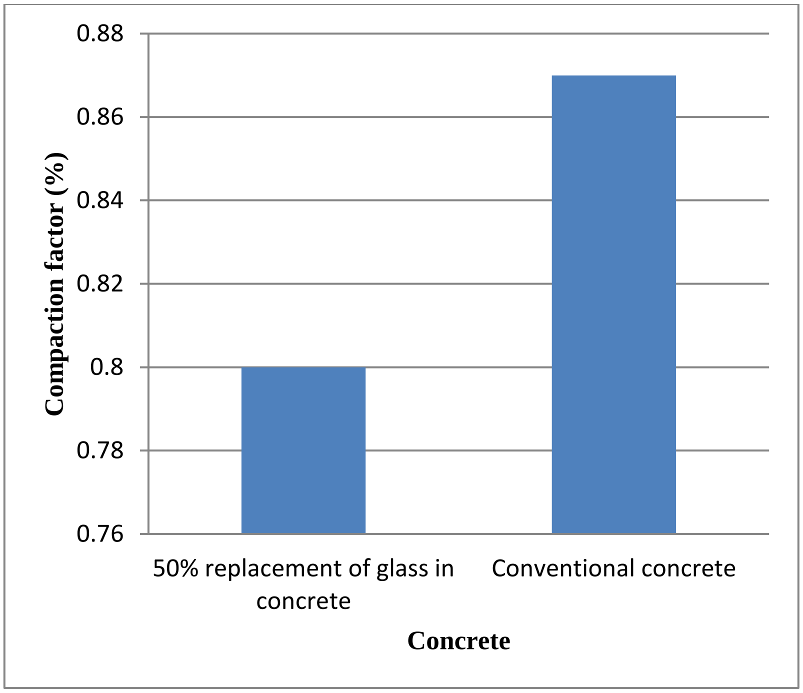

Fig 4.2 : Compaction factor test results graph

4.2 Harden properties of Concrete

4.2.1 Compressive strength test

The compressive strength test was performed on the cubes of size 15 cm x 15 cm x 15 cm to check the waste glasses based concrete and the results obtained are given in Table 5.3.

Table 4.3: Compressive strength

Concrete	Compressive strength (N/mm^2)		
	7days	14days	28days
Conventional concrete	27.21	31.1	36.2
50% replacement of glass in	23.21	25.7	30.5

concrete			

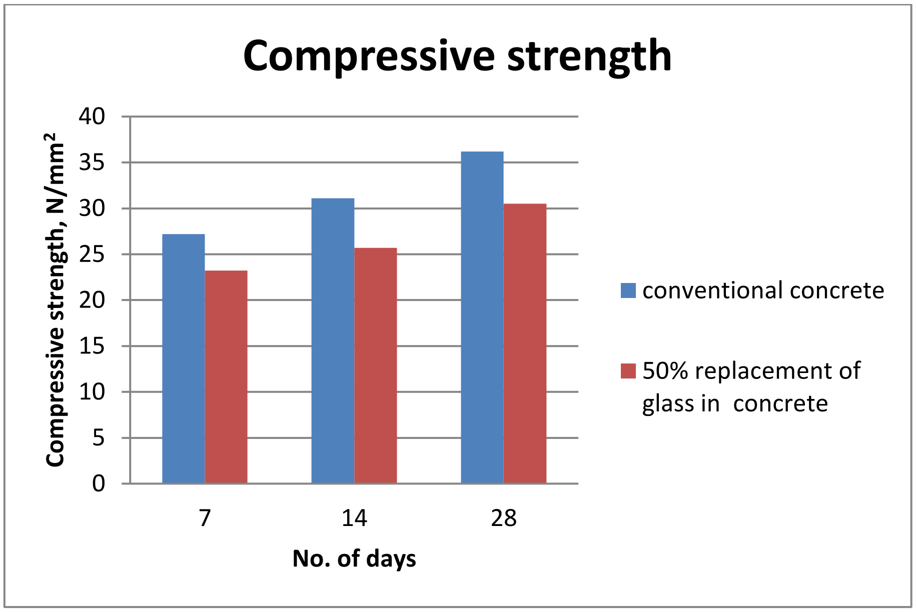

Fig 4.3 : Compressive strength test results graph

From the above graph the 50% replacement of glass in concrete compressive strength **15.74%** lesser than Conventional concrete for 28days curing.

4.2.2 Flexural strength test

The flexural strength test was performed on the cubes of size 10 cm x 10 cm x 50 cm to check the flexural strength of 50% replacement of glass in concrete and the results obtained are given in Table 7.4.

Table 4.4: Flexural strength

Concrete	**Flexural strength (N/mm^2)**		
	7days	**14days**	**28days**
Conventional concrete	2.83	4.06	4.51
50% replacement of glass in concrete	2.19	3.82	4

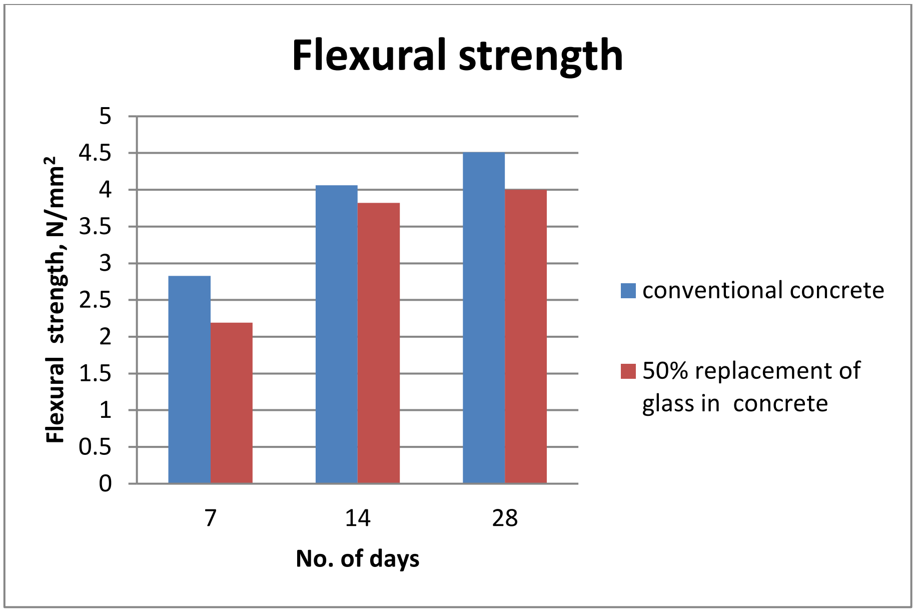

Fig 4.4 : Flexural strength test results graph

From the above graph the 50% replacement of glass in concrete flexural strength **11.3%** lesser than Conventional concrete for 28days curing.

4.2.2 Water absorption

The water absorption of the 50% replacement of glass in concrete surface has improved when compared with conventional concrete because of glass will not absorb that much water as compare to the aggregates.

Table 4.5: Water absorption

Concrete	**28days**
Conventional concrete	3.62
50% replacement of glass in concrete	2.41

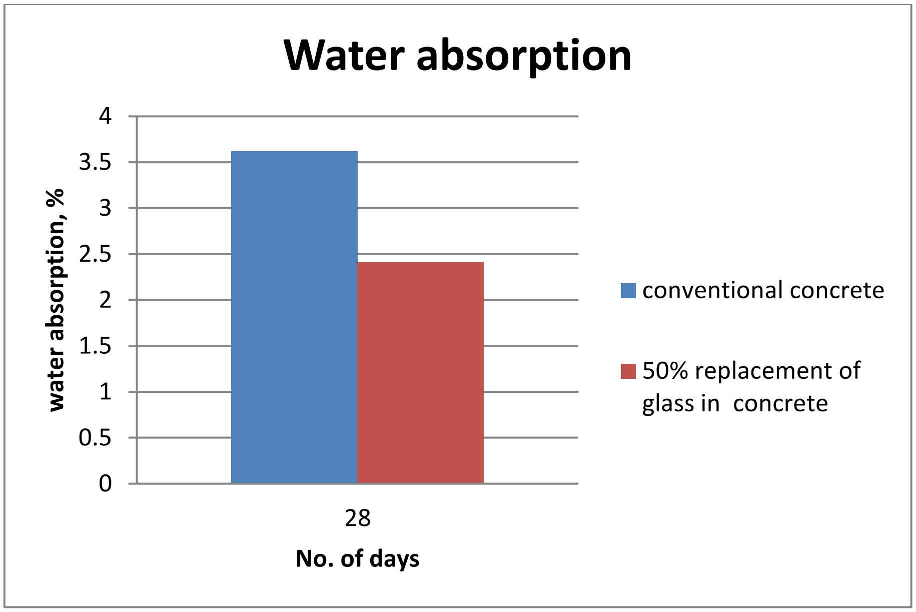

Fig 4.5 : Water absorption test results graph

From the above graph the 50% replacement of glass in concrete water absorption value 33.42% lesser than Conventional concrete for 28days curing.

5. CONCLUSIONS

This study used knowledge of material engineering and solid waste management to solve the ever-increasing rate of waste glass bottles generation in our society with the main objective of replacing cement and aggregates with crushed glass bottle in concrete block for sustainable waste management. Slump for fresh concrete made with 50% replacement of crushed glass bottles the workability is decreases as compare to the control mix. Even though there is reduction of slump values for concrete containing glass bottle powder, they have good workability. Compressive strength of concrete made with 50% replacement of crushed glass bottle decreased when compared with control concrete mix (0% glass). Concrete containing glass bottle powder indicated an improved compressive strength at the later ages for 28days compressive strength of 50% crushed glass is lesser than the control mix. Water absorption decreased with 50% of percentage ratio of waste glass bottle as replacement of cement and aggregates in concrete. All glass mixes (mixed colour mix, green colour mix, clear colour mix and brown colour mix) showed a decrease value of water absorption when compared with the control mix (0% glass).

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