Use of Waste Glass as Coarse Aggregate in Concrete: A Possibility towards Sustainable Building Construction

T. S. Serniabat, M. N. N. Khan, M. F. M. Zain

Abstract— Climate change and environmental pressures are major international issues nowadays. It is time when governments, businesses and consumers have to respond through more environmentally friendly and aware practices, products and policies. This is the prime time to develop alternative sustainable construction materials, reduce greenhouse gas emissions, save energy, look to renewable energy sources and recycled materials, and reduce waste. The utilization of waste materials (slag, fly ash, glass beads, plastic and so on) in concrete manufacturing is significant due to its engineering, financial, environmental and ecological benefits. Thus, utilization of waste materials in concrete production is very much helpful to reach the goal of the sustainable construction. Therefore, this study intends to use glass beads in concrete production.

The paper reports on the performance of 9 different concrete mixes containing different ratios of glass crushed to 5 mm - 20 mm maximum size and glass marble of 20 mm size as coarse aggregate. Ordinary Portland cement type 1 and fine sand less than 0.5 mm were used to produce standard concrete cylinders. Compressive strength tests were carried out on concrete specimens at various ages. Test results indicated that the mix having the balanced ratio of glass beads and round marbles possess maximum compressive strength which is 3889 psi, as glass beads perform better in bond formation but have lower strength, on the other hand marbles are strong in themselves but not good in bonding. These mixes were prepared following a specific W/C and aggregate ratio; more strength can be expected to achieve from different W/C, aggregate ratios, adding admixtures like strength increasing agents, ASR inhibitor agents etc.

Keywords—Waste glass, recycling, environmentally friendly, glass aggregate, strength development.

I. Introduction

BUILDING materials are one of the components in a sustainable building that may possess the maximum positive environmental impact as well as directly affecting the quality of both the building's interior and exterior appearance. They directly and indirectly impact the wider ecological context through the processes used to extract, manufacture, transport and ultimately reuse or dispose them.

Sustainable building materials by definition are materials that are locally produced and sourced (which reduces transportation costs and CO2 emissions); they may include recycled materials, they have a lower environmental impact, they are thermally efficient, they require less energy than more modern or conventional materials, they make use of renewable resources, they are lower in toxic emissions and they are financially viable [1].

Huge amount of natural aggregates, fuel, sand and water, are being consumed in cement and concrete production. Consequently, to minimize these, researches have concentrated on the use of waste materials as potential alternatives in the construction industry, especially in concrete construction. In fact, utilization of waste materials (i.e., slag, fly ash, plastics, glass beads etc.) in concrete construction is one of the prime research interests to reach the goal of achieving sustainable construction. In this aspect, consumption of waste glass beads in concrete manufacturing can be a new scientific sobriety in the field of sustainable concrete [2]-[4].

A large amount of useless glass residue, by-products, and waste materials are produced by different industries on regular basis. The residual and unused wastes are disposed into environment as burden without any commercial return. Consequently, huge money is being spent for their disposal reasons as well as environmental pollution occurs.

It is well known that addition of these wastes in concrete as a supplement of cement generally reduces the construction cost and more or less maintains the properties of concrete. In addition, waste materials, when properly processed, have shown to be effective as construction materials and readily meet the design specifications [5], [6].

This study focuses on producing concrete of acceptable strength with waste glass as coarse aggregate and determining the optimum coarse aggregate mix ratio to achieve this strength.

II. Significance of the Work

Since the demand in the concrete manufacturing is increasing day by day, the utilization of stone chips as coarse aggregate leads to exploitation of natural resources. Recent research findings have shown that concrete made with recycled glass aggregate are capable to provide better long term strength and better thermal insulation due to its better thermal properties of the glass aggregates [7], [8]. The use of recycled glass as aggregate can also greatly enhance the aesthetic appeal of the concrete. Glass is a unique inert material that could be recycled many times without changing its chemical properties. The major aim of environmental authorities is to reduce, as far as possible, the disposal of post-consumer glass in landfill and diversion to economically viable glass product streams [9].

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In this case, a well renowned television producing industry of Malaysia-Japan provided waste glasses for the study. The provided samples were in three different sizes as following,

i. Irregular glass beads of 20 mm size
ii. Irregular glass beads of 5 mm - 10 mm size
iii. Regular marble shaped glass (circular) of 20 mm size

The chemical composition of the provided waste glass sample is as following:

TABLE I
CHEMICAL COMPOSITION OF WASTE GLASS SAMPLE

Component	Percentage %
SiO_2	51.392
Al_2O_3	4.468
CaO	3.164
SO_3	0.068
Fe_2O_3	0.269
K_2O	7.554
MgO	1.562
Na_2O	6.411
B_2O_3	0.3
BaO	1.603
CeO_2	0.093
Cl	0.017
PbO	20.897
Sb_2O_3	0.223
SrO	1.453
TiO_2	0.103
ZnO	0.188
ZrO_2	0.323

III. EXPERIMENTAL WORK

Nine individual concrete mixes were designed where the selected mix design was 1:1.5:3 and the W/C ratio followed was 0.50. OPC type -1 cement and fine aggregate (sand) less than 0.5 mm were used. With these fixed criterions, the proportions of three types of waste glass (20 mm Marble, 20 mm glass beads, 5 to 10 mm glass beads) as coarse aggregate were different for nine different mixes.

The specifications of coarse aggregate in the mixes are as following:

TABLE II
COARSE AGGREGATE MIX RATIO

Mix Designation	Marble (20 mm) %	Glass (20mm) %	Glass (5mm-10mm) %
M-1	80	0	20
M-2	70	10	20
M-3	60	20	20
M-4	50	30	20
M-5	40	40	20
M-6	30	50	20
M-7	20	60	20
M-8	10	70	20
M-9	0	80	20

Standard concrete cylinders of 100 mm X 200 mm were prepared for each of the nine mixes. Compressive strengths of each mix at different curing days were measured.

IV. EXPERIMENTAL RESULTS

The objective of this study was to achieve an acceptable compressive strength of concrete cylinder and to figure out the optimum mix which provides the maximum compressive strength.

The average compressive strengths for different mixes are as following:

TABLE III
COMPRESSIVE STRENGTH OF DIFFERENT MIXES

Mix No	Mix Ratio	Average Compressive Strength in 3 Days		Average Compressive Strength in 7 Days		Average Compressive Strength in 14 Days		Average Compressive Strength in 28 Days	
		MPa	Psi	MPa	Psi	MPa	Psi	MPa	Psi
1	80:0:20	8.1	1173	10.1	1466	12.4	1799	17.3	2516
2	70:10:20	5.5	798	7.9	1146	9.1	1321	13.5	1959
3	60:20:20	4.9	718	7.3	1063	9.2	1334	16.4	2378
4	50:30:20	8.9	1295	11.1	1613	11.3	1639	15.5	2245
5	40:40:20	12.8	1861	14.2	2066	16.1	2340	26.8	3889
6	30:50:20	10.2	1481	12.2	1770	19.5	2829	20	2902
7	20:60:20	11.7	1702	13.9	2024	16.3	2365	23.1	3351
8	10:70:20	5.1	740	7.4	1079	10.1	1465	12.3	1784
9	0:80:20	7.24	1050	9.1	1320	13.5	1958	18.3	2655

From the results it is visible that Mix-5 provides maximum strength which is 3889 psi. From the tests and crack pattern of the cylinders it was found that circular glass marbles are strong enough individually and capable of providing strength but weak in bonding. On the other hand, glass beads are weaker than marbles but perform much better in bond formation within concrete. Mix-5 has a balance of both the properties of glass beads and marbles, for which it possesses maximum compressive strength. However, rough textured marble would have given more strength for the very same mix.

Following figures show the crack pattern and internal bonding of Mix-5.

Fig. 1 Concrete cylinders

Fig. 2 Waste glass sample

Fig. 3 Crack pattern in Concrete cylinder

Fig. 4 Crack pattern in Concrete cylinder

Fig. 5 Internal bond in Concrete cylinder

Fig. 6 A piece of Glass marble after crack

V. Previous Works

Researches have been made where glass beads, crushed glass, glass powder etc. are being used in concrete construction. Mostly, waste glass is used partially with cement, coarse aggregate and fine aggregate and sometimes as replacement of fine aggregate. Commercially, waste glass is already being used in architectural concrete or decorative concrete. For the most common applications of glass in decorative concrete are (1) seeding and (2) mixing integrally [10].

VI. Conclusion and Future Work

The paper presents the necessity of sustainable construction in present world and the possibility of waste glass recycling and using into concrete production. The study focuses on practical use of glass as coarse aggregate in concrete instead of stone chips or brick chips. Stone chips are costly and needed to collect straight from natural resource, brick chips are also expensive and its production causes environmental pollution. In this context, it can be said that waste glass may open a new path of economic and pollution free concrete construction if desired strength can be achieved. During the study, maximum of 3889 psi compressive strength was found from several mixes, which is quite acceptable; though rough textures in glass samples would have provided better bond and better strength.

In recent future, the optimum mix will be cast for other W/C ratios and different cement and fine aggregate ratios for achieving better strength. As glass doesn't absorb water, it is expected that same mix will provide better strength in lower W/C ratio. Admixtures like barium salts, lithium nitrate, lithium carbonate, lithium hydroxide will be added further to reduce the ASR (alkali silica reaction). After receiving the optimum combination, it will be required to do the durability test.

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