



Use of Broken Toughened Glass as a Replacement of Coarse Aggregates in Concrete

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ABSTRACT

This paper investigates the use of broken toughened glass as a coarse aggregate with marble sand to produce translucent concrete as a cheap building material having adequate strength. The product prepared from cheap waste material viz. marble sand and broken glass can be used as a structural member as well as used for architectural purpose. Concrete containing 100% replacement of coarse aggregates with glass pieces may pass some light as white marble sand and transparent toughened glass is used. This type of concrete leads new era in constructional material which is eco-friendly as well as environment friendly. The paper reports the use of glass pieces as replacement of coarse aggregates as 20%, 30%, 50% and 100% replacement and marble sand as fine aggregates as a whole. The gain in compressive strength was noted only at 20% replacement of coarse aggregates. Above 20% replacement, the strength reduces. The strength was drastically reduces at 100% replacement of coarse aggregates. The reduction in compressive strength was noted as 86.80% at 28 days of submerged water curing.

Keywords: Waste material, Toughened glass, Glass aggregate, Marble sand.

INTRODUCTION

In developing countries such as India, where diversified projects for industrialization and urbanization are vigorously embarked upon, the major problem is environmental pollution by increasing in generation of domestic and industrial waste. Disposal of waste has become a major problem in urban areas in India. In recent years, quantities of waste glass and marble waste have been raised due to rapid use of these materials to enhance standard of living. Unfortunately, the bulk of waste glass

isn't being recycled and is therefore, creating serious problems like waste of natural resources and environment pollution etc. This study has been conducted to utilize the waste through basic experimental research in order to analyze the possibilities of crushed waste glass as coarse aggregates in concrete and marble waste as coarse and fine aggregate in concrete¹ to check its effect on the compressive strength of concrete. Different products that are made from glass are: bottles, jars, flasks, windows and windshields, bulbs, tubes, etc.

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On the other hand, marble waste is a by-product obtained from the marble stones during mining, quarrying and waste collected after use as ornamental stone in residential and industrial buildings. Marble industry produces marble dust in large quantity during mining and processing stages. This waste is dumped on to open land which creates numbers of environmental problems. A high volume of marble production has generated a considerable amount of waste during the mining and polishing process. Therefore, the engineers have been challenged to convert waste glass and marble waste as construction materials. Glass in concrete generally provides the aesthetic properties to the concrete while marble aggregates enhance the compressive strength of concrete. The objective of the study is to check the improvement in physical and

ornamental properties of concrete using waste glass and marble waste as a replacement of fine and coarse aggregates. In our study, broken toughened glass was used.

MATERIALS AND METHODS

The materials used for making concrete specimens were white cement, fine and coarse aggregates, water, broken glasses and marble waste as aggregates.

2.1 Cement:

JK white cement from a single lot was used throughout the course of the study. The physical properties of the cement as determined from various tests conforming to Indian Standard IS 269: (1989) and IS 8042: (1989) are listed in Table 1. All the tests were carried out as per recommendations of IS: 4031 (1996;1995).

Table 1: Physical properties of cement

Properties	Observed Value	B.I.S. Requirements
Fineness as per IS: 4031 (Part-1)	0.8%
Standard consistency as per IS: 4031 (Part-4)	41 %
Initial Setting time as per IS: 4031 (Part-5)	65 minutes	Mini. 30 minutes
Final setting time as per IS: 4031 (Part-5)	125 minutes	Maxi. 600 minutes
Compressive strength		
3 days	38 MPa	Mini.16 MPa
7-days	44 MPa	Mini. 22 MPa
28-days	57 MPa	Mini. 33 MPa

2.2 Fine Aggregates:

Marble Sand was used as fine aggregate. The fineness modulus of the fine aggregates is determined by sieve analysis listed in Table 2. Figure-1 shows the marble sand used in the experiment.



Fig. 1: Marble sand

Table 2: Sieve analysis of fine aggregates

IS Sieve designation	Weight retained (Grams)	Percentage weight retained (%)	Cumulative percentage weight retained (%)	Cumulative percentage passing (%)
4.75 mm	120	6	6	94
2.36 mm	571	28.55	34.55	65.45
1.18 mm	908	45.4	79.95	20.05
600 micron	40	2	81.95	18.05
300 micron	15	0.75	82.7	17.30
150 micron	18	0.90	83.6	16.40
Pan	328	16.4	-	-
Total	2000		368.75	

Physical properties of fine aggregates are:

Grading Zone as per IS 383 (1970) = Zone I

Specific gravity = 2.65

Average Absorption = 0.83%

Fineness modulus = 368.75/100
= 3.69

2.3 Coarse Aggregate

Locally available crushed stone aggregates of 10mm nominal size were used as coarse aggregate. Sieve analysis of coarse aggregates is

listed in Table 3. The aggregate was first sieved through 50 micron sieve in order to remove the dirt and other impurities.

Table 3: Sieve analysis of coarse aggregates

IS Sieve designation	Weight retained (Grams)	Percentage weight retained (%)	Cumulative percentage weight retained (%)	Cumulative percentage passing (%)
40 mm	0	0	0	100
20 mm	0	0	0	100
10 mm	1120	56	56	44
4.75 mm	839	41.95	97.95	2.05
Pan	41	2.05	-	-

Physical properties of coarse aggregates are:

Fineness Modulus = 6.91

Specific Gravity = 2.67

Average Absorption = 0.79 %

The physical properties and fineness modulus of coarse aggregate were determined as per standard procedures and were found to conform to IS 383 (1970).

2.4 Water

Portable Water, fit for drinking was used for investigation. This water was used for mixing, curing and testing of concrete.

2.5 Waste Glass: Broken toughened/tempered glass was used as a replacement of coarse aggregates (Agarna, 2016; Topcu & Canbaz, 2004; Serniabat, 2014; Srivastava, 2014) as shown in Figure 2. The size of broken pieces varies from 4.75mm to 10mm.



Fig. 2: Broken toughened glass

2.6 Mix Proportion:

Mix proportioning of concrete (As per IS:10262-2009 Method)²:-

Step 1: Stipulations for proportioning:

• Grade designation	: M 20
• Type of cement	: JK white cement (confirming to IS 269: 1989)
• Maximum nominal size of aggregate	: 12.5mm
• Minimum cement content	: 300 kg per m ³ of concrete mix
• Maximum water-cement ratio	: 0.50 from Table 5 of code IS 456 (2000)
• Workability	: 60 mm (slump)
• Exposure condition	: Moderate
• Degree of supervision	: Good
• Type of aggregate	: Crushed angular aggregate
• Maximum cement (OPC) content	: 450kg/m ³

Step 2: Test data for materials:

a) Specific gravity of cement	: 3.15
b) Specific gravity of	
Coarse aggregate (10mm & 20mm)	: 2.85 & 2.89
Fine aggregate (Crushed stone)	: 2.75
(Broken Glass)	: 1.94 (by Pycnometer test)
c) Water absorption:	
Coarse aggregate (10mm)	: 0.8%
Fine aggregate (Crushed marble stone)	: 1.9%
d) Free (surface) moisture:	
Coarse aggregate	: NIL
Fine aggregate	: NIL

In order to study the effect of waste glass as replacement of coarse aggregate on the strength of concrete, the five mixes were prepared. Indian Standard -10262 (2009) was used for selection of proportions of different constituent materials for M20 grade concrete. Mix was designed using waste glass particle replacing 20%, 30%, 50% and 100% of coarse aggregate (Agarna, 2016). The detail of selecting mix proportion is explained below.

Ingredients & their properties for M20 concrete mix are as follows:-

- **Cement:** JK white cement confirming to IS 269: (1989) and IS 8042: (1989) was used.
- **Fine Aggregate:** Crushed white marble stone free from silt & clay, size between 4.75 mm to 0.002 mm (confirming to Zone – I, IS:383: (1970) was used.
- **Coarse Aggregate:** Coarse aggregate from local quarry (confirming to Zone – I, IS:383-(1970) was used.
- **Glass particle (coarse aggregate):** As replacement of coarse aggregate, broken toughened/tempered glass was used.

Step 3: Target strength for mix proportioning:

$$f_t = f_{ck} + K \cdot S$$

where f_t - target mean strength.

f_{ck} - characteristic strength,

K - a constant=1.65 (IS : 456-2000)

S - standard deviation.

$$f_t = f_{ck} + 1.65 \cdot S$$

$$f_t = 20 + 1.65 \times 4.6$$

$$f_t = 27.59 \text{ N/mm}^2$$

(1.65 taken from Table 39 of SP23 (1982))

Step 4: Selection of water – cement ratio

From Fig.46 of SP:23-(1982), Water/Cement ratio for 27.59 N/mm² is taken as 0.47

Step 5: Selection of water content:

From table -2 of IS:10262-2009², Maximum water content for 10 mm aggregate = 208 liter (for 25 to 50 mm slump range)

Considered water content for 50 mm slump = 195 liter

Step 6: Calculation of cement content:

Water – cement ratio = 0.47

Cement = 195/0.47

$$= 414.89 \text{ kg/m}^3$$

Water content = 195 kg/m³

Step7: Proportion of volume of coarse and fine aggregate:

(Table-3 of IS:10262-2009)² Volume of coarse aggregate per unit volume of total aggregates corresponding to 10mm size aggregate and fine aggregate (Zone I) = 0.44

Volume of coarse aggregate = 0.44

Volume of fine aggregate content = 1 - 0.44

$$= 0.66$$

Step 8: Mix calculations:

The mix calculations per unit volume of concrete shall be as follows:

a) Volume of concrete = 1 m³

b) Volume of cement = Mass of cement / specific gravity of cement x 1/ 1000
= 414.89/3.15 x 1/1000 = 0.1317 m³ of concrete

c) Volume of water = Mass of water / specific gravity of water x 1/ 1000
= 195/1 x 1/1000 = 0.195 m³

d) Volume of aggregate = a - (b + c)
= 1 - (0.1317 + 0.195)
= 0.6733 m³

e) Mass of coarse aggregate:

$$= f \times \text{volume of coarse aggregate} \times \text{specific gravity of coarse aggregate} \times 1000$$

$$= 0.6733 \times 0.44 \times 2.67 \times 1000$$

$$= 790.99 \text{ kg}$$

h) Mass of fine aggregate

$$= f \times \text{volume of fine aggregate} \times \text{specific gravity of fine aggregate} \times 1000$$

$$= 0.6733 \times 0.66 \times 2.65 \times 1000$$

$$= 1177.60 \text{ kg}$$

Step 9: Mix proportions for control mix concrete is shown in Table 4.

Table 4: M20 mix design (Control/Reference mix):

Quantity	Water	Cement	Fine Aggregate	Coarse aggregate	
			Crushed Stone	10 mm	Glass particle
Per cum	195	418.89	1177.60	790.99	---
Designed Mix Proportion	0.47	1	2.81	1.89	---

Mix proportion is 1 : 2.81 : 1.89 and w/c ratio of 0.47

Step 10: Mix proportions for all the mixes (including glass replacement as coarse aggregates) are shown in Table-5.

Table 5: M20 mix design with glass particle as replacement of Coarse aggregates

MIX	Water	Cement	Fine Aggregate	Coarse aggregate	
			Crushed marble Stone (White color)	10 mm	Replaced with Glass particles
M1	195	418.89	1177.60	790.99	---
	0.47	1	2.81	1.89	---
M2	195	418.89	1177.60	632.80	158.20 (20%)
M3	195	418.89	1177.60	553.70	237.30 (30%)
M4	195	418.89	1177.60	395.50	395.50 (50%)
M5	195	418.89	1177.60	---	790.99 100%)

3. PREPARATION OF CONCRETE SAMPLES AND TESTING FOR STRENGTH OF CONCRETE:

The concrete mix design is done in accordance with IS:10262 (2009). In order to study the effect of waste glass as partial replacement of coarse aggregate on the strength of concrete, five mixes were prepared as shown in table 5 above. Six cubes of size 150mm X 150mm X 150mm from each concrete mix were tested for determination of compressive strength at 14 and 28 days of water curing age as per IS: 516: (1959). The average of six cube samples was taken as the representative value of compressive strength. Total 60 cubes (i.e. 12 from each mix) were casted for testing. Workability test was conducted on freshly prepared concrete. The test was conducted on all the five mixes. The slump test was used to find the workability as per procedure laid in IS: 7320: (1999).

Hand mixing was used. The cement was first mixed dry with the aggregates. Water was then added to the mixer and mixed thoroughly for 3 to 4 minutes. The moulds used for casting were cleaned and oil was applied on its inner surface. The mould was filled 1/3 with the concrete and manual compaction was done with 25 strokes of tamping rod. Again the process was repeated 2 more times for completely filling the mould. The surface of the concrete was finished level with the top of the mould. The finished specimens were left to harden in air for 24 hours. The specimens were removed from the moulds after 24 hours of casting and were placed in the water tank filled with potable water in the laboratory. Figure-1 shows the texture of concrete Mix M2 and Mix M5.

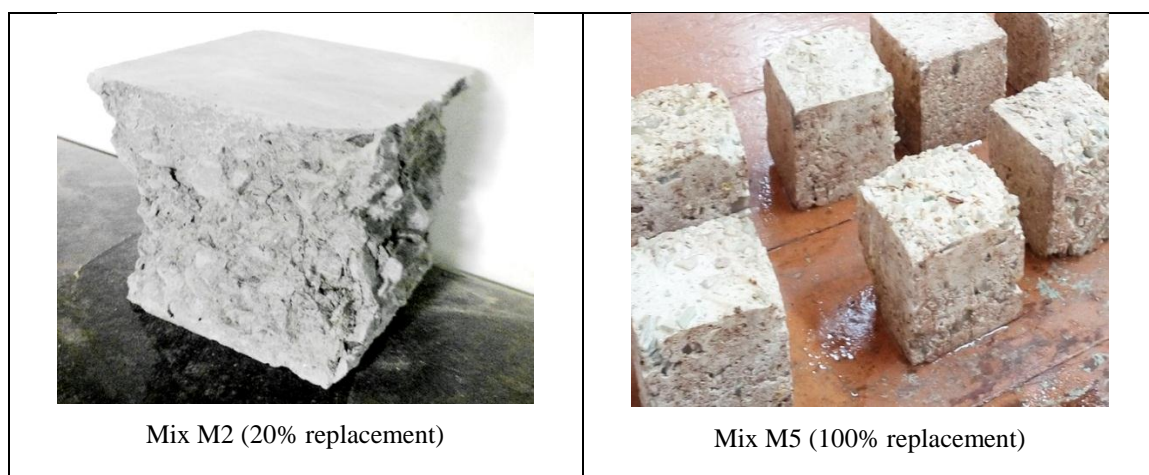


Fig. 1: Texture of concrete mix

An effort has been made to compare the strength of cubes made up with different percentage of broken toughened glass to the respective strength of conventional concrete at the end of 14 and 28 days of submerged water curing. Cubes were tested for compressive strength using Universal Testing Machine available in 'Material Testing Lab' of department of Civil Engineering of PAU Ludhiana.

RESULTS AND DISCUSSION

4.1 Workability of Concrete:

Slump test was used to check the workability of concrete. Table 6 shows the values of slump obtained using slump test on freshly prepared concrete.

Table 6: Values of Slump

Mix	M1	M2	M3	M4	M5
Slump Value (in mm)	68	57	45	30	16

From the above values, it is clear that the workability decreases with increase in broken glass particles in concrete mix. This is due to sharper & irregular geometric form of glass particles compared to crushed stone, which may give rise to high friction & much less fluidity.

4.2 Compressive Strength:

The results of Compressive Strength test carried out on all samples of five mixes viz. M1, M2, M3, M4 and M5 have been shown in table 7 and table 8 for 14-days and 28-days water curing age respectively.

Table 7: Values of Compressive Strength for 14-days water curing

Mix Sample	Replacement of CA with glass particles	Avg. Compressive Strength (MPa)	Percentage Increase/decrease
M ₁	0%	24.44	-
M ₂	20%	25.42	4.00 %
M ₃	30%	23.56	(-) 3.60 %
M ₄	50%	12.04	(-) 50.73 %
M ₅	100%	2.41	(-) 90.14 %

Table-7 shows that there is an increase in 14-days compressive strength for 20% replacement of coarse aggregates with glass waste particles. The percentage increase was recorded as 4.0%. The strength goes on

decreasing as we increase the replacement of CA with glass waste beyond 30%. At 100% replacement, the strength decreases about 90.14 % as compared to control mix.

Table 8: Values of Compressive Strength for 28-days water curing

Mix Sample	Replacement of CA with glass particles	Avg. Compressive Strength (MPa)	Percentage Increase/decrease
M ₁	0%	28.34	-
M ₂	20%	29.73	4.90 %
M ₃	30%	27.71	(-) 2.22 %
M ₄	50%	15.12	(-) 46.64 %
M ₅	100%	3.75	(-) 86.80 %

Table-8 shows that there is minor increase in 28-days compressive strength for 20% replacement of coarse aggregates with glass waste particles. The percentage increase was recorded as 4.90 %. The strength goes on decreasing as we increase the replacement of

CA with glass waste beyond 30%. At 100% replacement, the strength decreases to 86.80 % as compared to control mix. Figure-2 shows the increase in strength of concrete at 28 days curing over 14 days curing age.

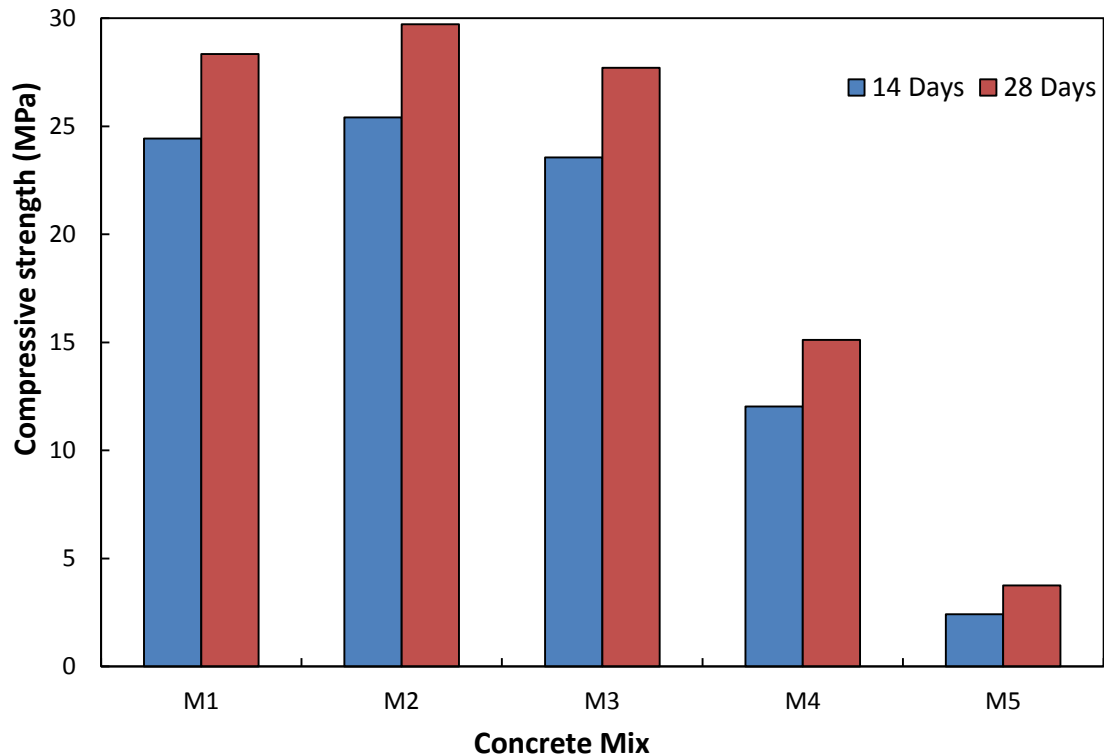


Fig. 2: Compressive Strength of concrete at 14 days and 28 days curing age

CONCLUSION

Based upon the work carried out in this investigation, the following conclusions are drawn.

1. Increase in % of glass particle workability decreases. Concrete is not workable at high percentage of glass particles. This is due to sharper & irregular geometric form of glass particles compared to crushed stone, which may give rise to high friction & much less fluidity.
2. Increase in compressive strength is reported at both curing age (i.e. 14 and 28 days curing age). There is an increase in compressive strength of 3.60% and 4.90% with respect to

control mix at 14 and 28 days curing respectively.

3. Compressive strength decreases as we increase the percentage replacement of coarse aggregates with glass particles beyond 30%.
4. The esthetic look is improved using fine aggregates as marble waste and white cement. The strength marble waste concrete is significantly high as compared to characteristic strength of M20 concrete calculated in design of concrete mix. Addition of glass has not shown any improvement in esthetic look of concrete.
5. The addition of glass particles in concrete makes it harsh, difficult to

- handle and increase the risk of injury as compared to control mix.
6. The prepared concrete may pass some light when used as a thin panel.

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