

# **Durability Behaviour of Concrete with Cement Replaced by GGBFS and Fine Aggregate Replaced by GBFS**

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**ABSTRACT:** This paper presents the investigation on durability of concrete with the usage of Ground Granulated Blast Furnace Slag (GGBFS) as alternate to Ordinary Portland Cement (OPC) and Granulated Blast Furnace Slag (GBFS) as substitute to fine aggregate and the combination of both. Durability Tests were conducted to assess the durability characteristics of concrete and the results were compared with that of the reference concrete. Three sets of replacements were carried out. In the first set cement was replaced with GGBFS, in the second set fine aggregate was replaced with GBFS and a combination of both GGBFS and GBFS was used in the third set. Replacement percentages used for three sets were 0%, 25%, 30%, 35%, 40%, 45%, 50%, and 55%. GGBFS was in the powdered form and GBFS in the granular form. Durability properties of concrete were compared for the optimum replacements of concrete. According to the test results durability properties were more in combination replacements. Test results showed that durable concrete with combination replacement of both GGBFS and GBFS can be produced. This more durable concrete can be used in marine structure constructions.

**KEYWORDS:** Durability, fine aggregate, Ground Granulated Blast Furnace Slag, Granulated Blast Furnace Slag, Ordinary Portland Cement, replacements

## **I. INTRODUCTION**

Cement is very essential for the construction sectors. Nowadays cementitious substitutes are used widely in the construction sector, one such substitute is Blast furnace slag. The utilization of Blast furnace slag which is produced by industrial processes has been focus of waste reduction research for economical, environmental and technical reasons. The production of Blast furnace slag involves only 30% CO<sub>2</sub> emission when compared to production of cement. Ground Granulated Blast Furnace Slag (GGBFS) and Granulated Blast Furnace Slag (GBFS) are waste products of the iron manufacturing industry whose use and production has increased during last decades. By using these waste products the construction cost can be reduced to a great extent. Recent constructions focuses more on using environmental friendly concrete to build taller structures and with smaller structural elements. The concrete needs to attain both high early strength and ultimate strength capacity to improve the process of construction. Other than the mechanical properties, the durability properties of the concrete have to be of good standards in order to have a longer life span. With longer life span the maintenance and rehabilitation costs can be reduced. The solution is to use above mentioned industrial wastes such as GGBFS and GBFS. Nowadays various types of durability tests are there, it includes high temperature test, freeze thaw resistance test, drying wetting effect, capillarity, surface abrasion, acid resistance test, water absorption test, sorptivity test etc.

# International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 4, Issue 11, November 2015

## II. MATERIALS USED

### A. Cement

Ordinary Portland cement of 53 grade conforming to IS: 12269-1987 has been used. The physical properties of the cement obtained on conducting appropriate tests as per IS: 12269-1987.

### B. Ground Granulated Blast Furnace Slag

GGBFS used in this experimental work was procured from Nandi Cements. Properties of GGBFS used is conforming to IS: 4031-1988.

### C. Fine Aggregate

The fine aggregate used in this thesis work is Manufactured sand and the following tests were carried out on sand as per IS: 2386(Part I)-1963.

### D. Slag Sand (Granulated Blast Furnace Slag)

The Granulated Blast Furnace Slag used in the present investigation was collected from Nandi cements. The tests on granulated blast furnace slag were carried out as per IS: 383-1970. Slag sand was of Zone II.

### E. Coarse Aggregates

The coarse aggregate used is crushed (angular) aggregate conforming to IS: 383-1970. The maximum size of aggregate considered is 20mm IS sieve passing and minimum size of aggregate considered is 12.5mm IS sieve passing. The results of sieve analysis conducted as per the specification of IS: 383-1970.

### F. Water

Clean potable water is used for casting and curing operation of the work. The water supplied is of the potable standard of pH value of 7.50 are used.

### G. Super Plasticizer

To improve the workability of fresh concrete Cera hyperplast. Cera hyperplast is supplied by Cera chemicals, 0.25% dosages was used to increase the workability of concrete.

## III. EXPERIMENTAL PROGRAMME

### A. Mix Proportions

Concrete mix design of M40 grade was designed conforming to IS: 10262-2009 and trial mixes were attempted to achieve workable concrete mix. The mix design is prepared as per the IS code. The values that have to be included in the design are found out by various tests. Totally five mixes have been designed. Cubes of standard size 150x150x150mm, Prisms of size 500x100x100mm and cylinders of diameter 150mm and height 300mm were casted and cured at room temperature and were tested at 28 days. Table I shows the mix design for M40 grade concrete. The mix design ratio is 1: 1.88: 2.69.

Table I Concrete Mix Design

Unit of batch	Water (liters)	Cement (Kg)	Fine aggregate (Kg)	Coarse aggregate (Kg)	SP
m <sup>3</sup>	167.4	418.25	787.73	1127.06	1.04
Ratio	0.40	1	1.88	2.69	0.25

### B. Fresh Concrete Properties

#### 1) Slump Test

The concrete was tested for slump cone test as per the IS: 1199-1959. The test results showed that slump flow have improved as the GGBFS content is increased the slump value is increased compared to the control mix. However all the concrete mixes were homogeneous and cohesive in nature also the slump had shear type of failure as the GGBFS content was increased. No segregation and bleeding in any of the mixes were observed.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

## C. Hardened Concrete Properties

### 1) Compression Strength Test

The compression test is used to determine the hardness of cubical specimens of concrete. The strength of a concrete specimen depends upon cement, aggregate, bond, w/c ratio, curing temperature, age and size of specimen. Mix design is the major factor controlling the strength of concrete. Cubes of size 15cmx15cmx15cm (as per IS: 10086-1982) should be cast. The specimen should be given sufficient time for hardening (approximately 24hr) and then it should be cured for 28 days. After 28 days, it should be loaded in the compression testing machine and tested for maximum load. Compressive strength should be calculated by using equation given below.

### 2) Splitting Tensile Strength Test

The splitting tensile strength is well known indirect test used for determining the tensile strength of concrete as it is one of the most important fundamental properties of concrete. Three cylinders of size 150mm diameter and 300mm in length are casted and cured for 28 days. Testing was made in 2000kN testing machine at rate of loading as  $(1.2 \text{ to } 2.4) \times (\pi/2) l^* d$ , N/min. The average of three cylinders for each replacement is noted down to get the strength split tensile of concrete

### 3) Flexural Tensile Strength

Flexural strength is defined as a materials ability to resist deformation under load. Three prisms of size 100mmx100mmx500mm are casted and cured for 28 days. Testing was done under two point loading in flexural testing machine. The specimens are placed in the machine such that the load is applied to the top surface as cast in the mould along two lines spaced 13.3 cm apart. The axis of the specimen is carefully aligned with the axis of the loading device. The rate of loading is 180 kg/minute. The load is applied until the specimen failed and the maximum load applied to the specimen during the test is recorded. Flexural strength is determined from the equation given below.

## IV. TESTS FOR DURABILITY

The optimum replacement percentages were used to cast specimens for durability tests. The optimum replacement for cement is 45%, for fine aggregate is 45% and optimum for the combination replacement is 30%.

### A. Test Specimens

Table I shows the specimens used for durability tests. Specimens includes cubes and cylinders.

Table I Specimens Used for Durability Tests

Tests conducted	Specimens	Size of specimen
Acid attack	Cubes	100mmx100mmx100mm
Water absorption	Cubes	100mmx100mmx100mm
Sorptivity	Cylinders	100mm dia, 50mm thick

### B. Acid Resistance Test

The test specimens used for acid resistance test is of dimensions 100mmx100mmx100mm. These specimens are immersed in sulphuric acid diluted with water. Concentrations of diluted sulphuric acid are 0.5%, 1%, 2%. Specimens such as CM, GGBFS, GBFS and GGBFS+GBFS are immersed in diluted sulphuric acid. Initial weights of the specimens are noted and then specimens weights were noted at intervals of 7, 14, 21, 30 and 60 days. The solutions were renewed at the end of 14 days. The visual appearance and change in compressive strength at 60 days were recorded.

### C. Water Absorption Test

Water absorption test is done on cubes of dimensions 100mmx100mmx100mm. Water absorption by concrete specimens was done based on ASTM C 642 (2006). At first the specimens were oven dried at a temperature of about 100 °C for 24 hours. After that the specimens are allowed to cool and the weights of the specimens are noted. The weights initially noted are denoted as 'A'. After that the specimens are dipped in water, the weight was taken at 60

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

minutes, 120 minutes and 24 hours. The weights noted are denoted as 'B'. The water absorption was calculated using the given equation.

$$\% \text{ Absorption} = [(B-A)/A] \times 100 \quad (1)$$

### D. Sorptivity Test



Fig 1 Lab Sorptivity Method

Sorptivity test was done based on ASTM C 1585 (2004). Sorptivity is done to measure the capillary absorption of water. Initially the specimens were oven dried for 24hrs at 100°C and after that the specimens are allowed to cool. Initial weight of the specimens are noted. Then the specimens are placed in a tray filled with water at a height not more than 5mm from the base of the specimen. Figure 1 shows the Lab Sorptivity Method. The specimen's weight was noted at intervals of 0, 5, 10, 20, 30, 60, 120, 180, 240, and 300 minutes, after wiping off any excess water. The quantity of absorbed water during each interval was then determined using Eqn. 2.

$$I = m_t / (a \times d) \quad (2)$$

Where, I = absorption in mm

t = elapsed time in minutes

$m_t$  = the change in specimen mass in grams, at the time t

a = exposed area of specimen through which water penetrates in  $\text{mm}^2$

d = density of water in  $\text{g/mm}^3$

A graph was plotted for I versus square root of time in seconds. The slope of best fit curve was taken as the sorptivity in  $\text{mm/s}^{1/2}$

## V. DURABILITY TEST RESULTS

Various durability tests were performed on the concrete specimens.

### A. Acid Resistance

With increase in sulphuric acid concentrations (0.5% to 2%) there is a reduction in the masses of the specimens and also there is a reduction in its compressive strength.

#### 1) Appearance

Acid attack on the concrete surface which results in loss of concrete from specimens. Reduction in concrete occurs more on the control mix specimens. White filmy mass were observed on the surface of the specimens from the 7<sup>th</sup> day onwards. Formation of a powdery surface on specimens can be observed and they turned whitish at the end of 60 days. The specimens in 2% sulphuric acid suffered severe mass loss along with loss of concrete cover exposing the aggregate. Figures 1 and 2 shows specimens before acid test and specimens immersed in sulphuric acid respectively

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015



Fig 1 Specimens before Acid Test



Fig 2 Specimens Immersed in Sulphuric Acid

## 2) Cubes after Acid Test



Fig 3 Control Specimen Fig 4 GGBFS Specimen



Fig 5 GBFS Specimen Fig 6 GGBFS + GBFS Specimen

Figures 3,4,5 and 6 represents control specimen, GGBFS specimen, GBFS specimen and GGBFS + GBFS specimen after acid test. White filmy substance can be seen on its surfaces.

## 3) Mass Loss

Mass reduction in the specimens immersed in solutions are noted at regular intervals. The mass loss of the specimens such as CM, GGBFS, GBFS, GGBFS+GBFS were 8.1%, 6.1%, 6.4%, 5.4% respectively. Blast furnace slag specimens suffered less mass loss when compared to control mix specimens. Mass reduction due to acid attack at various intervals are given in Table I.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

Table I Mass Reduction Due to Acid Attack at Various Intervals

Mix	% Acid soln	Dry mass (kg)	Mass taken at intervals (kg)					
			3 Days	7 days	14 Days	21 Days	30 days	60 days
CM	0.5	2.555	2.576	2.575	2.570	2.569	2.562	2.550
	1	2.562	2.568	2.567	2.561	2.560	2.555	2.540
	2	2.501	2.534	2.500	2.480	2.339	2.300	2.298
GGBFS	0.5	2.568	2.580	2.578	2.571	2.569	2.560	2.554
	1	2.561	2.579	2.577	2.502	2.496	2.390	2.298
	2	2.587	2.590	2.502	2.495	2.467	2.433	2.430
GBFS	0.5	2.532	2.532	2.528	2.520	2.515	2.510	2.505
	1	2.606	2.626	2.602	2.596	2.499	2.495	2.491
	2	2.676	2.680	2.654	2.632	2.598	2.580	2.504
GGBFS + GBFS	0.5	2.537	2.545	2.540	2.537	2.530	2.524	2.522
	1	2.535	2.546	2.545	2.501	2.496	2.486	2.480
	2	2.536	2.536	2.500	2.480	2.475	2.455	2.398

## 4)Compressive Strength Reduction

The specimens immersed in diluted sulphuric acid solution is then tested for compressive strength and it was found that there is a reduction in the compressive strength values. After 60 days the compressive strength values reduced by 21% for CM specimens, 14% reduction in GGBFS, 15.5% reduction in GBFS specimens and 13.8% reduction in GGBFS+GBFS specimens.

## B) Water Absorption

From the results obtained it's clear that the percentage water absorbed by control mix specimen is larger than that of the water absorbed by the specimens with GGBFS and GBFS specimens. This shows that the addition of GGBFS and GBFS helps to reduce the permeability, thereby helps to reduce water absorption. Table II represents percentage water absorption by specimens.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

Table II Percentage Water Absorption by Specimen

Specimen used	Dry weight (Kg)	Weight after 24hrs immersion in water (Kg)	% Absorption
CM	2.43	2.516	3.53
GGBFS	2.48	2.53	2.016
GBFS	2.53	2.59	2.37
GGBFS & GBFS	2.51	2.556	1.83

The reduction in water absorption by the concrete helps to increase the durability of the structures. There is a 43% reduction in water absorbed by GGBFS mix, 33% reduction in GBFS mix, and 48% reduction in water absorbed by GGBFS + GBFS mix.

## C. Sorptivity

Table III Capillary Absorption at Various Time Intervals

Sl. no	Time (min)	Mass Recorded at Intervals (kg)				Absorption I (mm)			
		CM	GGBFS	GBFS	GGBFS & GBFS	CM	GGBFS	GBFS	GGBFS & GBFS
1	0	0.756	0.760	0.771	0.775	0	0	0	0
2	1	0.758	0.761	0.771	0.775	0.254	0.127	0	0
3	5	0.759	0.761	0.772	0.776	0.381	0.127	0.127	0.127
4	10	0.760	0.761	0.772	0.776	0.509	0.127	0.127	0.127
5	20	0.763	0.761	0.773	0.777	0.891	0.127	0.254	0.254
6	30	0.765	0.761	0.773	0.777	1.145	0.127	0.254	0.254
7	60	0.767	0.762	0.774	0.777	1.400	0.254	0.381	0.254
8	120	0.77	0.762	0.774	0.778	1.782	0.254	0.381	0.381
9	180	0.771	0.764	0.775	0.778	1.909	0.509	0.509	0.381
10	240	0.773	0.765	0.775	0.778	2.164	0.636	0.509	0.381
11	300	0.775	0.766	0.776	0.779	2.419	0.763	0.636	0.509



# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

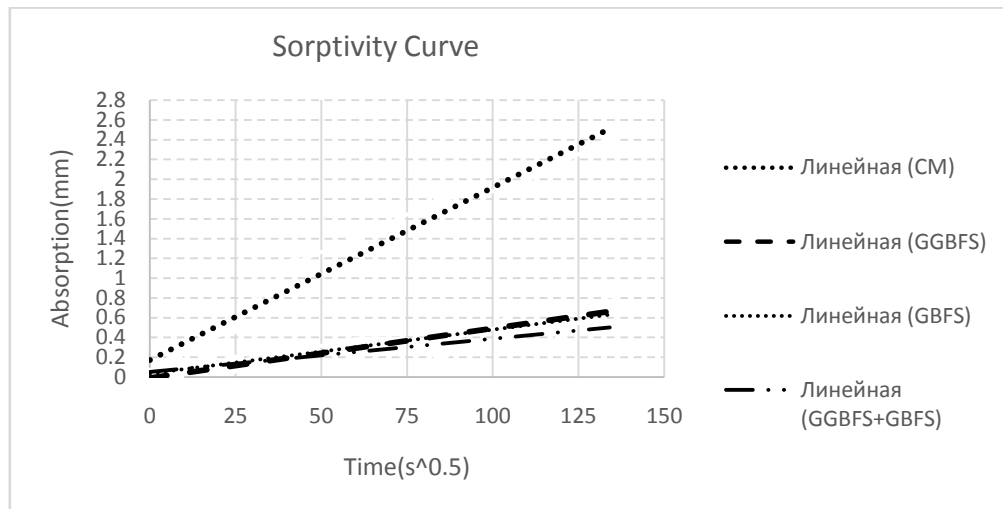


Fig 7 Sorptivity Curve of Specimens

Table III shows Capillary absorption at various time intervals. The sorptivity or the capillary absorption values of the specimens were calculated and it was found that the sorptivity is less in case of specimens made with GGBFS and GBFS when compared with control mix specimens. The addition of GGBFS and GBFS decrease the capillary absorption of the control mixes. Figure 7 shows the sorptivity curve of specimens. The sorptivity of CM, GGBFS, GBFS, GGBFS & GBFS mixes after 300 minutes were  $0.018 \text{ mm}/(\text{s})^{0.5}$ ,  $0.005687 \text{ mm}/(\text{s})^{0.5}$ ,  $0.00474 \text{ mm}/(\text{s})^{0.5}$ ,  $0.00379 \text{ mm}/(\text{s})^{0.5}$  respectively. Hence the sorptivity value has decreased by 68% by addition of GGBFS in control mix. GBFS mixes underwent a decrease of 73% in sorptivity compared to the control specimens. GGBFS and GBFS mixes underwent a decrease of 78.9% in sorptivity compared to the control specimens. This indicates that the rate of water absorption reduces in control mix with the addition of GGBFS, GBFS and a combination of both GGBFS and GBFS.

## VI. CONCLUSIONS

- Percentage reduction in masses of specimens in acid is 8.1% for control mix, 6.1% for GGBFS, 6.4% for GBFS, 5.4% for GGBFS + GBFS specimens
- Mass loss in GGBFS + GBFS specimen is less when compared to other specimens, GGBFS + GBFS specimens are less affected by acids
- There is a 43% reduction in water absorbed by GGBFS mix, 33% reduction in GBFS mix, 48% reduction in water absorbed by GGBFS + GBFS mix
- Percentage reduction in water absorbed by GGBFS + GBFS specimen is more than other specimens
- Sorptivity value has decreased by 68% for GGBFS specimens, the decrease in sorptivity is 73% in GBFS specimen, GGBFS + GBFS mixes underwent a decrease of 78.9% in sorptivity
- Percentage decrease in sorptivity of GGBFS + GBFS specimen is more than other specimens
- Blast furnace slags can be used as effective replacement material
- Effective replacements increases aspects such as strength and durability
- Strength properties are more in GGBFS specimens and durability properties are more shown by GGBFS + GBFS specimens.

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(An ISO 3297: 2007 Certified Organization)

**Vol. 4, Issue 11, November 2015**

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