Self-Healing Of Mechanically-Loaded Concrete With Ground Granulated Blast Furnace Slag

Dr. Binu Sukumar[(1)], Ra. B. Depaa[(2)]

(1) Professor & Head, Department Of Civil Engg., R.M.K Engg. College, Chennai

(2) Assistant Professor, Department Of Civil Engg., R.M.K Engg. College, Chennai

ABSTRACT

Self-healing phenomenon in cementitious materials has been noticed and been studied for a long time. This project outlines effect of self-healing on normal concrete incorporating high volume of Ground Granulated Blast Furnace Slag (GGBFS) when subjected to continuous water exposure. For this purpose, normal concrete with ggbfs replacement ratios of 0%, 35%, and 55% were prepared having a constant water-cementitious material ratio of 0.45. A uniaxial compression load was applied to generate micro cracks in concrete where cube specimens were pre-loaded up to 70% and 90% of the ultimate compressive load determined at 28 days.

Later, the extent of damage was determined as percentage of loss in mechanical properties (as determined by compressive strength) and percentage of increase in permeation properties (sorptivity index). After pre-loading, concrete specimens were stored in water for a month and the mechanical and permeation properties are monitored at every two weeks. The self healing action of GGBFS was found effective as it healed the micro cracks and also the mechanical properties too increased.

INTRODUCTION

Indian cement industry has been utilizing cementitious and pozzolanic by-products for manufacture of cement and concrete in a prudent and cost-effective manner. **Concrete** is a composite construction material made primarily with aggregate, cement, and water. The main problem with cement is its production in terms of the high amount of energy and carbon fuel that are used and the gases like carbon dioxide and nitrogen oxide that are released into the atmosphere and affect our air quality.

Wastes such as Fly-Ash from thermal power plants, slags from metallurgical industries, red mud and spent pot lining from aluminium industries, sludges from different chemical industries, spent catalyst from petroleum industry, marble dust from marble industry, and chemical gypsum and phosphochalk from fertilizer industry, which pose serious disposal and ecological problems in addition to occupying large areas of valuable land, are now being used in various cement plants in India, as blending components and performance improvers in cements and also as raw mix components.

The two major by-products of the steel industry are slag and fly ash. Effective utilization of these wastes can increase the performance of concrete and minimization in waste disposal as well. The main components of blast furnace slag are CaO (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%), and MgO (1-18%). In general increasing the CaO content of the slag results in raised slag basicity and an increase in compressive strength.

EXPERIMENTAL STUDY

Use of GGBFS in concrete significantly reduces the risk of damages caused by alkali–silica reaction (ASR), provides higher resistance to chloride ingress — reducing the risk of reinforcement corrosion — and provides higher resistance to attacks by sulphate and other chemicals.

Increased durability of reinforced concrete is typically associated with a dense concrete matrix, i.e. a very compact microstructure is expected to lower permeability and reduce the transport of corrosive agents to reinforcement .Conceptually, a dense matrix can be achieved by a well-graded particle size distribution, by the use of mineral additives such as GGBFS, or by the use of low water-to-cement ratios. For this purpose, concrete specimens were prepared by keeping the total mass of binder (Portland cement + GGBFS) constant at 500 kg/m^3, in which 35% and 55% of binder, by mass, was replaced by GGBFS. For comparison, a conventional mixture without GGBFS was also produced. The mechanical and permeation properties of pre-loaded SCC specimens were monitored for 7 and 28 days. These properties included the compressive strength, split tensile strength, flexural strength and sorptivity. In addition, the physical properties of the materials used in concrete mix were determined by means of conducting standard tests like consistency, setting time, water absorption, specific gravity and density. M30 grade concrete was used for testing.

TEST RESULTS

The physical properties of GGBFS have been found out and the results are given in table 1.

Physical Parameters	GGBFS
Colour	Brown
Shape	Sub-rounded to angular
Grain size composition (%)	
Silt & clay	1.5
Fine sand	16
Medium sand	72.5
Coarse sand	10
Uniformity coefficient ($C_U = D_{60} / D_{10}$)	3.85
Coefficient of curvature, $C_C = (D_{30})^2 / (D_{10} \times D_{60})$	1.43
Specific gravity	2.61
Plasticity index	Non Plastic

Table 1 Physical properties of ggbfs

The physical properties of the cement, fine aggregate and coarse aggregate used in concrete mix were determined by means of conducting standard tests like consistency, setting time, water absorption, specific gravity and density and the results are given in table 2.

CEMENT	
Specific gravity	3.15
Fineness of cement by dry sieving	1%
FINE AGGREGATE	
Fineness modulus	3.416
D_{10}	0.25 mm
D_{30}	0.42 mm
Uniformity coefficient	3.28
Coefficient of curvature	0.86
Percentage of coarse sand	46.2%

Percentage of medium sand	45.8%
Percentage of fine sand	1.0%
Specific gravity	2.575
Bulk density in loose state	1550 kg/m^3
Bulk density in rodded state	1674.2 kg/m^3
COARSE AGGREGATE	
Fineness modulus	3.169
Bulk density in loose state	1680.22 kg/m^3
Bulk density in rodded state	1823.20 kg/m^3
Specific gravity	2.833
Water absorption	0.41%

Table 2 Physical Properties of cement, fine aggregate and coarse aggregate

In order to determine the mechanical properties of conventional concrete and the concrete made with GGBFS, compressive strength, split tensile strength and flexural strength tests were conducted and the results are given below:

Specimen no	Days	Percentage of GGBFS		
		0%	35%	55%
1	7	22	40	40
2		20	36	37
3		21	42	36
1	28	33	56	57
2		28	54	52
3		32	58	54

Table 3 Compressive strength results

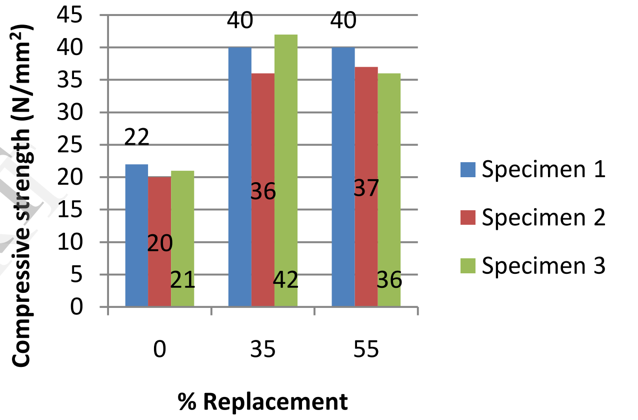

Fig 1 Compressive strength results

Specimen no	Days	Percentage of GGBFS		
		0%	35%	55%
1	7	2.551	3.53	3.2
2		2.21	2.94	2.6
3		2.906	3.29	2.8
1	28	2.806	3.89	2.92
2		3.219	3.24	2.84
3		3.072	3.62	3.12

Table 4 Split tensile strength results

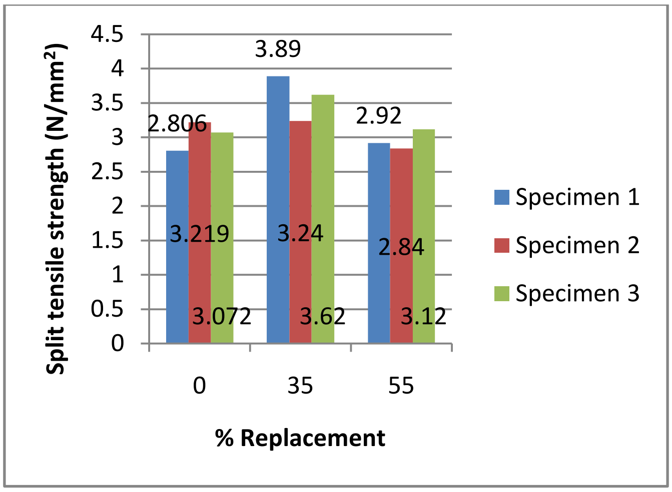

Fig 2 Split tensile strength results

Specimen no	Days	Percentage of GGBFS		
		0%	35%	55%
1	7	6.2	10.8	11.2
2		5.8	9.72	10.1
3		5.6	11.34	9.7
1	28	9.2	15.76	15.6
2		10.3	14.58	14.1
3		8.6	15.66	14.6

Table 5 Flexural strength results

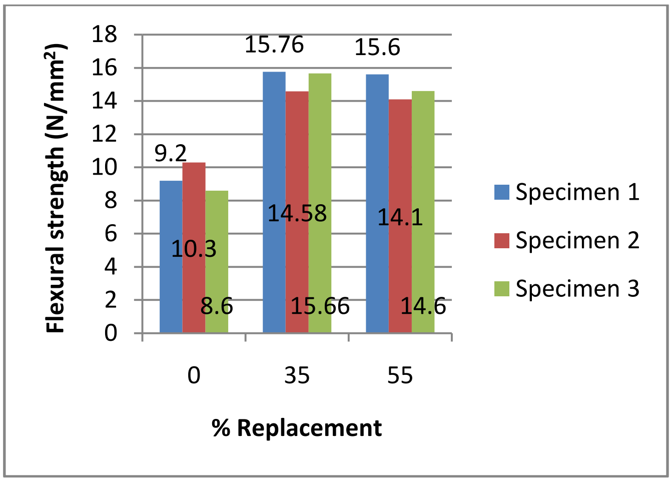

Fig 3 Flexural strength results

The self healing property of concrete made with GGBFS has been studies using Sorptivity tests and the results are given below:

GGBFS(%)	0%	70%	90%
0	0.113	0.141	0.177
35	0.084	0.122	0.151
55	0.089	0.129	0.162

Table 6 Sorptivity test results

CONCLUSION

In this research work, GGBFS cement concrete was tested for compressive strength, split tensile strength and flexural strength for ultimate loading. It was found that the mix has given maximum strength at 35% replacement ratio of GGBFS. The GGBFS concrete had good workability and the hardened concrete had good durability and is ecofriendly and cost effective.

As the study describes the presence of an important amount of unhydrated particles available in the microstructure of GGBFS, these observations are attributed to the self-healing of the pre-existing cracks, mainly by hydration of anhydrous particles (GGBFS) on the crack surfaces.

In this research, the innovative use of GGBFS appears to be an interesting alternative because of the following advantages:

- Reduction of cracks
- Excellent compatibility with cement matrix
- More energy absorption
- Extends serviceability of concrete
- Long term durability of concrete
- More shattering control
- High resistant to impact
- GGBFSs when added to PCC as per calculation, they prevent cracking and also improves the performance of concrete. In RCC construction the reinforcement inside can be protected from corrosion and any other chemical reactions. When 0.35% of GGBFS added to total weight of PCC, the strength increases twice the target mean strength, the compression increases and hence there is increase in tensile strength and hence ductility increases and the cracks are reduced.

REFERENCES

1. Anonymous: IS 4031: (Part 7) 1988 Methods of physical tests for hydraulic cement, Determination of compressive strength of masonry cement, Bureau of Indian Standards.

2. Anonymous: IS 516: 1959 Method of test for strength of concrete, Bureau of Indian Standards.

3. Anonymous: IS 5816: 1999 Splitting Tensile Strength of Concrete Method of Test, Bureau of Indian Standards.

4. Beshr.H, Almusallam.A.A and Maslehuddin.M, Effect of coarse aggregate quality on the mechanical properties of high strength concrete, Construction and Building Materials, Vol.17, pp.97-103, May 2003.

5. Fujii .T Ayano.T and Sakata .K, Strength and durability of steel-slag hydrated matrix without cement, Proc.on29th conference of our world Concrete & Structures., pp.253-258, Jan 2004.

6. Fujii .T, Tayano.T and Sakata .K, Freezing and thawing Resistance of Steel making slag concrete, Journal of Environmental Sciences for sustainable society ., Vol1 , pp.1-10, Dec 2007.

7. Garg.M and Singh.M, Strength and durability of cementious binder produced from fly ash–lime sludge-portland cement, Indian Journal of Engineering & Materials Sciences., Vol 13, pp.75-79, Dec 2006.

8. Hisham .Q, Faissal .S and Ibrahim .A, Use of low CaO unprocessed steel slag in concrete as fine aggregate, Construction and Building Materials., Vol 23 ,1118-1125, Sep 2009.

9. Khidhair .J, Falak .O and Mohammed .O, Using of Steel Slag in Modification of Concrete properties, Engineering & Technology journal., Vol 27(9), 1711-1721, Dec 2009.

10. Kimur .T & Otsuk.N., Study on applicability of Steel Slag Hydrated Matrix to steel reinforced members under marine environment, Technical Report of International Development Engineering., ISSN 1880-8468 , June 2006.

11. Matsunga, D., “Development environmental friendly block made from steel slag”, Concrete Journal, Vol. 41, No. 4, pp. 47-54, June 2003.

12. Matsunga. H ,Tanishiki .K and Tsuzimoto.K, Environment-Friendly Block Ferroform made from Steel Slag, JFE technical report no. 13, pp. 53-57, May 2009.

13. Wang.C, QI.Y and He .J, Experimental study on steel slag replacing sand in concrete, International Workshop on Modelling simulation and Optimization., Vol.13, pp.451-455, May 2008.