Chapter 5
Usage of Ground Granulated Blast Furnace Slag on Mechanical and Absorption Properties of Concrete

S. Panda, T. Jena, S. Mishra, K. C. Panda, and C. R. Panda

Abstract Mineral admixtures serve a critical function in improving the characteristics of concrete. The characteristics of blended concrete are investigated in this research utilizing varying quantities of ground granulated blast furnace slag (GGBS). The mix design is prepared as per M30 grade of concrete. The controlled specimen was prepared with 100% ordinary Portland cement (OPC). The blended concrete samples were prepared with 5%, 10%, 15%, 20%, 25%, 30%, 40%, and 50% substitution of OPC with GGBS. The prepared samples are cube, cylinder, and prism which were cured in normal water for a period of 7 and 28 days. The studied parameters are compressive strength, split tensile strength, and flexural strength for 7 and 28 days of curing. The durability properties, such as water absorption and sorptivity, were also tested after 28 days of normal water curing (NWC). The study reveals that up to 30% replacement of OPC with GGBS represents better strength properties compared to controlled specimen. For less water absorption and sorptivity, the replacement level of OPC is 15% and 20% with GGBS, respectively.

Keywords Compressive strength · Blended concrete · Water absorption · Sorptivity · GGBS

5.1 Introduction

The recent time's use of pozzolans as a potential material for replacing cement partially is gaining importance. To obtain high-performance and durability concrete, GGBS could be used as a partial replacement for cement. Few researchers have published journals regarding GGBS-blended concrete. Ground granulated blast furnace

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slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steelmaking) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. The main novelty of this study is to find the durability properties such as water absorption and sorptivity of blended concrete replaced with GGBS. Absorption property of concrete is very much important in recent aggressive environmental conditions. 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. The MgO and Al_2O_3 content show the same trend up to, respectively, 10–12% and 14%, beyond which no further improvement can be obtained. Several compositional ratios or so-called hydraulic indices have been used to correlate slag composition with hydraulic activity, the latter being mostly expressed as the binder compressive strength. A review of a few papers is presented here. Rajkumar et al. [1] investigated the strength properties of M35 grade of concrete using 30% replacement of GGBS as an optimum dose with cement. Jena et al. [2] found the optimal replacement of silpozz and fly ash 20% and 10% with cement, respectively, and obtained better strength as well as absorption capacity of blended concrete. Jena and Panda [3, 4] investigated the strength and durability properties of concrete with fly ash and silpozz in seawater replaced by OPC and found better performance. Karri et al. [5] found the mechanical properties of M20 and M40 grade concrete replaced by GGBS with OPC up to 50%, and the study reveals remarkable performance with 30% replacement. Arivalagan [6] investigated the increasing of later age strength on M35 grade of concrete using GGBS with good workability and durability. Awasare and Nagendra [7] enhanced the strength of M20 grade concrete using GGBS replaced with cement up to 50%. In this paper, the strength and absorption properties of M30 grade concrete are investigated when partially replacing GGBS with cement. Dadsetan and Bai [8] investigated the self-compacting concrete properties using GGBS, metakaolin, and fly ash and revealed good results in terms of compressive strength and microstructural properties. Rashad and Sadek [9] studied the behavior of compressive strength on high-volume GGBS concrete with micro metakaolin at elevated temperature and found that the residual compressive strength reached peak level at 400^0C. This work employs GGBS to investigate the strength and absorption qualities of mixed concrete.

5.2 Experimental Programs

5.2.1 Materials and Methods

The materials such as GGBS, OPC 43 grade, fine aggregate, coarse aggregate, and normal water are used. The high-end superplasticizer CERA HYPERPLAST XR-W40 is used. Table 5.1 represents the chemical and physical properties of OPC and GGBS provided by the supplier.

Table 5.1 Chemical and physical properties of cementitious materials

Oxides (%)	Cement (OPC)	GGBS
SiO_2	20.99	32–36
Al_2O_3	6.05	18–25
Fe_2O_3	6.01	0.8–3.0
CaO	62.74	30–34
MgO	1.33	0.6–10
K_2O	0.40	1.67
Na_2O	0.04	–
SO_3	1.82	0.1–0.4
TiO_2	.025	–
Loss on ignition (%)	1.14	–
Specific surface, m^2/g	0.33	400–600 m2/kg
Bulk density (gm/cc)	1.43	0.7–0.8
Specific gravity	3.15	2.9
Particle size (Micron)	35	25
Color	Gray	White powder

5.2.2 *Mix Proportions and Identifications*

The basic mix design was M30 grade concrete design according to Indian standard code 10262-2009 [10]. A detail of mix identity with proportions and quantity per cubic meter of concrete is given in Tables 5.2 and 5.3. In order to maintain the workability of concrete, the doses of SP increased as the percentage of GGBS increased.

5.3 Results and Discussion

5.3.1 *Properties of Fresh Concrete*

The fresh concrete was prepared and tested slump and compaction factor immediately to get good workable concrete, which is shown in Table 5.4.

5.3.2 *Hardened Concrete Properties*

By analyzing the specimens at the required period, the characteristics of hardened concrete can be determined. Wet curing is done properly before testing to produce a definite strength. The findings of hardened concrete that was cured in normal water for 7 and 28 days are shown in Figs. 5.1, 5.2 and 5.3.

Table 5.2 Proportion and identity of plain and blended concrete

Mix identity	Cement (%)	GGBS (%)	SP (%)
MC100G0	100	00	0.25
MC95G5	95	05	0.20
MC90G10	90	10	0.28
MC85G15	85	15	0.40
MC80G20	80	20	0.45
MC75G25	75	25	0.33
MC70G30	70	30	0.22
MC60G40	60	40	0.30
MC50G50	50	50	0.38

where *M* mix, *C* cement, *G* ground granulated blast furnace slag, *SP* superplasticizer

Table 5.3 Mix quantity per m^3 of concrete

Mix identity	Cement (Kg/m^3)	Fine aggregate (Kg/m^3)	Coarse aggregate (Kg/m^3)	GGBS (Kg/m^3)	Water	Superplasticizer (Kg/m^3)
MC100G0	391.11	637	1278.55	0	176	0.750
MC95G5	371.56	637	1278.55	19.55	176	0.781
MC90G10	352.00	637	1278.55	39.11	176	1.005
MC85G15	332.45	637	1278.55	58.66	176	0.781
MC80G20	312.89	637	1278.55	78.22	176	0.800
MC75G25	293.34	637	1278.55	97.77	176	1.229
MC70G30	273.78	637	1278.55	117.33	176	1.005
MC60G40	234.67	637	1278.55	156.44	176	0.781
MC50G50	195.56	637	1278.55	195.55	176	1.005

Table 5.4 Slump value and compaction factor for various mixes

Mix identity	Slump	Workability	Compaction factor (%)	Workability
MC100G0	60	Medium	98.60	High
MC95G5	55	Medium	82.5	Low
MC90G10	50	Medium	98.64	High
MC85G15	40	Low	81.3	Very low
MC80G20	47	Low	91.1	Medium
MC75G25	45	Low	82.3	Low
MC70G30	55	Medium	98.64	High
MC60G40	50	Medium	80	Very low
MC50G50	50	Medium	85	Low

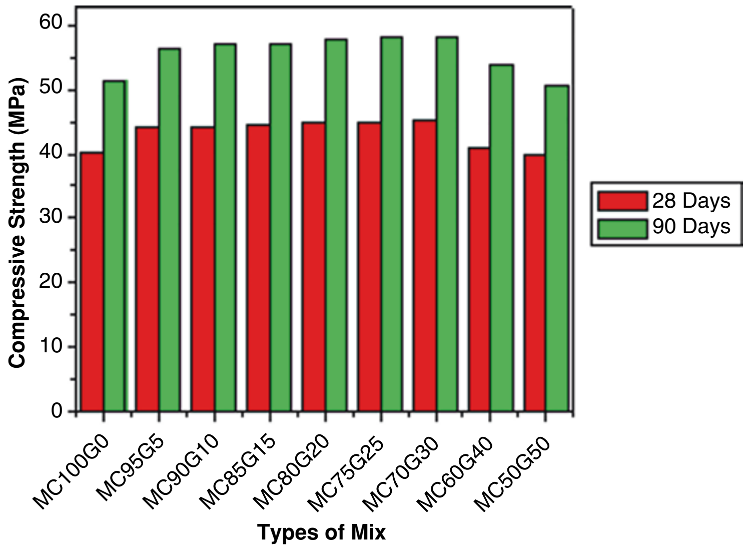

Fig. 5.1 Compressive strength versus types of mix

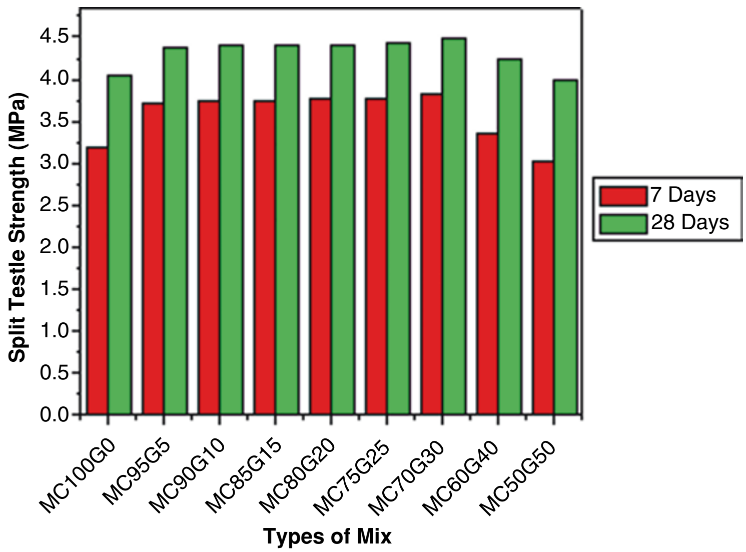

Fig. 5.2 Split tensile strength versus types of mix

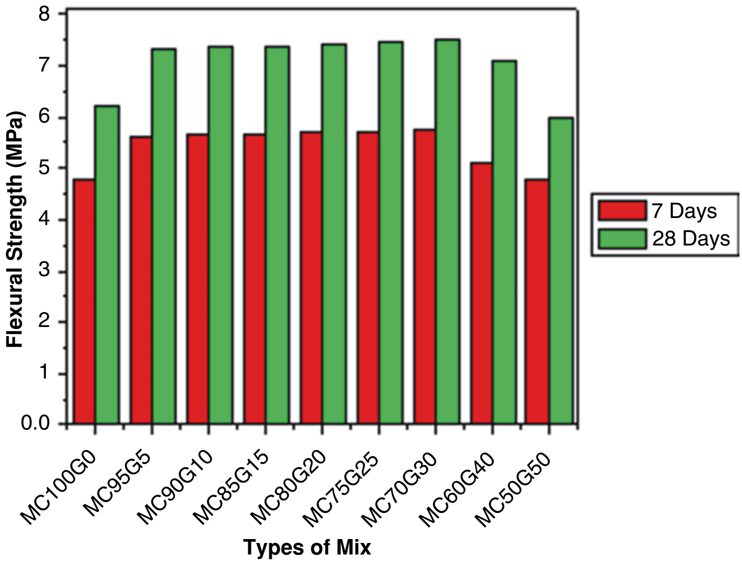

Fig. 5.3 Flexural strength versus types of mix

5.3.2.1 Compressive Strength

For each mix that was cured in ordinary water, six cubes were cast. Three of the six cubes were cured in normal water for 7 days, while the remaining three cubes were cured in normal water for 28 days. Compressive strength versus types of mix is shown in Fig. 5.1. It is observed from Fig. 5.1 that the compressive strength of MC70G20 is maximum followed by MC70G30. The lowest value was found to be MC50G50. The GGBS particles are highly reactive during the hydration process; thus, reduction of porosity leads to denser microstructure; as a result, compressive strength increases.

5.3.2.2 Split Tensile Strength

For each mix that was cured in ordinary water, six cylinders were cast. Out of these six cylinders, three were cast for 7 days and three for 28 days. Split tensile strength versus a type of mix is shown in Fig. 5.2. From Fig. 5.2, the split tensile strength of MC70G30 is maximum, MC70G20 is found to be second strongest, while MC50G50 is found to be lowest. This again may be due to more C-S-H gel formation in the presence of GGBS particles, especially for the specimens cured in 28 days of curing.

5.3.2.3 Flexural Strength

For each mix that was cured in ordinary water, six prisms were cast. Three of the six prisms were cured in normal water for 7 days and three for 28 days. The sample MC70G30 has the highest flexural strength, as illustrated in Fig. 5.3. Due to micro-sized particles of GGBS interstices, the pores of concrete lead to dense microstructure and enhance the flexural strength as compared to normal mix.

5.4 Durability Properties

Durability is defined as the ability to resist against different kinds of damages, such as chemical attack, natural weathering, corrosion (abrasion), and the potential to retain long without any significant damage. We conducted two tests, namely, water absorption and sorptivity test, after 28 days of curing.

5.4.1 Water Absorption Test

The test procedure involves casting 100 mm × 50 mm and immersing it in normal water for 28 days. It was oven-dried for 24 h at the temperature of 110° C to a constant weight and weighted as dry weight (W1) of cylinder. It was immersed in hot water at 85 °C for 3.5 h and again weighted as wet weight (W2) of cylinder. The difference in weight per original weight is expressed as its absorption in percentage. Water absorption versus concrete mix is shown in Fig. 5.4, from which it can be concluded that the mix identity MC50G50 has the highest value and mix identity MC75G15 has the lowest value of water absorption followed by MC80G10, which is the second lowest. Water absorption has a direct relationship with the voids, so the absorption decreases as the voids decrease. The incorporation of 15% GGBS as partial cement replacement material has notable effect on its water absorption.

5.4.2 Sorptivity Test

The samples were cast and cured for 28 days, with a diameter of 100 mm and a height of 50 mm. The specimen was then kept in an oven to dry for 3 days at 100 °C temperature and thereafter allowed to cool. Soon the specimen is kept in a water tub with water level not more than 5 mm above the base of specimen; and one thing is kept in mind—the flow from the exterior surface is prevented by sealing it properly

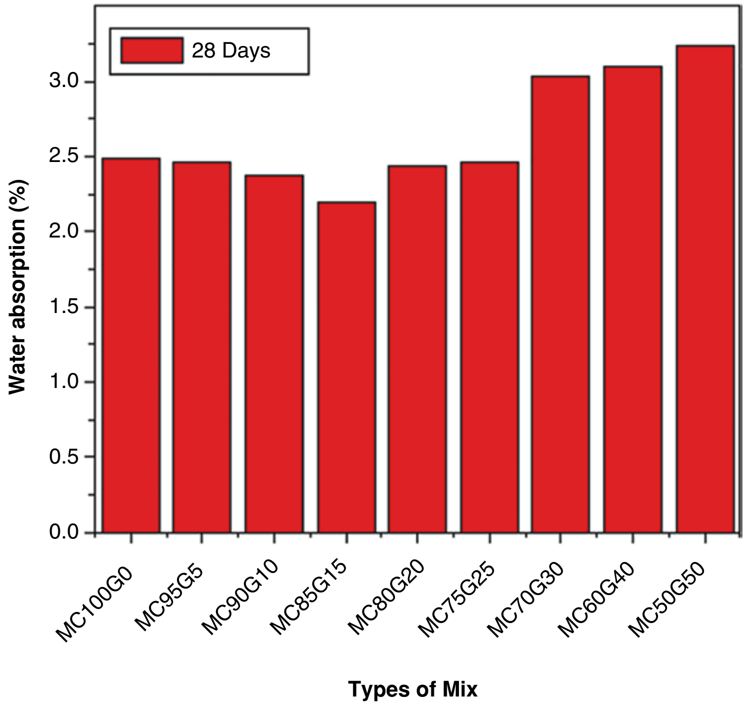

Fig. 5.4 Water absorption versus concrete mixes

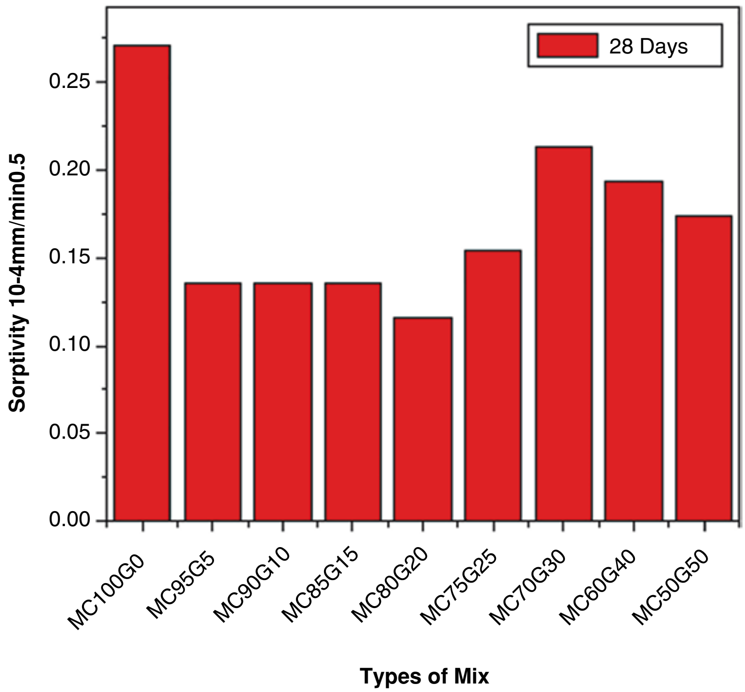

Fig. 5.5 Sorptivity versus types of mix

with nonabsorbent coating. Specimens were removed from the tray at an interval of 30 min and weighted. Figure 5.5 depicts sorptivity versus types of mix. Basically, sorptivity is the absorption of water due to capillary voids present in concrete. The value of sorptivity coefficient is decreasing when increasing the percent replacement of GGBS. The capillary absorption coefficients were also significantly influenced by the binder combination used and were improved through the use of GGBS as cement replacement. This improvement of the capillary water absorption is due to the more pore structure refine and the distribution and dimension of the capillary porosity which is mainly due to the formation of the secondary C-S-H gel issued from the pozzolanic reaction of GGBS [11].

5.5 Conclusions

Based on the present work, a few conclusions are drawn, which are as follows:

- It is concluded from the study that the mix of 10% GGBS replacement of cement gives the maximum values of compressive strength, split tensile strength, and flexural strength, followed by 30% replacement of GGBS with cement.
- When the percentage replacement of GGBS in place cement increases up to 30% or more, the strength properties decrease with respect to conventional concrete.
- The rate of water absorption increases in mixes having more than 40–50% of GGBS, and 15% GGBS with cement provides minimum absorption.
- Sorptivity shows that conventional concrete has maximum value followed by MC50G50 mix.
- MC50G50 represents maximum water absorption capacity as compared to normal mix because of such low cement content and eco-efficiency. As the replacement level increases, the absorption capacity also increases.
- Considerable amount of strength can be observed by using superplasticizers.
- As a result, it can be stated that utilizing GGBS in a specific percentage can improve the durability and strength of concrete.

References

1. B. Kaviya, R. Arjun, P. Rajkumar, S. Ramakrishnan, S. Subash, Study on partial replacement of cement by ground granulated blast furnace slag (GGBS). Int. J. Pure Appl. Math. **116**(13), 411–416 (2017)
2. T. Jena, K.C. Panda, J.R. Behera, Usage of fly ash and silpozz on strength and sorptivity of marine concrete. Int. J. Appl. Eng. Res. **12**(16), 5768–5780 (2017)
3. T. Jena, K.C. Panda, Compressive Strength and Carbonation of Sea Water Cured Blended Concrete. Int. J. Civil Eng. Technol. **8**(2), 153–162 (2017)
4. T. Jena, K.C. Panda, Mechanical and durability properties of Marine concrete using Fly ash and Silpozz. Adv.Concrete Constr. **6**(1), 47–68. ISSN: 2287-5301 (Print), 2287-531X (Online) (2018). https://doi.org/10.12989/acc.2018.6.1.047

5. V. Awesare, M.V. Nagendra, Analysis of strength characteristics of GGBS concrete. Int. J. Adv. Eng. Technol. **V**, 82–84 (2014)
6. S. Karri, Strength and Durability Studies on GGBS Concrete. SSRG Int. J. Civil Eng. **2**(10), 2348–8352 (2015)
7. S. Arivalagan, Sustainable studies on concrete with GGBS as a replacement material in cement. Jordan J. Civil Eng. **8**(3), 263–270 (2014)
8. S. Dadsetan, J. Bai, Mechanical and microstructural properties of self-compacting concrete blended with metakaolin, GGBS and FA. Constr. Build. Mater. **136**, 658–667 (2017)
9. M.A. Rashsd, M.D. Sadek, An investigation on Portland cement replaced by high volume GGBS pastes modified with micro-sized metakaolin subjected to elevated temperature. Int. J. Sustain. Built Environ. **6**, 91–101 (2017)
10. IS: 10262:2009, Concrete Mix Proportioning-Guidelines. Bureau of Indian Standards, New Delhi, India.
11. A. Akyildiz, Water absorption and Sorptivity of Properties Concrete Containing GGBS. IOSR J. Mech. Civil Eng. **15**(6), 66–69 (2018)