Effect of Replacement of GGBS and Fly Ash with Cement in Concrete

Rachita Panda and Tanmaya Kumar Sahoo

Abstract Use of ordinary Portland cement as a binding material is well accepted for construction purposes globally. The huge demand for cement in construction leads to a rise in the use of absolute energy from the cement industry and high CO_2 emissions. As a result, the global cement sector is facing increasing difficulties in the conservation of material and energy resources, as well as decreasing its CO_2 emissions. Similarly, many industrial wastes like fly ash, ground granulated blast furnace slag, waste recycled product, cement kiln dust, silica fume, quarry dust, glass waste, rubber waste, red mud are generated nowadays due to growth in industrialization, increasing urbanization and rising standards of living due to technological innovation, which is leading to harmful threats to the environment along with the waste disposal problem. Therefore, in this paper efforts have been made for not only to control environmental pollution but also to reduce the cost of waste management and concrete production by utilizing ground granulated blast furnace slag (GGBS) and fly ash (FA) with partial replacement of cement. Industrial wastes, such as GGBS and FA, are waste by-products from iron industry and thermal power plants, respectively. In the present study, these by-products at different percentages as a partial replacement of cement have been utilized in concrete. The tests were conducted with partial replacement of GGBS at different percentages of 0, 10, 15, 20 and 25% and with FA at different percentage of 0, 5, 7.5, 10, 12.5 and 15% by the dry weight of cement. Tests on workability and compressive strength were carried out on concrete mixes prepared at different percentages of GGBS and FA. The experimental results show a significant improvement in the strength with increase in GGBS and FA content in partially replaced cement-concrete, making it viable for practical uses in the building industry. On the basis of experimental results, it is concluded that with an increase in GGBS and fly ash percentage the compressive strength of concrete increases and the evaluation allows the design of GGBS and FA mixed concrete for medium strength concrete.

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B. B. Das et al. (eds.), *Recent Developments in Sustainable Infrastructure*, Lecture Notes in Civil Engineering 75, https://doi.org/10.1007/978-981-15-4577-1_68

Keywords Ground granulated blast furnace slag · Fly ash · Concrete · Compressive strength

1 Introduction

Concrete has a significant role worldwide for being used as construction material. The blooming infrastructure and development have led to an increase in construction, hence the demand of cement. In order to meet the requirement of cement, production of cement has been increased which not only enhances the huge requirement of resources for cement industry but also emitting 5–7% CO_2 worldwide [1]. The ultimate strength of ordinary Portland cement-concrete is largely dependent on the formation of C–S–H gel from the hydration process of cement. Hence in recent technologies alternative materials have been selected to get the required strength of concrete replacing cement.

On the other hand, a large amount of industrial wastes has been generated due to the rapid industrialization. These wastes require huge space for dumping or various treatment process to be useful. Hence utilization of these waste products in the preparation of concrete by keeping an eye on the characteristics will reduce the environmental burden, the cost of waste management and the concrete cost of manufacturing.

In the present study, wastes from iron industry and thermal power plant, popularly known as GGBS and FA, respectively, have been utilized in the mixture of concrete. The cementitious behaviour of these wastes is dependent on the specific surface area and the pozzolanic behaviour of its mineral composition. Globally, it is estimated that annual output of fly ash ranges from 0.75 to 1 billion tons [2]. Similarly, GGBS output typically varies from around 300–540 kg for each ton of pig or rough iron created for mineral feed involving 60–65% of iron, whereas during steel production 150–200 kg per ton of slag is produced per ton of liquid steel [3]. As demand for inexpensive energy increases in developing nations, this amount is anticipated to increase in the coming years. Hence bulk utilization of these wastes can be achieved by its civil engineering applications [4].

2 Experimental Study

2.1 Materials Used

2.1.1 Cement

OPC-43 grade cement conforming to **IS: 8112/2013** was collected from Bhubaneswar, Odisha to carry out this experiment. In order to avoid energy consumption of cement industry and environmental protection from excessive CO_2 emission, the use of non-conventional cementitious waste materials have been used in this experiment in the production of concrete.

2.1.2 Fly Ash

Fly ash is a waste generated at thermal power stations constituting about 60–88% of total combustion residues. In this study class F fly ash from NALCO, Talcher, Odisha at Rs. 25/- per bag was collected. As FA is cheaper than cement and has binding property, hence can contribute towards concrete preparation.

2.1.3 Ground Granulated Blast Furnace Slag

GGBS is a consequence of iron industry acquired by heating of the earthy constituents of iron-ore with the limestone and coke at high temperature in the blast furnace about 1500 °C. It was collected from steel industry, Bhubaneswar, Odisha at Rs 200/- per bag. GGBS shows cementitious behaviour, which can be a replacement of cement in concrete.

Portland cement, fly ash and GGBS were the cementitious materials used in this experiment and their physical and chemical characteristics are shown in Table 1.

Table 1 Physical and chemical properties of cement, GGBS and FA

S. no.	Particulars	OPC	GGBS	FA
1	Specific gravity	3.02	2.74	2.43
2	Specific surface area (m^2/kg)	320	558	443
3	Compressive strength (MPa)	40.88	–	–
4	SiO_2 (%)	20.61	33.64	54
	Al_2O_3 (%)	5.028	21.5	26
	CaO (%)	62.61	33.2	18.10
	Fe_2O_3 (%)	3.329	0.2	19.28
	MgO (%)	2.237	9.5	3.30
	SO_3 (%)	2.723	0.66	1.5
	Na_2O (%)	0.328	0.34	–
	K_2O (%)	0.577	0.39	1.34
	P_2O_5 (%)	0.32	–	–
	TiO_2 (%)	0.27	–	1.20
	LOI	1.968	0.56	1.02

Table 2 Physical properties of aggregates

S. no.	Particulars	CA	FA
1	Specific gravity	2.8	2.65
2	Fineness modulus	6.4	2.47
3	Water absorption	0.2 (%)	0.55 (%)

2.1.4 Aggregates

In concrete, aggregates are the major constituents. They are giving the concrete body, reducing shrinkage and increasing strength. The concrete consists of 70–80% of aggregate volume so that any change in the percentage of aggregate will cause insufficient strength. The 10 and 20 mm crushed stones of satisfactory properties were used as coarse aggregates in the present study. The fine aggregates passing through 4.75 mm, conforming to zone II as per the specification of **IS: 383-2016**, were used.

The physical properties of aggregates are given in Table 2.

2.2 Methods

2.2.1 Compressive Strength Test of Concrete

The maximum bearing load sustained by the specimen without causing failure of the specimen to the cross-sectional area under gradually applied load is known as the compressive strength. The concrete was prepared by mixing cement, fine aggregate, coarse aggregate homogeneously with required quantity of water. The assembly of concrete was filled the moulds, compacted in three layers, both by hand compaction just as by table vibrator after compaction, giving the specimen a smooth completion and expelling them from the vibrator. The specimens were demoulded following 24 h and moved to restoring tanks where they were allowed to cure for the required number of days. Cubes of size 150 mm have been made according to IS:456 and compression testing machine is used to test the solid blocks. The compression strength was calculated using the formula:

$$\text{Compressive strength} = \frac{\text{load}}{\text{area}} \text{MPa}$$

Cubic blocks of concrete were drawn out of water at each required curing period and retained for surface drying. The blocks have been tested for the desirable quality of strength in a 40T compression testing machine.

2.3 Concrete Mix Preparation

A composite mixture of concrete is prepared by adding cement, fine aggregate, coarse aggregate and water. In this study GGBS and FA are mixed with concrete partially replacing cement in various proportions. Mix design of concrete has been done referring IS 10262:2009 for proportioning of all concrete materials for design strength.

Mix design				
W/C ratio	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
0.48	394	790	1043.6	197.16

Cement, fine aggregate and coarse aggregate were taken in the 1:2:2.65 ratio corresponding to concrete grade M-25. All the ingredients of concrete are mixed homogeneously. The preparation of composite concretes were carried out by partially replacing dry weight of cement with 10, 15, 20 and 25 of GGBS and 0, 5, 7.5, 10, 12.5 and 15% of fly ash, respectively. By keeping the percentage of GGBS constant, fly ash percentage has been varied and mix proportions were prepared accordingly. Then compressive strength testing was performed at 7 days and 28 days for each and every sample.

3 Results and Discussion

The development of compressive strength of concrete mixtures was determined at 7 and 28 days of curing with given percentages of GGBS and FA. Workability and strength properties are improved when GGBS is added to concrete. FA provides progressive compressive strength and higher resistance from sulphate attack to the structure. The average of three samples was taken for each proportion of GGBS and FA. The increase in strength completely depends upon the increase in curing period as the addition of water will enhance the chemical reaction of mineral components strengthening the bond. In the reaction process the pozzolanic phenomenon takes place only when the available calcium hydroxide reacts with silica and alumina. The chemical reaction of the Portland cement is conveyed as follows [5]:

$$\text{Cement}\,(C_3S,\ C_2S) + H_2O\ (H) \rightarrow\ C{-}S{-}H{-}\text{gel} + Ca(OH)_2(CH)$$

The pozzolanic reaction is:

$$Ca(OH)_2(CH)\ +\ SiO_2(S)\ +\ H_2O(H) \rightarrow C{-}S{-}H{-}\text{gel}$$

$$Ca(OH)_2(CH) + Al_2O_3(A) + H_2O\ (H) \rightarrow C{-}A{-}H{-}gel$$

Portland cement hydration generates calcium hydroxide, and then pozzolanic reaction occurs by combining silica with calcium hydroxide. The combination of higher GGBS percentage and reduced FA percentage improves concrete strength.

The relation between the compressive strength of concrete at constant GGBS and varying FA content is provided in Figs. 1, 2, 3 and 4.

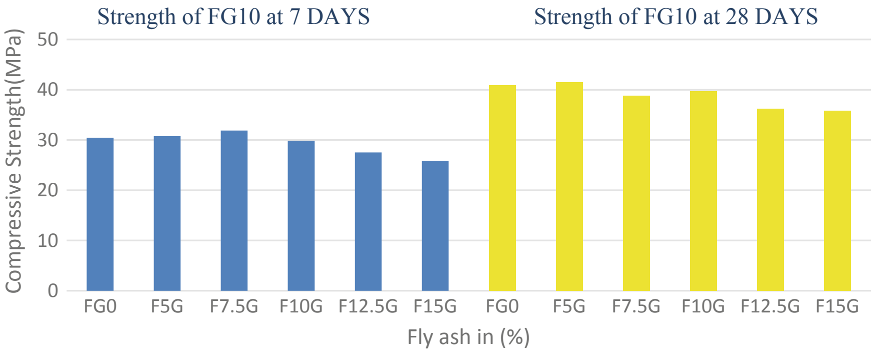

Fig. 1 Compressive strength of samples at 7 days and 28 days having 10% GGBS content at various fly ash content

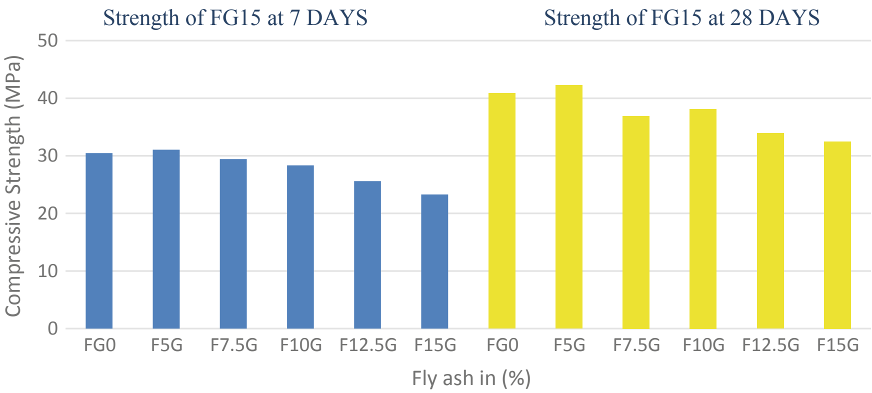

Fig. 2 Compressive strength of samples at 7 days and 28 days having 15% GGBS content at various fly ash content

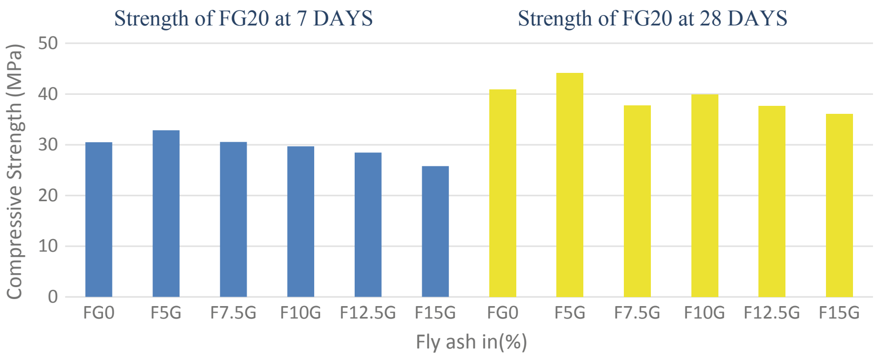

Fig. 3 Compressive strength of samples at 7 days and 28 days having 20% GGBS content at various fly ash content

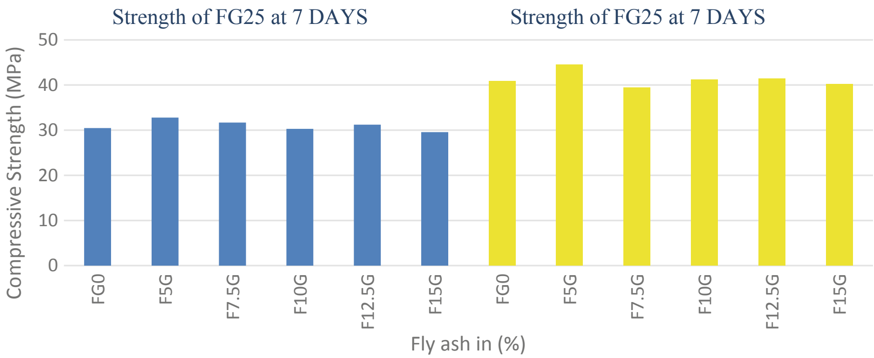

Fig. 4 Compressive strength of samples at 7 days and 28 days having 25% GGBS content at various fly ash content

4 Conclusion

In the present study, the feasibility of using GGBS and FA as a cementitious material with partial replacement of cement was investigated by conducting a series of compressive strength tests at 7 and 28 days with varying percentage of GGBS and FA. The conclusions of the study are as follows:

1. With constant GGBS content and varying FA content, the strength of concrete varies between 30 and 42 MPa, meeting the requirement of medium strength concrete.
2. The higher proportion of GGBS and the lower proportion of FA increases the strength, whereas the lower proportion of GGBS and higher proportion of FA decreases the strength.
3. The maximum strength is obtained at 25% of GGBS and 5% of FA content, which is 42 MPa.

4. The utilization of GGBS and FA not only increases the strength but also reduces the construction cost significantly.

These mix proportions of concrete using GGBS and FA are valid for a wide range of mix proportioning and provide an effective means of determining the influence of industrial wastes on the properties of concrete. They also provide optimization of blending and quality control between the above outcomes. Although these trial mixes are based on a certain set of materials, they can be readily used with other components to produce future outcomes.

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