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Influence of incorporation of granulated blast furnace slag as replacement of fine aggregate on properties of concrete

Rakesh Kumar Patra, Bibhuti Bhusan Mukharjee*

Department of Civil Engineering, Veer Surendra Sai University of Technology, Burla, India

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ABSTRACT

Conservation of natural resources, efficient utilization of industrial waste and reduction of environmental pollution are major driving forces behind the use of waste products generated from different industries in making various cementitious products. Moreover, alternate sources of fine aggregates are to be explored to fulfill the acute shortage of natural aggregates in various parts of the world. Therefore, the present study tries to explore alternative sources of fine aggregate by investigating the effect of incorporation of granulated blast furnace slag (GBS) as replacement of natural fine aggregate on the properties of concrete mixes. For this, concrete mixes are prepared with two water/cement ratios (0.45 and 0.5) and three different percentages of GBS (20%, 40%, and 60%). Various properties of concrete mixes such as workability, compressive strength after 7, 28 and 90 days, splitting tensile and flexural strength, and rebound number have been studied to ascertain the influence of incorporation of GBS in concrete. The test results show an improvement in compressive and tensile strength of concrete with the incorporation of GBS in concrete mixes. The development in compressive strength at different curing time is similar to that of normal concrete. Furthermore, the study depicts that rebound number of concrete increases with increasing percentages of GBS, which indicates the improvement in the quality of concrete with the incorporation of GBS in concrete.

1. Introduction

Sustainable development could be achieved through minimization of the use of natural resources and optimum utilization of different industrial waste in developing various types of construction materials. Moreover, materials and construction cost, environmental friendliness and conservation of natural resources for the future generations, are the most important factors to be considered for sustainable construction (Mehra et al., 2016). This can be fulfilled by utilizing various types of waste products such as recycled aggregates, waste plastic, fly ash, bottom ash, blast furnace slag, and rice husk ash etc. in construction works (Mukahrjee and Barai, 2014; Aprianti, 2017; Paris et al., 2016; Rana et al., 2016; Sharma and Bansal, 2016). Concrete, the most widely used construction material is not known to be an eco-friendly material. In recent years, the enormous enhancement in the usage of concrete in various construction activity creates several problems like depletion in natural resources, increase in air pollution and generation of huge amount of waste. Aggregates, which forms the major component of concrete primarily retrieved from various natural resources. Currently, vast enhancement in the production of concrete throughout the world has a significant impact of sources of natural aggregates. Therefore, several parts of across the globe have been facing acute shortage of natural aggregates, which increases the cost of construction in many folds. Several waste products such as bottom ash, crushed glass, copper slag, recycled fine aggregates etc. are incorporated in concrete in place of river sand (the primary source of natural fine aggregate) to mitigate the aforementioned demand (Bogas et al., 2016; Ling and Poon, 2017; Oliveira et al., 2015; Saha and Sarker, 2017a). The use of aforementioned aggregates retrieved from waste products allows to extend the limits of use of construction material scale and to overcome the deficit of natural resources (Tiwari et al., 2016).

Granulated blast furnace slag (GBS) is a primary waste material obtained from the blast furnace of the steel and iron industries. The blast furnace is generally operated at 1500 °C. Controlled mixture of limestone, iron ore and coke are fed to the blast furnace. Iron and slag are produced in the molten form when limestone, iron ore, and coke are melted in the blast furnace. The slag in the molten form

* Corresponding author.
E-mail addresses: bibhuti.2222@gmail.com, 10ce90r15@iitkgp.ac.in (B.B. Mukharjee).

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floats on molten iron due to light weight. Silicates from the iron ore and alumina which are combined with some oxides from limestone are the primary composition of molten slag. The slag in the molten form from the blast furnace is rapidly cooled with powerful water jets, which turned the molten slag into a fine, granular and glassy form known as granulated blast furnace slag. Generally, the size of these particles of slag is less than 5 mm. The rapid cooling method is used to prevent the formation of large sized crystals. This results in the formation of granular materials which is comprised of around 95% non-crystalline calcium-aluminosilicates (Siddique and Kaur, 2012). Several literature were found regarding the application of ground granulated blast furnace slag produced from iron and steel industry as a replacement of cement due to the pozzolanic behavior of slag (Crossin, 2015; Li et al., 2016; Mo et al., 2016).

The choice and quality of aggregate play an important role in determining the quality of cementitious products and the properties of these materials are significantly influenced with the replacement of natural aggregates (Neville, 1997). The static compressive strength and fatigue life of cement mortar incorporating blast furnace slag and copper slag was found to be enhanced and more than control mortar made with natural aggregates (Farooq et al., 2017). Moreover, the compressive strength of mortar increased with the incorporation of granulated ferronickel slag up to 50% and beyond this replacement level strength started decreasing (Saha and Sarker, 2017b). The use of GBS as replacement of natural aggregates in alkali activated slag mortar subjected to elevated temperature was found to be beneficial (Rashad et al., 2016). The workability of concrete was found to be decreased with increases in GBS (%) in concrete, however, fresh concrete density was similar or slightly higher than control mix without GBS (Binici et al., 2008). The compressive strength of concrete mixes increased with the enhancement in the amount of GBS in concrete and compressive strength higher than control mix could be achieved with the incorporation of 60% GBS. Moreover, strength development in GBS incorporated mixes at early days was comparable with control concrete specimens (Binici et al., 2009). It was reported that incorporation of GBS as fine aggregate replacement up to 50% showed an improvement in compressive strength as compared to that of normal concrete, whereas compressive strength was found to be decreased beyond this level (Singh et al., 2015). The pozzolanic activity GBS was found to help in improving the strength of concrete (Binici et al., 2008). Moreover, the strength of concrete mixes containing GBS was found to be higher in the case of concrete subjected to natural curing than the steam curing (Zeghichi, 2006). Other studies reported that compressive strength of concrete increased up to incorporation of 25% GBS and the strength of concrete enhanced with the increase in curing period (Babu and Mahendran, 2014). The durability properties of concrete such as effect of high temperature, freeze-thaw resistance, drying-wetting effect, capillarity and sulfate resistance of concrete were investigated for varying GBS(%) and stated that concrete containing GBS had better durability than reference concrete without GBS (Yüksel et al., 2007). Furthermore, permeability and sulphate resistance similar to normal concrete could be achieved with the incorporation of 15% GBS as replacement of natural fine aggregates (Binici et al., 2012). Other investigations reported about the use of fine aggregates retrieved from steel furnace slag and copper slag in developing geopolymer concrete mixes (Khan et al., 2016; Mithun and Narasimhan, 2016).

A number of studies are available in the area related to the application of ground granulated blast furnace slag (GGBS) as replacement of cement in concrete. Protection of natural resources, shortage of natural fine aggregate and effective utilization of industrial waste are major factors which lead to the use of granulated blast furnace slag (GBS) as replacement of fine aggregate in concrete. However, the investigations dealing with the extensive study of fresh concrete behavior, mechanical and durability characteristics of concrete using GBS as replacement of fine aggregate are not often found in existing literature. Therefore, the present study comprises of systematic examination of the different properties of concrete containing a varying percentage of GBS as replacement of natural fine aggregates. The objectives of the present investigation are stated as follows:

- Comparison of properties of natural aggregates and GBS collected from a steel plant.
- Examination of the influence of incorporation GBS on the fresh concrete behavior.
- Assessment of the effect of replacement of natural fine aggregate by GBS on compressive and tensile strength of concrete.
- Investigation of influence of GBS (%) on non-destructive characteristics of concrete.

2. Experimental programme

2.1. Materials

Ordinary Portland Cement (OPC) of 43 Grade conforming to the requirements of the Bureau of Indian Standard Specifications (BIS) (IS 8112, 1989) was used for making concrete. An experimental programme was planned in such a manner that the whole experiment was completed within one month of procurement of cement. The standard tests are conducted to characterize the cement and those results are illustrated in Table 1. In addition to the above, the chemical composition of cement and GBS is represented in Table 2.

Scanning electron microscope (SEM) analysis of GBS has been conducted and the image which is obtained in the bright field mode

Table 1
Properties of cement.

Fineness (%)	Consistency (%)	Specific gravity	Initial Setting time (min)	Final setting time (min)	Soundness (mm)	Compressive strength (MPa)		
						3 days	7 days	28 days
99.98	31	3.09	132	328	9	34.8	44.9	54.1

Table 2
Composition of cement and GBS.

Component type	CaO	SiO_2	MgO	Al_2O_3	S	FeO or Fe_2O_3	P_2O_5	MnO	Na_2O	KO	SO_3
GBS (%)	41.7	35.6	10.7	8.4	1.3	0.8	0.7	0.5	–	–	–
Cement (%)	65.67	16.57	1.31	11.74	–	0.34	–	–	0.44	2.11	1.47