ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 17 (2017) 511–519

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Performance of reinforced concrete beams cast with different percentages of GGBS replacement to cement

Rami A. Hawileh *, *Jamal A. Abdalla*, *Fakherdine Fardmanesh*, *Poya Shahsana*, *Abdolreza Khalili*

Department of Civil Engineering, American University of Sharjah, P.O. Box 26666, Sharjah, United Arab Emirates

ARTICLE INFO

Article history:
Received 29 June 2016
Accepted 20 November 2016
Available online

Keywords:
Ground Granulated Blast Furnace Slag
Cement
Compressive strength
Flexural strength
Reinforced concrete beams

ABSTRACT

The aim of this paper is to study the effect of using Ground Granulated Blast Furnace Slag (GGBS) as a partial replacement to cement in reinforced concrete (RC) beams. A total of eight beams were cast with different percentages of GGBS replacement of 0%, 50%, 70%, and 90%, respectively. The performance of the tested specimens were evaluated and compared to that of a control beam without GGBS (0%). In addition, the concrete compressive and tensile strength of the different concrete mixes were evaluated and compared. Overall, test results indicated that the compressive and tensile strength of the different mixtures were quite similar. In addition, the performance of RC beams with GGBS replacement up to 70% is similar to that without GGBS. However, the stiffness and strength for the beam specimens with 90% GGBS were lower than that without GGBS by 16% and 6%, respectively. It was also concluded that the use of high percentage of GGBS up to 70% as a replacement to cement is practical and will not comprise the performance of RC beams. Furthermore, such replacement will contribute to the reduction in CO_2 emission (carbon footprint) and therefore encourage the use of such sustainable and green concrete.

1. Introduction

Recently, governments and construction companies start to pay great attention to building construction materials that are being used in structures in terms of their impacts on environment. Ordinary Portland cement (OPC) is one of the main materials used in casting reinforced concrete (RC) structures. However, it causes the emission of a significant amount of CO_2 to the atmosphere and therefore contributes widely to the formation of the greenhouse effect [1]. The increasing use of such OPC materials in construction projects had led to the initiation of global environmental warming [2]. This is due to the fact that for each ton of produced OPC,

* *Corresponding author*. Fax: +971 6 515 2979.
E-mail address: rhaweeleh@aus.edu (R.A. Hawileh).

http://dx.doi.org/10.1016/j.acme.2016.11.006

approximately a ton of CO_2 is released to the atmosphere [3]. It is estimated that the emissions of CO_2 from OPC production worldwide is about 6–8% of the total global emitted CO_2 [4–6]. In addition, quarrying of OPC causes destruction of wildlife habitats. Therefore, one of the main focuses of corporations was to reduce the use of OPC or to find a better alternative material in order to reduce its impact on the environment [7–9].

One of the known alternative materials to OPC in the concrete mix is Ground Granulated Blast Furnace Slag (GGBS) [10]. GGBS is a byproduct extracted from blast furnaces used to produce iron. It is usually produced by heating the combination of iron-ore, coke, and limestone in the blast furnace to 1500 °C. The products of these materials are molten iron and molten slag [11,12]. The molten slag which contains silicates and alumina has lower density, thus floats above the molten iron and make it is easy to separate the molten slag from the molten iron. After separation, the molten slag is cooled down by using high pressure water jet which quenches the slag into crushed particles which are often less than 5 mm. Such particles are then left to dry and grinded in a rotating ball-mill to produce a very fine powder of GGBS [13–15].

The chemical properties of GGBS are composed of a non-metallic product which is known as blast furnace slag that consists of silicates and alumnio-silicate of calcium with different bases and a metallic product which consist of iron and manganese. In addition, it has two different phases, glassy and crystalline. The glassy phase is responsible for its cementitous properties, whereas the crystalline phase is mostly responsible for hydration [16,17]. Moreover, in terms of physical properties, GGBS is originally white in color that is identified as a very finely glassy powder and depending on its level of moisture can vary from light brown to dark brown [18,19].

Due to its chemical and physical properties, GGBS can be highly effective in enhancing the durability [20–22] and corrosion resistance [23–25] of concrete structures. Since GGBS is a very finely glassy powder, it increases the bond between particles [26–30], and it reduces the permeability of concrete [31–33], and thus can protect the internal steel reinforcement from corrosion [34]. According to an experimental study conducted by Yeau and Kim [35], the chloride-ion permeability of GGBS concrete samples was decreased and the time of curing or amount of GGBS by binder weight was improved over PC concrete samples. Furthermore, based on a research study conducted by Khan and Ghani [36], there was a significant increase in the concrete's workability when the percentage of GGBS replacement of cement was increased. This was measured based on slump tests. In addition to that, the use of GGBS in OPC concrete can reduce shrinkage and thermal cracking [36]. Moreover, it was shown that using higher percentage of GGBS in the mixture of concrete can increase the tensile strength of concrete [1,13,17]. Also, it has been shown that the compressive strength of structure consisting of GGBS is significantly increased after 56 days [1].

Elchalakani et al. [37] recently conducted an experimental program that investigated the compressive strength performance of 13 different types of concrete mixes with 50, 60, 70, and 80% GGBS replacement to OPC. The main goal of the study was to design a concrete mix to build the city of Masadar in the United Arab Emirates with an efficient low-carbon construction that would help in reducing the carbon footprint. In addition, a concrete mix with 30% fly ash was also investigated. It was concluded from the test results that the concrete mixes with GGBS significantly reduce the carbon footprint up to about 60%. It was also recommended to use a concrete mix with 80% GGBS and OPC to build the city of Masdar.

The literature is lacking adequate experimental studies on testing of beams cast with high percentages of GGBS use as cement replacement in the concrete mix. Limited studies [38,39] investigated the performance of RC beams cast with up to 40% GGBS replacement only. To the authors' best knowledge, there are no studies reported in the literature on the performance of RC beams cast with different percentages of GGBS, especially higher than 65%.

In this paper, eight RC beams were cast with different percentages of GGBS as cement replacement of 0%, 50%, 70%, and 90%, respectively. The different concrete mixes were designed to achieve a concrete compressive strength of about 30 MPa. The performance of the beams cast using different mixes was compared with a RC beam cast with 100% OPC (0% GGBS). The beams are simply supported and were designed to fail in flexure and tested under four-point bending. The test results that include the load-midspan displacement response curves, load-carrying capacity, ductility, and failure mode (concrete crushing with steel yielding) were evaluated and compared. In addition, standard tests were conducted to examine the concrete's compressive and tensile strength for each mix, respectively.

2. Experimental program

In this study, different percentage of GGBS of 0%, 50%, 70%, and 90% were used to design different concrete mixtures. Cylinders, cubes, prisms and beams were cast from each mix design. Compressive strength and flexural tensile strength tests were conducted on cylinders, cubes and prisms. In addition, four-point bending flexure tests were carried out on beams. The physical and mechanical properties of the used materials, concrete design mixes, and detailing of the tested beam specimens are described in the following subsections.

2.1. *Materials*

2.1.1. *Aggregates*

Crushed limestone with a minimum and maximum size of 4.75 mm and 20 mm are used as coarse aggregates in this study. Crushed limestone powder and dune sand was used as fine aggregates (<4.75 mm). Table 1 shows the physical properties of the coarse and fine aggregates used in this study in terms of dry unit weight, fineness modulus, oven dry

Table 1 – Physical properties of aggregates.

Aggregates	Dry unit weight (kg/m^3)	Fineness modulus	SP.GR (OD) (kg/m^3)	SP.GR (SSD) (kg/m^3)
Coarse	1578	–	2.62	2.7
Fine	–	3.60	2.62	2.702