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Effect of ground granulated blast furnace slag (GGBFS) on RCCP durability

Arash Aghaeipour, Morteza Madhkhan *

Department of Civil Engineering, Isfahan University of Technology (IUT), Isfahan, Islamic Republic of Iran

HIGHLIGHTS

- The effects of ground granulated blast furnace slag were studied on RCCP durability.
- The durability properties such as water absorption, permeability and freeze-thaw cycles were considered.
- The moisture content required for the concrete to reach its maximum compaction increased with increasing slag content.
- 40% replacement of cement by slag led to reduced porosity, water absorption and permeability.

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ABSTRACT

Having recorded a profile of success in mass concrete applications such as in dam building, roller compacted concrete has recently stimulated a growing interest in road pavement construction as a novel application. The present study was designed to investigate the effects of ground granulated blast furnace slag (GGBFS) used in concrete mixtures on durability properties of roller compacted concrete pavements as water absorption, permeability and freeze-thaw cycles. For this purpose, eight principal concrete mixes were designed containing four blast furnace slag levels (0, 20, 40, and 60% relative to the weight of the cementitious materials) and two cementitious material levels (12 and 15% relative to the aggregate weight) at an optimum moisture content. Results showed that the moisture content required for the concrete to reach its maximum compaction increased with increasing slag content. Moreover, cracking and porosity declined with increasing slag content up to a certain level beyond which both took a rising trend. This was evidenced by the minimum and maximum levels of concrete cracks and porosity for slag contents of 40% and 60%, respectively, compared to the levels observed in plain concrete lacking GGBFS. Concrete permeability was also observed to decline with the experimental concrete mix designs containing 20 and 40% GGBFS but increased for a GGBFS content of 60%. Finally, increasing cementitious materials from 12 to 15% was observed to reduce concrete permeability. The highest destructive effect due to 150 and 300 freeze-thaw cycles was observed with mix designs having a GGBFS content of 40%; however, mix designs containing a GGBFS of 60% exhibited relatively improved resistance against the effects of freeze-thaw cycles.

1. Introduction

According to ACI 207.5R-11, Roller Compacted Concrete (RCC) is defined as the no-slump concrete compacted by roller compaction that will support a roller in its unhardened state [1]. Clearly, the designation for this type of concrete reflects the requirement for its roller compaction [2]. Given its high sensitivity to concrete moisture content, it will look shiny when any moisture above the optimum level is used such that roller traces will remain on it. Inadequate moisture has the adverse effect that it will create a soil-like concrete. RCC is manufactured according to the same principles recommended for soil-cement structures or other types of earth works [3]. The advantages of RCC include reduced costs due to the rapid construction methods employed [4]. However, due to their lower surface quality, they are solely designed for pavements carrying heavy load vehicles or slow traffic [5]. Madhkhan et al. researched on the effect of Pozzolan with steel and polypropylene fibers on the mechanical properties of RCC with the optimum moisture and different values of Pozzolan, steel and polypropylene fibers. Using Pozzolan, the maximum increase in

* Corresponding author.
E-mail addresses: a.aghaipor@cv.iut.ac.ir (A. Aghaeipour), madhkhan@cc.iut.ac.ir (M. Madhkhan).

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compressive strength was observed between the ages of 28 and 90 days. In addition, rupture modulus was decreased. However, no significant change was observed in toughness indices. The influence of steel fibers was more than that of polypropylene fibers on the compressive strength. Similarly, using steel fibers increased the toughness indices significantly [6]. Hazarei et al. investigated the effects of a combined concrete mixture on concrete properties and freeze-thaw resistance. Their main goal was to determine the effects of cement content (100–450 kg/m^3) and entrapped air on the physical and mechanical properties as well as the freeze-thaw resistance of roller compacted concrete. They detected a considerable deviation in the physical and mechanical properties of RCC from those of conventional concrete. They also observed improved specific gravity, compressive strength, volume of penetrable voids, and water absorption of the compacted concrete with increasing cement content by up to a given quantity (225 kg/m^3 of the cementitious materials). The optimum range of the cement content was found to be 225 ± 25 kg/m^3. Finally, they showed that entrapped air had a positive effect on enhancing the freeze-thaw resistance of the mixed roller compacted concrete [7]. Mardani et al. investigated the freeze-thaw resistance and traffic properties of a roller compacted concrete mix containing a high volume of fly ash which was designed for maximum compaction. They showed that the traffic properties, mass loss, and freeze-thaw resistance increased in those mix designs in which fly ash was replaced for cement but reduced in those with aggregate replaced for fly ash. Moreover, replacement of 20% fly ash for aggregate was found to be the most effective level. The authors also showed that more pressurized water permeated into concrete when permeation orientation was parallel, rather than orthogonal, to the cast concrete layers, which they claimed was due to the cold joint between the compacted layers [8]. Vahedi-Fard et al. examined the effects of silica fume and ground pumice as replacements for cement on the compressive strength, freeze-thaw resistance, and efficiency of RCC. They subjected all their specimens to at least 300 freeze-thaw cycles to observe that concrete efficiency reduced with silica fume but increased with ground pumice. They also found that increasing the cementitious material content from 12% to 15% led to enhancements in compressive strength, freeze-thaw resistance, and concrete efficiency. Finally, they reported reduced values of compressive strength and freeze-thaw resistance when ground pumice was added to the mixture [9]. Hesami et al. examined Mechanical properties of roller compacted concrete pavement containing coal waste and limestone powder as partial replacements of cement. The results showed that the use of coal waste powder and coal waste ash increased the water/cementitious materials ratios, and the combination of limestone powder and coal waste ash led to higher mechanical properties, especially at ages of 28 and 90 days [10]. Rao et al. studied the Abrasion resistance and mechanical properties of roller compacted concrete with GGBFS. Results showed that the replacement of cement with six percentages of GGBFS content reduced the compressive strength, flexural strength and splitting tensile strength at the age of 3 days, but there was a continuous and significant improvement in strength observed at 7, 28 and 90 days. They also found that abrasion resistance of roller compacted concrete with GGBFS as mineral admixture was strongly influenced by its compressive strength irrespective of GGBFS content [11]. Karimpour studied the effects of the lag time between mixing and compacting of RCC containing GGBFS used in dam building. Results showed that delayed compaction in RCC specimens lacking ground blast furnace slag led to the loss of properties while it led to either no loss or even improved compressive strength, permeability, water absorption, and adsorption in those specimens in which GGBFS was replaced for part of the cementitious materials [10]. Toutanji et al. observed that concrete specimens made with Portland cement in their mixture exhibited a higher freeze-thaw resistance than did those containing GGBFS; the reason they claimed was that the freeze-thaw test had been conducted 14 days after the curing of the concrete specimen [13]. The objective of the present study was to investigate the durability of the roller compacted concrete containing GGBFS which, according to Ref. [14], is defined as the nonmetallic by-product during the smelting process in the blast furnace and that mainly consists of silicates and aluminosilicates of calcium or other minerals. Several advantages have been claimed for the use of blast furnace slag including power saving, reduced greenhouse emissions, and lower consumption of natural raw materials [15].

2. Experimental program

In this experiment, preliminary tests were conducted to determine the specifications of the raw materials used, which were then compared against the relevant standards. Once appropriate mix designs had been selected, the main test specimens were manufactured and cured. The 90 and 150-day specimens were finally subjected to the permeability tests and the 28-day specimens were finally subjected to the freeze-thaw cycle and water absorption tests. Specimens used for the purpose of the present study were manufactured in two stages. Initially, specimens containing 2% cementitious materials were made using 40 different mix designs to determine the optimum moisture content. Once the optimum moisture content was determined for each mix design, new specimens were made using eight main mix designs.

2.1. Properties of materials

For the purposes of this experiment, coarse aggregate, sand, cement, and GGBFS were used to make the concrete specimens. Coarse aggregate consisted of the two medium gravel (with a maximum particle size of 19 mm) and small gravel (with a maximum particle size of 12 mm). The 12–19 mm gravel was added at a ratio of 10% of the total weight of the aggregate while the 5–12 mm gravel accounted for 20% of the total aggregate used. Sand consisted of fine sand with a maximum particle size of 5 mm. The specifications of both the coarse and fine aggregates used conformed to the ASTM C33 Standard [16]. Fig. 1 shows the particle grading of the aggregates and their comparison with the limits recommended by ACI 325 [17]. Conventional Portland cement Type I (1–425) was purchased from Isfahan Cement Plant. Table 1 presents the results of the chemical analysis of the cement used. Finally, use was made of granulated blast furnace slag from Isfahan Steel Mill supplied as powder with a specific weight of 2.85 g/cm^3 and a fineness modulus of 4500 cm^2/g. The results of its chemical analysis are reported in Table 2.

2.2. Specimens

Initially, 40 different mix designs were created using the soil-based RCC mix design procedure to determine the optimum moisture levels. For this purpose, the ingredients were mixed in a 40-liter mixer run at a speed of 60 rpm. Three cubic specimens of 150 × 150 × 150 mm were made from concrete samples taken from each mixer, molded, and compacted according to ASTM D1557 [18]. Once the optimum moisture was determined for each mix design, eight main mix designs were selected in which two different weights of cementitious materials (12 and 15 wt% of dry aggregate), 4 slag quantities (0, 20, 40, and 60 wt% of slag replacement for cement), and the optimum moisture levels obtained in the previous stage were used. The specifications of all the mix designs are reported in Tables 3 and 4.