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Portland slag and composites cement concretes: engineering and durability properties

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ABSTRACT

The use of different cementitious main constituents is permitted within the BS EN 197-1 for use in concrete construction. The selection of cement types made depends on requirement of enhanced engineering and durability properties of concrete as well as exploiting potential for producing environmentally friendly concretes for practical applications. The main results of a laboratory experimental programme aimed at examining the performance of Portland-slag and composite cement (CEM II/B-S, CEM II/B-M, CEM V/A and CEM V/B) concrete mixes designed for equivalent 28-day compressive cube strengths of 40 and 50 N/mm^2 are reported in paper. The effect of up to 30–50% of ground granulated blast-furnace slag (GGBS) and its' combination with the silica fume (SF) and fly ash (FA) -within the BS EN 197-1 permitted limits-on fresh, engineering and durability properties have been established and its suitability for use in a range of practical applications was assessed.

The loss of workability in all mixes was of a uniform nature and was found to be more for CEM V/B concrete mixes. Studies of hardened concrete properties, comprising bulk engineering properties (compressive cube and cylinder strength, flexural strength, drying shrinkage) and durability (initial surface absorption, carbonation rates) showed enhanced performance for Portland-slag and composite cement concrete mixes of equivalent strength, except resistance to carbonation.

1. Introduction

The European Standard for common cements, BS EN 197-1 (BS EN 197, 2011) offers a broad range of cement constituents for concrete production with opportunities for utilising many of the industrial by-products. Thus, this offers environmental benefits to concrete construction, and a real potential for contributing in achievement of sustainable development goals. Amongst the cement types permitted within this standard is the use of Portland slag cements containing 21–35% GGBS (Type II/B-S) and composite cements containing: (i) 18–30% GGBS with the same amount of pozzolana with fly ash and up to 5% minor additional constituents (Type V/A), and (iii) 31–50% GGBS with the same amount of pozzolana with fly ash and up to 5% minor additional constituents (Type V/B). However, lack of full scientific data on the engineering and durability performance of such concrete mixes limits its full application.

The review of technical data suggests, GGBS cement concretes have improved the fresh properties of concrete (Megat Johari et al., 2011; Teng et al., 2013). Extensive research carried out on the use of GGBS in combination with PC and other cementitious constituents in concretes indicated that lower early compressive strength due to slower hydration rate of GGBS (Megat Johari et al., 2011; Teng et al., 2013; Akçaözoglu and Atiş, 2011; Erdem and Kirca, 2008; Khatri et al., 1995; Hui-sheng et al., 2009; Guneyisi et al., 2010; Kuder et al., 2012; Oner and Akyuz, 2007; Li and Zhao, 2003; Berndt, 2009). The lower early strength reported in the existing studies have become more obvious as the replacement levels, on mass basis, increases (Megat Johari et al., 2011; Guneyisi et al., 2010). In addition, Teng et al. (2013) and Qiang et al. (2013) stated that the difference in early age compressive strength becomes smaller at lower water/cement (w/c) ratios. However, this lower strength development was monitored to be compensated with the prolonging curing periods (Megat Johari et al., 2011; Teng et al., 2013; Erdem and Kirca, 2008; Khatri et al., 1995; Hui-sheng et al., 2009; Guneyisi et al., 2010; Oner and Akyuz, 2007; Li and Zhao, 2003; Berndt, 2009). However, there is no agreement on the replacement level of GGBS in blended cement concrete for optimum performance concrete. According to Megat Johari et al. (2011), maximum

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long term strength was obtained with an optimum level of 20%. Similar finding was noted by Qiang et al. (2013) that 15% and 30% GGBS replacement levels gives better compressive strength at post 28 days. Khatri et al. (1995) also stated that 35% GGBS provides better compressive strength at 28 days. In addition to these, Akçaözoglu and Atiş (2011) stated that use of 50% GGBS replacement in mortar can slightly improve compressive strength at 28 days. Moreover, slightly improved and comparable results were obtained by Guneyisi et al. (2010) for 40% and 60% replacement level of GGBS. Studies carried out by Khatri et al. (1995) and Berndt (2009) with 70% slag replacement in binary blend cement and 65% GGBS with silica fume (SF) in ternary blend cement concretes respectively indicated improved compressive strength at longer ages. Gesoğlu et al. (2009) stated that use of GGBS in ternary blend cement concrete with another mineral admixture fly ash (FA) with replacement levels of 10% for both admixtures provided the best performance strength at 28 days. Guneyisi et al. (2010) also studied GGBS in ternary blend with SF and FA and stated comparable or improved results monitored for GGBS + SF blend cement concretes regardless the increase in the replacement level (15% GGBS + 5% SF, 30% GGBS + 10% SF, 45% GGBS + 15% SF). However, GGBS blend with FA resulted in lower compressive strengths and 10% GGBS + 10% FA blend cement concretes indicated the best results at both 28 and 90 days.

Previous studies have shown that slag utilization enhances drying shrinkage of concrete at longer ages. Akçaözoglu and Atiş (2011) stated that 50% GGBS replacement demonstrated comparable performances up to 90 days but showed reduction after 90 days. In addition to this, Qiang et al. (2013) observed that slag cement concretes were investigated to develop shrinkage quickly within 40 days as the slag replacement increases (45%). Qiang et al. (2013) also reported that slag utilization has slight influence on concretes with lower w/c ratio (0.35). Guneyisi et al. (2010) reported that as the replacement level increases the drying shrinkage decreases. This reduction is higher in ternary blend cement (PC + GGBS + SF) concretes. Jianyong and Yan (2001) also defined that binary (PC + GGBS) and ternary (PC + GGBS + SF) blend cement concretes could reduce drying shrinkage significantly.

Existing literature on the slag cement concretes has indicated reduction in the carbonation resistance (Akçaözoglu and Atiş, 2011; Hui-sheng et al., 2009; Jones et al., 1997; Bernal et al., 2011; Song and Saraswathy, 2006). Hui-sheng et al. (2009) stated that carbonation resistance reduces as the slag content (15%, 30%, 45% and 60%) increases for the same w/c ratio. Similar findings were observed by Younsi et al. (2013) and Borges et al. (2010) with the slag contents up to 75% and 90% respectively leads to reduction in the carbonation resistance. In contrast, Qiang et al. (2013) stated that concrete with 15% slag content indicated better resistance whereas lower resistance monitored by 30% slag replacement. However, previous studies (Hui-sheng et al., 2009; Bernal et al., 2011; Younsi et al., 2013; Borges et al., 2010) reported that increasing the binder content of slag results in lower carbonation depth comparing to lower binder contents. Akçaözoglu and Atiş (2011) reported that there is a relation between carbonation resistance and loss of workability.

The effect of slag as substitute to PC with various replacement levels in Portland-slag and Portland-composites cements on the performance of concretes is of significant interest as far as the mechanical and durability parameters are concerned. However, the results led to uncertainty on the optimization of slag content for the optimum performance for slag cement concrete. This paper gives a part of extensive study carried out a range of engineering and durability properties of concretes having similar 28-day design strengths made with binary and ternary blended BS EN 197-1 cements (and natural aggregates). These concretes were designed with various proportions of GGBS as a partial substitute of PC, different water/cementitious content (w/c) ratios and total cementitious contents. On the other hand, there is also a potential for producing concretes with reduced environmental footprint for practical applications as the PC content is replaced with more environmentally friendly additional cementitious constituents.

2. Experimental and testing programme

2.1. Materials

In order to promote wider use of Portland-slag and composite cements concrete, a range of BS EN 197-1 cement types with limited data on its influence on the engineering and durability properties of concrete were selected. These include; CEM II/B-S (35% GGBS), CEM II/B-M (30%GGBS & 5%SF), CEM V/A (30%GGBS & 30%FA), CEM V/B (50%GGBS & 30%FA), were used within the framework of cement types covered in BS EN 197-1. Portland-cement (CEM I; 100% PC) was used as reference, and other main constituents were used as direct replacement of PC. The natural aggregates (NA) used were natural uncrushed Thames valley gravel of 20 mm maximum size and natural sand of 5 mm maximum size. Table 1 gives the physical and mechanical properties of natural aggregates used. GGBS was obtained from iron-making production in the UK conforming to BS EN 15167-1 (BS EN 15167, 1516). FA and SF used were conforming to BS EN 450-1 (BS EN 450, 2012) and BS 13263-1 (BS EN 13263, 2005) respectively. FA was obtained from Drax coal-fired power station in the UK. SF incorporated was in slurry form including 50% water and 50% silica powder. The chemical composition of cementitious materials provided by the manufacturers is presented in Table 2. Water reducer admixture conforming to BS EN 934-2:2009 + A1 (BS EN 934, 2009) was used throughout the study to achieve nominal design slump.

2.2. Mix proportions and concrete mix design

Conventional BRE mix design method (Building Research Establishment Ltd, 1997) was used to produce trial mixes. Mixes were designed to achieve workability between 60 and 180 mm and 28-day cube strength of 40 and 50 N/mm^2. The free water contents of these mixes were modified according to type of the cementitious constituents used. Additional cementitious constituents (GGBS, FA and SF) were used by blending with CEM I, PC, at the mixer for CEM II and CEM V cement concretes. To achieve equivalent 28-day cube strength as CEM I concrete, the w/c ratios and total cementitious contents were altered depending upon the relationship between the compressive cube strength and the w/c ratios of trial mixes. Detailed summary of mix proportions used are given in Table 3. It is noteworthy to mention that SF values given is in slurry form, thus

Table 1
Physical and mechanical properties of aggregates used.

Properties	Aggregates	
	Sand	Gravel
Physical (BS EN 1097, part 6)		
Unit weight (Mg/m^3)	1.52	1.51
Apparent density (Mg/m^3)	2.75	2.60
Water absorption capacity (%)	0.70	1.65
Fineness modulus	2.62	3.31
Mechanical (BS 812, parts 110–112)		
Aggregate crushing value (% ACV)	–	18
Aggregate impact value (% AIV)	–	6.5
10% Fines (KN)	155	

*Mechanical properties were measured on 10–14 mm test samples.

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