Construction and Building Materials 80 (2015) 132–140

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Influence of Portland cement and ground-granulated blast-furnace slag on bleeding of fresh mix

Hong Jae Yim [a], Jae Hong Kim [b,*], Seong Ho Han [b], Hyo-Gyoung Kwak [c]

[a] Department of Construction and Disaster Prevention Engineering, Kyungpook National University, Sangju, Gyeongsangbuk-do 742-711, Republic of Korea
[b] School of Urban and Environmental Engineering, Ulsan National Institute of Science and Technology, 50 UNIST-gil, Eonyang-eup, Ulju-gun, Ulsan 689-798, Republic of Korea
[c] Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea

HIGHLIGHTS

- Bleeding of cement paste and ground-granulated blast-furnace slag (GGBFS) paste is measured under high pressure.
- The bleeding ratio and volume decrease are automatically measured by the proposed device.
- They evaluate the packing density and permeability of the paste mixed with the two powder.
- As a result, the GGPFS paste has lower packing density and higher permeability than the cement paste.
- The findings support that a concrete mix incorporating GGBFS shows lower amount and faster rate of its bleeding.

ARTICLE INFO

Article history:
Received 10 June 2014
Received in revised form 19 October 2014
Accepted 24 December 2014

Keywords:
Cement
GGBFS
Bleeding
High pressure
Flocculation

ABSTRACT

Bleeding occurs when freshly mixed cement-based materials settle in a form, and this phenomenon influences the quality of the fresh state as well as the hardened state. This paper attempts to measure the bleeding of Portland cement and ground granulated blast furnace slag (GGBFS) paste mixtures. To investigate the influence of water-to-powder ratio and the used powders under high pressure on bleeding, a pressure vessel and various types of freshly mixed paste were prepared. The packing density and permeability were measured and discussed to understand material effects on the bleeding phenomenon.

1. Introduction

Concrete is composed of a combination of cementitious materials, water, sand, and gravel and is the most widely used construction material. Bleeding generally occurs after those components have been mixed and then placed. Bleeding is water drainage out to the surface of freshly mixed concrete due to the settlement of solid components (cement particles or aggregates) of fresh mixtures [1], and it is related to the physical properties, permeability, of fresh concrete. Free water is not captured in clusters or flocs of cement particles. It has intra-mixture mobility and flows out due to a pressure gradient. The water drainage is beneficial to casting of concrete in some cases as well as pumping efficiency. However, this bleed water is unwelcome in terms of and surface quality.

Prediction of bleeding amount is necessary for quality control and evaluation of fresh mixtures. Several factors, such as constituents of the mix, mixing protocol, mix proportion, and dimensional or environmental conditions, mainly influence the occurrence of bleeding [1–3]. For example, an environmentally dried condition after placing a concrete mixture leads to high evaporation and induces a decrease of bleeding [2]. Similarly, additionally used steel fibers of a concrete mixture control the occurrence of bleeding [4], and characteristics of aggregates (shape and size effect) that are used in the mixture significantly influence the bleeding parameters [3]. The total bleeding amount and the draining rate according to the proportional ratio of net mixing water are representative bleeding parameters, and in order to manually measure both bleeding parameters of cement-based materials, a conventional test method based on self-weight settlement is widely used in accordance with ASTM C232 or ASTM C243 [5,6].

To describe and predict the bleeding phenomenon of cement-based materials, various theoretical models based on large strain upon consolidation under self-weight loading have been proposed [1,7–17]. A prediction model based on small strain upon consolidation was recently proposed by the authors to identify the external

---

* Corresponding author. Tel.: +82 52 217 2817.
E-mail address: jaekim@unist.ac.kr (J.H. Kim).

http://dx.doi.org/10.1016/j.conbuildmat.2014.12.051
0950-0618/© 2015 Elsevier Ltd. All rights reserved.

and internal bleeding via linear poroelasticity theory [3], where the internal bleeding is defined as abnormally trapped bleeding water under rebar or angular aggregates after consolidation. The internal bleed water induces decreased durability and bonding strength after concrete hardens [18,19]. Bleeding properties are also affected by the pressure generated on the mixture, and an experimental simulation was recently performed to investigate the bleeding phenomenon under high pressure [20]. Such high pressures typically occur in the case of pumping processes, high column construction, and precasting process, such as extrusion flow of paste [27].

Meanwhile, self-consolidating concrete (SCC) is now widely used around the world and chemical admixtures (such as superplasticizer) or mineral admixtures (fly ash or GGBFS) are frequently incorporated. Even though experimental results of SCC reportedly shows little surface bleeding [21,22], high dosage of chemical admixture reduces bleeding rate and leads to unstable paste [28]. The bleeding of cement paste as a function of the high-range water-reducing admixture and water content is recently reported by Perrot et al. [29]. Little bleeding on the surface conversely indicates a risk of internal bleeding in SCC. In addition, the influence of GGBFS or fly ash in terms of promoting bleeding was reported by some researchers [23–25]. That is probably due to the change of packing of their binders. This study applied an experimental approach to measure the bleeding of a paste mixture under high pressure and to identify the effects of GGBFS, which have not been reported in the literature. A total of 10 mixtures were prepared using Portland cement and GGBFS to investigate the influence of water-to-powder ratio. To apply high pressure in the fresh mixture, a fabricated pressure vessel was used and pressurized bleeding tests were performed according to different high pressures of up to 25 bar (2.5 MPa). Visual investigation was performed using SEM images to identify morphological similarity of the used powders before mixing and during flocculation of setting pastes. The measured packing density and permeability were thus evaluated with different powders and mix proportions.

2. Sample preparation

Two types of freshly mixed paste samples were prepared and grouped into Type I Portland cement (labeled C) and GGBFS (labeled S). Each group consists of five mixtures having a different water-to-powder ratio (*w*/*p*) by mass to investigate the influence of water-to-powder ratio on bleeding under high pressure as well as the powder effect. Mix proportions and the solid volume fraction of prepared samples are also reported in Table 1. Other chemical admixtures were not used. Table 2 shows the oxide composition of the used powders, such as Portland cement and GGBFS. The specific density of Portland cement and GGBFS was 3.14 and 2.95, respectively, and their Blaine numbers were 3350 cm^2/g and 4140 cm^2/g, respectively. The measured Blaine number indicates that the average particle dimension of the GGBFS used in this study is generally smaller than that of the cement particles, which is valid assuming that both powders have the same shape. Measurement of the particle size distributions of both powders was also performed under a condition of alcoholic dilution using a laser diffraction particle size analyzer. The obtained distributions in log-scale are compared in Fig. 1. The maximum size of both powders is about 200 μm, and the median of cement is higher than 20 μm whereas that of GGBFS is lower than 20 μm. As can be seen from the compared distributions, cement powder is more normally distributed than GGBFS powder, but the overall distributions of the two powders are similar.

Table 1
Mix proportion of prepared mixtures.

Label	Water [g]	Cement [g]	GGBFS [g]	*w*/*p* [%][†]	ϕ[‡]
C1	105	299	–	35	0.48
C2	111	278	–	40	0.44
C3	117	260	–	45	0.41
C4	112	244	–	50	0.39
C5	127	260	–	55	0.37
S1	99	–	299	33	0.49
S2	106	–	278	38	0.46
S3	112	–	260	43	0.43
S4	117	–	244	48	0.40
S5	121	–	232	52	0.38

[†] Water-to-powder ratio by mass.
[‡] Solid volume fraction.

To ensure an identical mixing protocol, a planetary mixer was used and the following mixing conditions were maintained. Total mixing time was 5 min including 1 min of scraping, and the mixed sample was then placed immediately for bleeding measurement. The following bleeding measurement thus starts at 6 min after the water contacts the powder.

To identify whether the used powders have the same particle shape as stated in the foregoing assumption, both powders (cement and GGBFS), as well as fly ash for comparison, were visualized at the micro-scale via scanning electron microscopy (SEM). The SEM backscattered electron images provide morphological information of cement-based materials at the micro-scale, and have been used in studies such as investigation of morphological change due to thermal damage of concrete [26]. This study attempted to visualize the prepared powders before mixing with water. Specimens were prepared for SEM by sprinkling powdered samples onto a carbon tape sample holder, and then coating them with gold. Fig. 2 shows SEM images of the cement, GGBFS, and fly ash powder with different magnification from 1000 to 15,000 times, respectively. As can be seen in Fig. 2, cement and GGBFS powders have similar morphology as crushed particles, but fly ash has a spherical shape even though the size distribution appears to be in a similar range with the other powders. The crushed morphology of cement and GGBFS is indicative of pulverized powders. The similar morphology of the used powders in this study therefore excludes the shape effect during bleeding measurement under high pressure.

3. Experimental setup

To measure the bleeding of a paste mixture under high pressure, a pressure vessel was fabricated using a pneumatic cylinder. The experimental setup is illustrated in Fig. 3. An LVDT displacement sensor was located on the top of the pneumatic cylinder to monitor the total settlement of the pressurized mixture and its settled ratio. The pneumatic cylinder produces elevated stress up to 25 bar (2.5 MPa) into the pressure vessel through an internal

Table 2
Oxide composition of the used powders (%).

Chemical	CaO	SiO_2	Al_2O_3	MgO	SO_3	Fe_2O_3	K_2O	TiO_2	Na_2O	Cr_2O_3
Cement	63.6	19.2	4.8	3.8	3.7	3.0	1.1	0.3	0.2	–
GGBFS	44.3	33.7	11.6	4.3	1.5	1.2	0.4	0.7	0.2	1.3