ELSEVIER

Cement & Concrete Composites 22 (2000) 253–257

Cement & Concrete Composites

www.elsevier.com/locate/cemconcomp

The influence of ground granulated blastfurnace slag (GGBS) additions and time delay on the bleeding of concrete

P.J. Wainwright [a,*], N. Rey [a,b]

[a] School of Civil Engineering, University of Leeds, Leeds LS2 9JT, UK
[b] Scott Wilson Scotland Ltd., 6 Park Circus, Glasgow G3 6AX, UK

Abstract

Bleed tests were performed in accordance with ASTM C232-92 on concretes in which up to 85% of the cement was replaced with ground granulated blastfurnace slag (GGBS) obtained from a number of different sources. The time at which the bleed test was started was varied from 30 to 120 min to simulate site conditions. The addition of up to 55% slag increased the bleed capacity by 30% (compared to the plain Portland cement (OPC) mix) but had little effect on bleed rate. Increasing the slag content to 85% had no further significant effect on bleeding. The source of slag was also found to have little effect on the bleeding but comparisons made with results from 10 years ago suggest that now the present day slags have a much less marked effect on bleeding probably because they are ground finer. Delaying the start of the bleed test from 30 to 120 min reduced the bleed capacity of the OPC mix by more than 55% compared with 32% for the slag mixes. The reduction in bleed rate was similar for all mixes at about 45%. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Bleeding; Ground granulated blastfurnace slag; Concrete

1. Introduction

The work presented in this paper is an extension of previously published work by the author [1] investigating the influence of cement source and slag additions on the bleeding of concrete.

Bleeding is the term used to describe the movement of water to the surface of the freshly placed concrete; it is in fact a form of settlement, the water being forced to the surface as the heavier solids in the concrete begin to settle [2,3]. All concrete bleeds to some extent but bleed water is only observed on the surface when the rate of bleeding exceeds the rate of evaporation. Immediately after compaction there is a short dormant period which is followed by a period in which the rate of bleeding is almost uniform. Bleeding will end when the movement of water is blocked by the growth of the hydration products or by the solids effectively coming into contact with each other or by a combination of both.

Bleeding results in a variation in the effective water content throughout the concrete element which produces corresponding changes in the concrete properties [4,5]. The water that rises to the surface can significantly increase the near-surface water/cement ratio to form a network of capillary pores, which will subsequently reduce the durability of the concrete in the cover zone [6]. Bleed water trapped along the underside of reinforcing steel can result in a reduction in the bond but more importantly may lead to an increased risk of corrosion.

The partial replacement of Portland cement with ground granulated blastfurnace slag (GGBS) leads to a delay in hydration which will potentially make the concrete more prone to bleeding, where comparisons have been made on the basis of equal water/binder ratio or workability, tests have shown that the partial replacement of cement with slag on an equal weight to weight basis results in an increase in bleeding which is significantly more noticeable at high replacement levels [7–11]. However, the work of Wainwright and Ait-Aider [1], referred to earlier, showed that when making comparisons on the basis of equal 28-day strength, the replacement of cement with up to 70% GGBS had little effect on bleeding. This work also looked at the influence of cement source on bleeding and showed that in one case, when making comparisons on the basis of equal water/binder ratio, a change in the source of cement had

* Corresponding author. Tel.: +44-0113-2332294; fax: +44-0113-2332265.
E-mail address: p.j.wainwright@leeds.ac.uk (P.J. Wainwright).

0958-9465/00/$ - see front matter © 2000 Elsevier Science Ltd. All rights reserved.
PII: S0958-9465(00)00024-X

as large an influence on bleeding as the use of up to 40% GGBS.

The work reported in this paper is an extension to this earlier work and was designed to address the following objectives:

(i) to study the influence of slag source on the bleeding of concrete;

(ii) to study the effect of delaying the start of the ASTM bleed test on the bleeding of concrete.

2. Experimental work

GGBS from four different sources in the UK and Portland cement from one source were used in the investigation. The chemical and physical characteristics of all the materials are shown in Table 1 and Fig. 1 shows the results of particle size analysis as supplied by the manufacturers.

One basic mix with a nominal cement content of 300 kg/m^3 was used throughout the investigation, details of which are shown in Table 2. Slag replacement levels of 55% and 85% by weight of cement were used throughout with all mixes being made to the same nominal free water/binder ratio of 0.56. The coarse aggregate was natural irregular quartzite gravel with a nominal maximum size of 10 mm and the sand was from the same source.

Bleed tests were performed in accordance with ASTM C232-92 [12] with the following modifications:

1. Plastic containers were used measuring 250 mm in height with top and bottom internal diameters of 300 and 230 mm, respectively.

2. From each mix made, three bleed tests were performed starting 30, 75 and 120 min after completion of mixing. The containers were filled just prior to the beginning of each test, the concrete being kept covered in the mixer until required. All concrete was re-mixed just

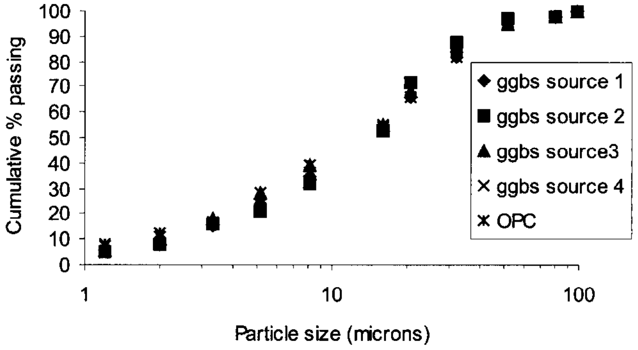

Fig. 1. PSD of all binders.

prior to being used for the bleed tests. This procedure was adopted to try and simulate a practical situation where concrete is likely to be placed any time between 1/2 and 2 h after mixing.

All testing was carried out in the laboratory and temperature measurements taken at the start of each test ranged from 20°C to 21.5°C.

From each mix a total of six 100 mm cubes were cast for the measurement of compressive strength at ages of 7, 14 and 28 days in accordance with BS1881 [13] (Table 3).

3. Results and discussions

For the purpose of this paper, bleeding rate is defined as the volume of water collected per second during the first 40 min of the test. The volume is expressed in ml/cm^2 of exposed surface. Bleed capacity is defined as the fraction of the initial volume of the concrete that has separated out as bleed water during the entire course of the test.

In an attempt to minimise the number of variables and make comparison easier all mixes were made to

Table 1
Binder properties

	OPC	GGBS source				1988 material	
		1	2	3	4	OPC	GGBS source 3
CaO%	63.63	41.83	40.82	39.72	42.03	64.25	41.89
SiO_2%	21.03	35.46	36.47	35.74	35.24	20.96	36.83
Al_2O_3%	4.73	12.67	11.94	13.62	14.24	5.01	9.97
Fe_2O_3%	2.93	0.26	1.09	0.47	0.74	3.2	1.19
MgO%	2.67	8.27	9.16	8.66	7.05	2.84	7.21
C_3S%	51.33	–	–	–	–	59.1	–
C_2S%	21.14	–	–	–	–	14.8	–
C_3A%	7.49	–	–	–	–	7.7	–
C_4AF%	8.86	–	–	–	–	9.7	–
SS Area (m^2/kg)	370	441	438	427	434	358	341
Chem. Mod.	–	1.41	1.40	1.35	1.39	–	1.33

Table 2
Mix proportions and workability

Mix	Mix proportions (Kg/m^3)					Water/binder	Slump (mm)
	OPC	GGBS	Fines	Coarse	Water		
OPC	300	–	750	1080	168	0.56	15
55% GGBS	135	165 (1)	750	1080	168	0.56	30
	135	165 (2)	750	1080	168	0.56	20
	135	165 (3)	750	1080	168	0.56	25
	135	165 (4)	750	1080	168	0.56	45
85% GGBS	45	255 (1)	750	1080	168	0.56	30
	45	255 (2)	750	1080	168	0.56	40
	45	255 (3)	750	1080	168	0.56	25
	45	255 (4)	750	1080	168	0.56	20

Note: Figures in ( ) denotes slag source.

Table 3
Compressive strength results

Mix code	Compressive strength (MPa)		
	7 days	14 days	28 days
OPC	39.5	45.3	53.1
55% GGBS source 1	18.5	28.5	42.5
55% GGBS source 2	26.0	38.5	50.5
55% GGBS source 3	22.5	36.0	50.5
55% GGBS source 4	25.0	41.5	51.5
85% GGBS source 1	17.5	28.0	33.5
85% GGBS source 2	21.5	33.5	41.0
85% GGBS source 3	17.5	25.5	29.5
85% GGBS source 4	19.0	26.5	32.5

nominally the same free water/binder ratio (0.56) which inevitably lead to variations in workability as shown in Table 2. As expected the addition of slag at both levels leads to an improvement in workability from 15 to between 20 and 40 mm. Although these differences are only small, increasing the workability of the OPC mix to a similar value to that of the slag mixes would have resulted in a slight increase in bleeding of this mix.

The bleed time curves for tests started 30 min after casting for all nine mixes cast are shown in Figs. 2 and 3. The slag source can be seen to have virtually no effect on bleed rate and only a marginal effect on bleed capacity. These results are probably not surprising when the material properties are compared (see Table 1 and Fig. 1). For any given slag replacement level the bleeding is likely to be influenced by the reactivity of the slag, the more reactive the slag the less the bleeding would be expected to be. One measure of slag reactivity is chemical modulus (i.e., [CaO + MgO] $\div$ SiO_2), the higher the modulus the more reactive the slag. A second measure is slag fineness, the finer the slag the more reactive and therefore the less the bleeding. However, as can be seen in Table 1 and Fig. 1 there are little differences between chemical modulus, slag fineness or particle size distribution for any of the slag sources used, which probably explains the similarity in the bleeding results. If anything the results throw up a slight anomaly because according to Figs. 2 and 3, the mixes made with the slag from source 1 have the highest bleed capacity yet this slag has a slightly higher chemical modulus and fineness than the others which would suggest lower bleeding. The differences though are only small and are probably not significant. Similar trends were observed for tests started at 75 and 120 min after casting, but for brevity the results will not be presented here.

The influence of the addition of slag per se on bleed capacity and rate can also be seen in Figs. 2 and 3. Replacing 55% of the cement with slag results in an average increase in bleed capacity of about 30% but has little effect on bleed rate, if anything it leads to a slight

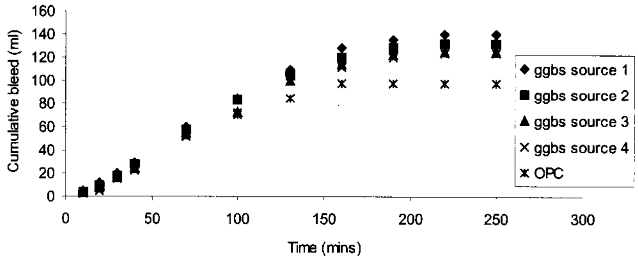

Fig. 2. Bleed time curves for 55% slag mixes.

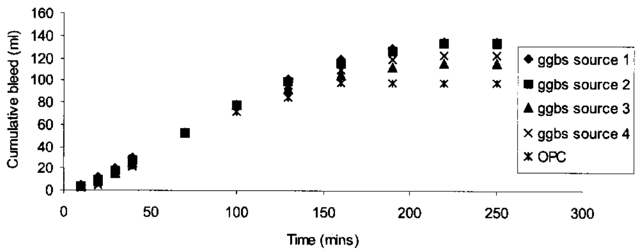

Fig. 3. Bleed time curves for 85% slag mixes.

reduction. Increasing the slag content to 85% has virtually no further effect on bleeding above that observed at 55% which is somewhat surprising in view of the findings of the previous work referred to earlier in which high slag content mixes (i.e., above about 75%) were shown to bleed significantly more. It is interesting to make comparisons between the results published here and those of the author published earlier on work carried out about 10 years ago [1]. This earlier work was carried out using cement from the same source as that used in this present investigation together with slag from source 3 as referred to in this paper. Using similar mix proportions to those used here, compared to the OPC control, the inclusion of 40% GGBS resulted in 48% and 45% increases in bleed capacity and bleed rate, respectively. Furthermore increasing the slag content to 70% resulted in a 100% increase in both properties. A comparison of the properties of the binders used in both investigations is given in Table 1 (chemical and physical properties) and Fig. 4 (particle size distribution). As far as the cements are concerned, the most obvious changes are in the percentages of C_3S and C_2S; over the past 10 years there has been a reduction in C_3S content of 8% and an increase in C_2S content of 6%. These changes would tend to make the cement less reactive and if anything leads to an increase in bleeding. As for the slags the chemical compositions have remained reasonably consistent, the chemical modulus increasing only marginally from 1.33 to 1.35. The most marked changes are in the fineness, which has increased from 341 to 427 m^2/kg; this will obviously lead to an increase in reactivity and a potential reduction in bleeding. This increase in slag fineness may help to explain why the effects of slag addition on bleeding are significantly less marked than those observed 10 years ago although it is still surprising to see no increase in bleed as the slag level is increased from 55% to 85%.

The effect of delaying the start of the bleed test (to simulate the time delay between mixing and placing on site) is shown in the bleed time curves in Figs. 5–7. Because of the similarity in behaviour between the slags from the different sources, results of only one of the slags (source 2) are shown. As might be expected, delaying the start of the test results in a reduction in

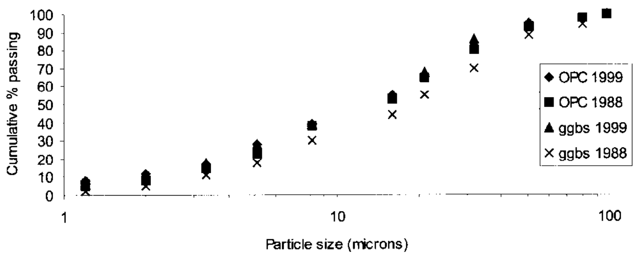

Fig. 4. Comparison of PSD of binders from 1988 to 1999.

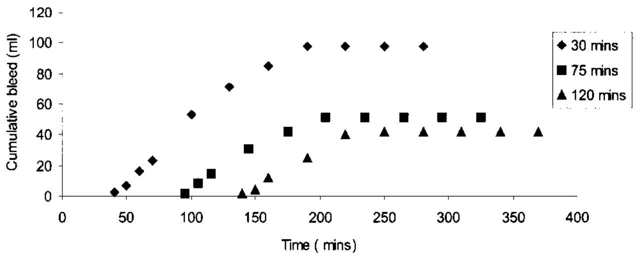

Fig. 5. Effect of delaying start time on bleeding of Portland cement concrete.

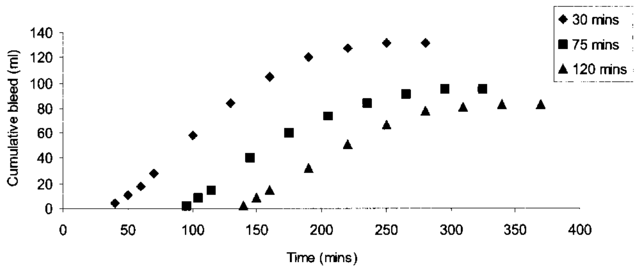

Fig. 6. Effect of delaying start time on bleeding of 55% slag (source 2) concrete.

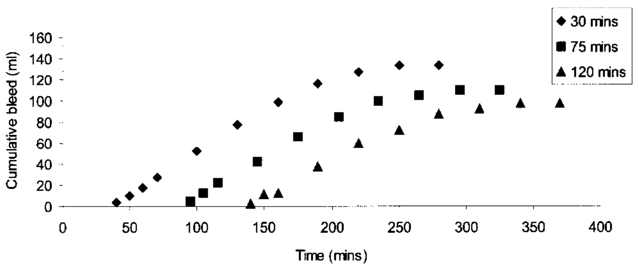

Fig. 7. Effect of delaying start time on bleeding of 85% slag (source 2) concrete.

bleeding for all mixes. The percentage reduction in bleed capacity and bleed rate is shown in Table 4. Delaying the start of the bleed test from 35 to 120 min results in more than a 50% reduction in the bleed capacity for the Portland cement mix compared to an average of only about 32% for the two slag mixes. The reduction in bleeding rate on the other hand is similar for all three mixes and is on average about 45%. The greater reduction in bleed capacity with the OPC mix is most likely related to the fact that the Portland cement is more reactive than the slag cements particularly during these early stages. It is again interesting to note the similarities in trends between the two slag mixes highlighting the small effect increasing the slag content from 55% to 85% appears to have.

Compressive strength results for all mixes up to 28 days are shown in Table 3 As with bleeding, the source of the slag appears to have little influence on strength development with the possible exception of those mixes

Table 4
Influence of test start time on bleed capacity and rate

	Bleed capacity (ml/ml)			Bleed rate $(ml/cm^2/s) \times 10^{-6}$		
	30 min	75 min	120 min	30 min	75 min	120 min
OPC	8	8.1 [27%]	7.9 [29%]	17.8	10.5 [41%]	9.0 [49%]
55% GGBS	10.7	7.7 [28%]	6.7 [37%]	18.5	11.5 [38%]	9.8 [47%]
85% GGBS	11.1	4.2 [48%]	3.5 [56%]	16.5	14.5 [12%]	10.5 [36%]

Note: Figures in [ ] represent % change from 30 min reading.

containing 55% of slag from source 1 and 85% of slag from source 2. From the data available on slag composition, there are no obvious reasons why these two mixes should show any differences in trend. After 28 days the mixes containing 55% slag have reached similar strengths to the control whereas those containing 85% slag have reached just over half this strength.

4. Conclusions

The following conclusions can be drawn from the results presented here on tests in which up to 85% of the cement has been replaced by GGBS. All mixes have been made to nominally the same water/binder ratio.

- The addition of slag at both levels of 55% and 85% resulted in an increase in workability from 15 mm slump (for the OPC mix) to between 20 and 40 mm for the slag mixes.
- The partial replacement of cement with up to 55% GGBS increased the bleed capacity by 30% (compared to the OPC control) but had little effect on the bleed rate. Increasing the slag level to 85% had no further significant effect on bleeding.
- The slags from four different sources that were used had similar physical and chemical properties and the source of the slag was found to have little effect on bleeding. However, comparisons made with results from earlier work suggest that the slags used in this present study had a much less marked effect on bleeding than those produced 10 years ago probably because they were finer ground.
- Delaying the start of the bleed tests from 30 to 120 min reduced the bleed capacity of the OPC mix by more than 55% compared with 32% for the slag mixes. The reduction in bleed rate was similar for all mixes at about 45%.

5. Future work

The observations and conclusions described above are based on only a limited experimental programme and further work needs to be undertaken to substantiate some of the findings; extensions to the experimental work should include:

- Testing over a range of cement contents from say 250 to 450 kg/m^3;
- Increasing the workability to between 50 and 100 mm slump and making comparisons on the basis of both equal workability and equal water/binder ratio;
- Examining the influence of the additional chemical admixture such as plasticisers/water reducers and air entrainers.

References

[1] Wainwright PJ, Ait-Aider H. The influence of cement source and slag additions on the bleeding of concrete. Cement Concrete Research 1995;25(7):1445–56.

[2] Powers TC. The bleeding of Portland cement paste, mortar and concrete. Research Laboratory of Portland Cement Association, Bulletin 2, 1939.

[3] Steinour HH. Further studies of Portland cement paste. Research Laboratory of Portland Association. Bulletin 4, 1945.

[4] Kasai, YMI. Studies on concrete strength of structure in Japan. Symposium Papers, vol. 2, Quality control of concrete structures, RILEM, Stockholm, Sweden, June 1979.

[5] Giaccio G, Giovambattista A. Bleeding: evaluation of its effects on concrete behaviour. Materials and Structures (RILEM) 1986;112:265–71.

[6] Dewar JD. Concrete durability: specifying more simply and surely by strength. Concrete 1982;12(2):19–21.

[7] Cesareni C, Figione G. A contribution to the study of the physical properties of hardened pastes of Portland cement containing granulated blastfurnace slag. In: Proceedings of the Fifth Symposium on the Chemistry of Cements, Tokyo, Japan, 1968.

[8] Allard AJ. Bleeding, plastic settlement cracking and initial surface. Absorption of PFA and cemsave concrete. M.Sc. Dissertation, University of Leeds, England, 1984.

[9] Ait-Aider H. Influence of ground granulated blastfurnace slag on the bleed characteristics of concrete. M.Phil. Thesis, University of Leeds, England, 1988.

[10] Rickett SCE. An investigation of the controlling factors in the bleeding of Portland blastfurnace cement concrete. Advance concrete Technology course project Beaconsfield. Institute of Concrete Technology, England, 1990, p. 139.

[11] Concrete Society. Non-structural cracks in concrete. TR No. 22. Concrete Society Slough, England, 1992.

[12] American Society for Testing and Materials. ASTM C232-92, Standard test methods for bleeding of concrete. ASTM Standards 1992;4.02:139–42.

[13] British Standards Institution. BS1881 Part 116: Methods for determining the compressive strength of cubes, 1983.