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THE INFLUENCE OF CEMENT SOURCE AND SLAG ADDITIONS ON THE BLEEDING OF CONCRETE

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ABSTRACT

Excessive bleeding of plastic concrete can result in problems with finishing and a weak surface layer particularly on flat slabs, a reduction in the bond between the steel and the concrete and an increased risk of the occurrence of plastic settlement cracks. Bleeding is controlled primarily by the fine material in the mix in particular, the quantity and reactivity of the cement. The partial replacement of OPC by ground granulated blastfurnace slab(ggbs) leads to a reduction in the rate of hydration and, as most other workers have reported, an increase in bleeding. However the authors have found that if comparisons are made on the basis of an equal 28 day compressive strength, and not on equal water/cement ratio as is usually the case, there are little if any differences between the OPC and the slag cement concretes. The reason for this is believed to be due to the increase in the overall cement content of the slag cement concretes which is necessary inorder to achieve parity in strength at 28 days with the OPC concretes.

Tests were also performed using Portland cement from different sources, the property of the cement having the most influence on bleeding was the particle size distribution.

Introduction

Bleeding is the term used to describe the movement of water to the surface of freshly placed and compacted concrete. Bleeding is a form of settlement the water being forced to the surface as the heavier solids in the concrete begin to settle(1,2). All concretes bleed 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.

The consequences of bleeding are to some extent conflicting and depend in part on the rate at which it occurs; generally speaking the greater the rate the more harmful the effects. The more a concrete bleeds the greater the risk of plastic settlement cracks yet the smaller the risk of plastic shrinkage cracks(3). In reinforced concrete the bond between the steel and the concrete can be reduced due to the entrapment of the bleed water along the underside of the steel. Bleeding results in variations in the effective water content throughout the depth of the concrete which produces corresponding changes in the concrete properties(4,5). Excessive bleeding can result in the concrete at or near the top being weaker and less durable then the remainder; this can be particularly troublesome on slabs which have a very large surface area. If, on the other hand, an attempt is made to remove the bleed water from the surface this could lead to delays in the finishing operations and may consequently be an important economic consideration on large jobs(3).

Bleeding is controlled by many factors and tends to occur more in concretes that have:- retarded setting (due either to the type of cement or the use of a retarding admixture), low cement content, high water/cement ratio, coarse ground cement or poorly graded aggregates(1,2).

Effect Of Slag On Bleeding

Ground granulated blastfurnace slag (ggbs) has been used as a partial replacement for cement for a number of years in many different countries. Many of the potential benefits and drawbacks from the use of this material are well understood and extensively published but information on some of the properties is less well documented than others. One such property is that of bleeding where there exists only a limited amount of published data. There is agreement that the inclusion of slag as partial replacement for the cement leads to an increase in both the rate and amount of bleeding and that the effects are more at higher replacement levels (i.e. greater than 60%)(6-10). The main reason for this increase is the delay in hydration brought about by the inclusion of the slag and thus a reduction in the rate of growth of the hydration products. In all the work reported above comparisons have been made on the basis of equal water/cement ratio or workability with replacement of cement by ggbs on a weight to weight basis. In practise however concrete is invariably specified in terms of its compressive strength at 28 days and at a fixed workability. The inclusion of slag in a mix will slow down the rate of gain of strength. In order to reach parity in strength at 28 days with a comparable Portland cement mix the overall cement content of the slag cement mix will need to be increased. It is possible that this increased cement content may offset to some extent the detrimental effects that the ggbs has on bleeding. The work reported here was designed to investigate this effect. In addition Portland cements from three different sources were used to study the influence of cement composition as well as slag addition on the bleeding of concrete.

Experimental Work

Five series of concrete mixes were made with cement contents ranging from 200kg/m^3 to 400 kg/m^3 and slag replacement levels of 40% and 70%.

The coarse aggregate used throughout this programme was a quartzite gravel from the Nottinghamshire Trent Valley and fine aggregate was from the same source. The grading of the coarse aggregate conformed to the 10 mm maximum size limits of BS 882(11) and the fine aggregate conformed to the grade M limits of the same standard.

Portland cements from three different sources in the UK were used and their properties are shown in Table 1. The ground granulated blastfurance slag used came from a single UK source and its properties are also shown in Table 1.

TABLE 1 Chemical Composition of OPCs

Oxide	Percentage (by weight)			
	OPC Source			ggbs
	1	2	3	
SiO_2	20.45	20.76	20.96	36.83
Al_2O_3	6.12	6.20	5.01	9.97
Fe_2O_3	2.35	2.80	3.20	1.19
CaO	65.56	64.90	64.25	41.89
MgO	1.12	1.07	2.84	7.21
SO_3	2.83	2.30	2.63	0.08
Composition by Calculation: (using Bogue's equation)				
C_4AF	7.1	8.5	9.7	
C_3A	12.3	11.7	7.7	
C_3S	58.8	54.1	59.1	
C_2S	14.3	18.8	14.8	

Test were performed to measure the setting times(12) of all 3 Portland cements and the blends when combined with 40% and 70% of ggbs. The results of these tests are shown in Table 2.

TABLE 2 Setting Times Details of the Different Cements

Cement Type	% ggbs (by weight)	Consistency %	Initial Setting (mins)	Final Setting (mins)
Source 1	0	31.2	108	182
"	40	29.0	164	224
"	70	26.5	241	318
Source 2	0	30.6	105	171
"	40	28.2	153	219
"	70	26.8	248	322
Source 3	0	30.4	118	169
"	40	30.1	170	213
"	70	27.0	249	310

The mix proportions for the concrete mixes are shown in Table 3; the aggregates used were in a saturated surface dry condition and slag addition was on a weight for weight basis. All mixes were made to nominally the same workability of 75 $\pm$ 25 mm as measured by the slump test(13). The partial replacement of the cement by the slag had only a marginal effect on the workability and for each cement content the water/cement ratio remained sensibly constant for all three mixes (i.e. for slag levels of 0, 40, 70%).

The ASTM C232 standard test method for measuring the bleeding of concrete was used throughout with the exception of one minor modification. The containers used were made from 8 mm thick UPVC (Unplasticised Polyvinylchloride Compound) pipe material with the same internal

TABLE 3 Mix Proportions of all Concrete Mixes

Ingredients	Proportion (by weight)				
	Cement Content kg/m³				
	200	250	300	350	400
Cement	1.00	1.00	1.00	1.00	1.00
Water	1.01	0.70	0.61	0.54	0.50
Fine Aggregate	4.12	3.12	2.46	2.00	1.66
Coarse Aggregate	5.65	4.56	3.83	3.31	2.92
% Fines	42	41	39	38	36
Slump (mm)	75 ± 25mm				

diameter and height as specified in the standard. The test evaluates the relative quantity of mixing water that will bleed from a sample of freshly mixed concrete. Each container was filled in two layers and each layer was vibrated for 10 seconds on a vibratory table. The specimen container was then placed on a level platform free from vibration and covered to prevent evaporation of the bleed water. A pipette was used to draw off the bleed water at 10 minute intervals during the first 40 minutes and at 30 minute intervals thereafter until cessation of bleeding.

From each of the nine mixes made a total of six 100 mm cubes were cast for the measurement of compressive strength in accordance with BS 1881(15); tests were performed at the ages of 7, 28 and 90 days.

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 minutes of the test. The volume is expressed in ml. per sq. cm. 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. A criteria of less than 5 ml. of collected bleed water in any thirty minute period was adopted as defining the point of cessation of bleeding.

Influence of Cement Type

Figure 1 shows typical bleed-time curves for concretes made at two different cement contents (250, 350 kg/m^3) from all 3 sources of OPC; results for all mixes are summarised in Table 4.

As expected the reduction in bleeding with an increase in cement content is clearly evident; for example increasing the cement content from 250 to 350 kg/m^3 results in approximately a 60% and 50% reduction in bleed rate and bleed capacity respectively. Such reductions are related to the increase in surface area and hydraulic reactivity associated with the higher cement content.

The influence of cement source on bleeding is not as obvious; the only clear trend from Table 4 is that the cement from source 2 shows bleeding rates which are between 14 to 20% below those of the other two cements. The corresponding reductions in bleed capacity are less obvious being between only 3% and 13%. Reductions in bleeding can be attributed to a more reactive cement but a comparison of those relevant properties of the cements used in this study (see Tables 1 and

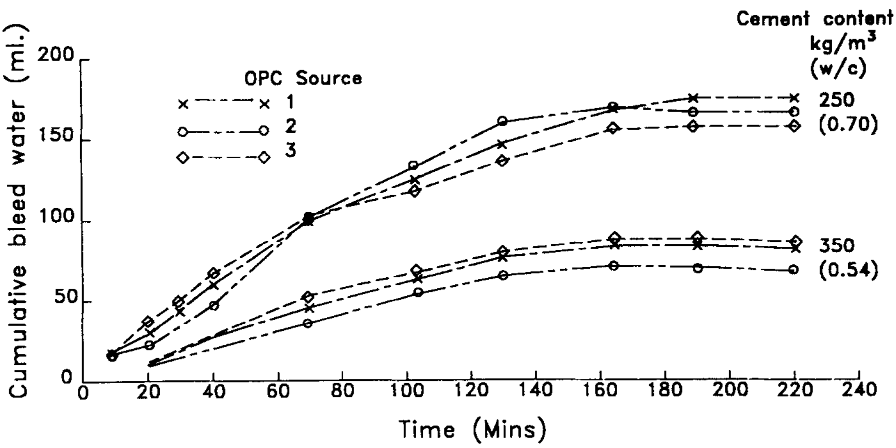

FIG. 1
Bleed-time Curves for OPC Concretes

TABLE 4 Bleed Characteristics of the OPC Concrete Mixes.

Cement Source	Cement Content kg/m³	Bleeding Rate ml/cm²/s (10^{-6})	Bleeding Capacity ml/ml (10^{-2})	Bleeding Time min	Degree of Channelling
1	200	186.7	26.0	130	Very Severe
2	200	162.9	24.7	130	Very Severe
3	200	207.1	28.3	130	Very Severe
1	250	51.7	14.2	190	Severe
2	250	42.4	13.7	190	Severe
3	250	54.3	13.2	190	Severe
1	300	28.0	9.0	160	Slight
2	300	23.7	8.4	160	Slight
3	300	26.3	9.4	160	Slight
1	350	22.9	6.8	160	No
2	350	18.6	6.0	160	No
3	350	22.0	7.2	160	No
1	400	18.6	5.3	130	No
2	400	14.4	5.0	130	No
3	400	20.3	5.4	130	No

2) would suggest that this is not the reason for the trends shown. The values for standard consistency and setting times (Table 2) are very similar for all three sources. In addition an increase in reactivity can be associated with a high C_3A and C_3S content combined with a high specific surface area; compared with the other two cements the cement from source 2 possesses none of these properties (see Table 1). The only explanation that can be offered at this stage is related to the particle size distribution (psd) of the cements rather than their surface area. The results of psd for all three cements are shown in Figure 2 from which it can be seen that the cement from source 2 has a slightly narrower size distribution than the other two. Investigations into the effect of particle size distribution of cements on the water demand of pastes and concretes has shown that cements with a narrower size range require more water for a constant

workability(16-18). In addition such materials tend to pack together less well then materials with a wider size range. There is a tendency therefore for the mix water to be held within these voids in preference to being available to lubricate the particles(18). Therefore when making comparisons on the basis of constant water/cement ratio the lower bleeding rates observed with the cement from source 2 could be attributed to its narrower particle size distribution. It is also possible that the differences in bleeding could be attributed to other factors, not examined by the authors, such as the crystallographic form of the cement constituents.

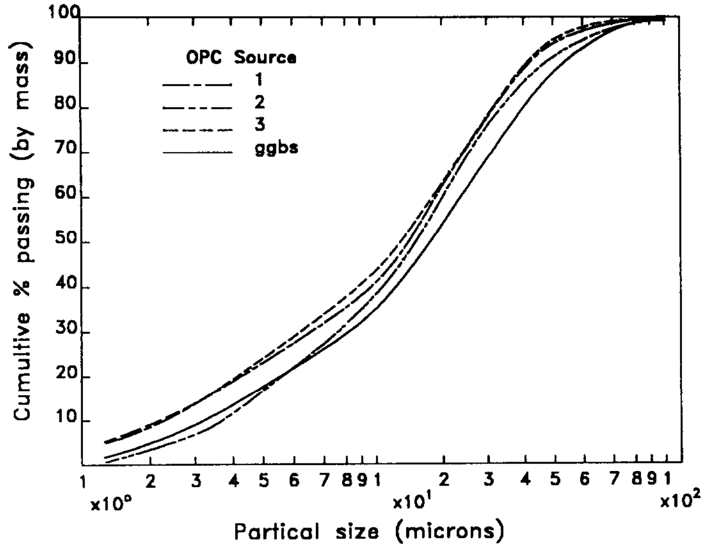

FIG.2
Particle Size Distribution Curves of Different Cementitious Materials

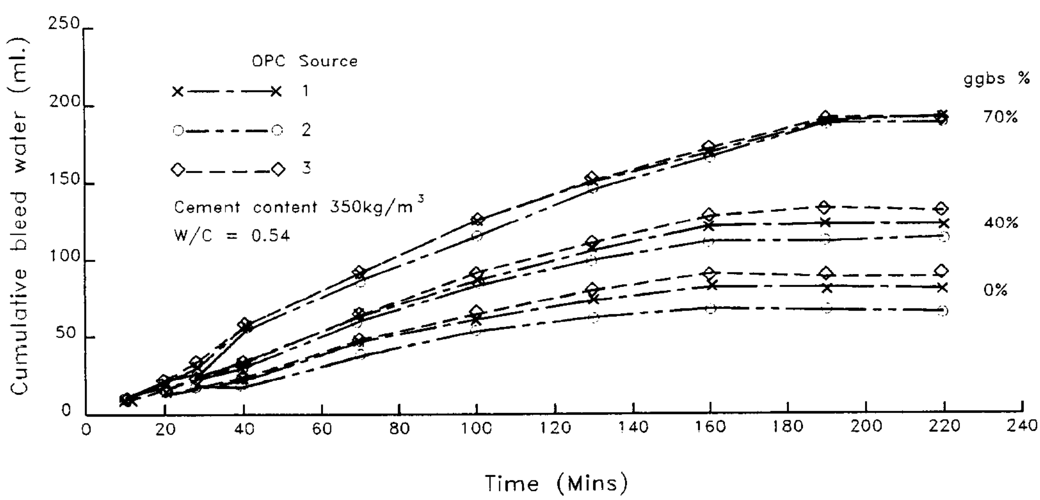

FIG. 3
Typical Bleed-time Curves for OPC/ggbs Concretes

Influence of Slag Additions

Typical bleed - time curves for concretes with a nominal cement content of 350 kg/m^3 made with three different cements and at two different slag replacement levels are shown in Figure 3. In addition results for all mixes are summarised in Figures 4 and 5 where the bleed capacities and rates are compared on the basis of equal cement content. As discussed earlier for the range of mixes made at any one cement content (i.e. for cements from all three sources and at slag levels of 0, 40, 70%) it was possible to maintain the water content constant whilst achieving nominally the same workability within the range 75 $\pm$ 25 mm of slump. In this case then a comparison on the basis of equal cement content is also a comparison on the basis of equal water/cement ratio.

It can be seen from these figures that for a given water/cement ratio (cement content) the partial replacement of OPC with ggbs leads to increases in all aspects of bleeding (i.e. rate, capacity and time). In addition the greater the level of slag used the greater the increase. For example, when comparing with the equivalent OPC mix and at a nominal cement content of 250 kg/m^3, the use of 40% and 70% ggbs results in average increases in bleed rate of 31% and 91% respectively. The equivalent increases in bleed capacity are 44% and 75%.

Such increases are only to be expected and similar findings have been reported previously by other researchers(6-8). The main reason for the increase is related to the fact that the slag is inherently slower to react than the OPC and the reactivity is reduced as the percentage of slag is increased.

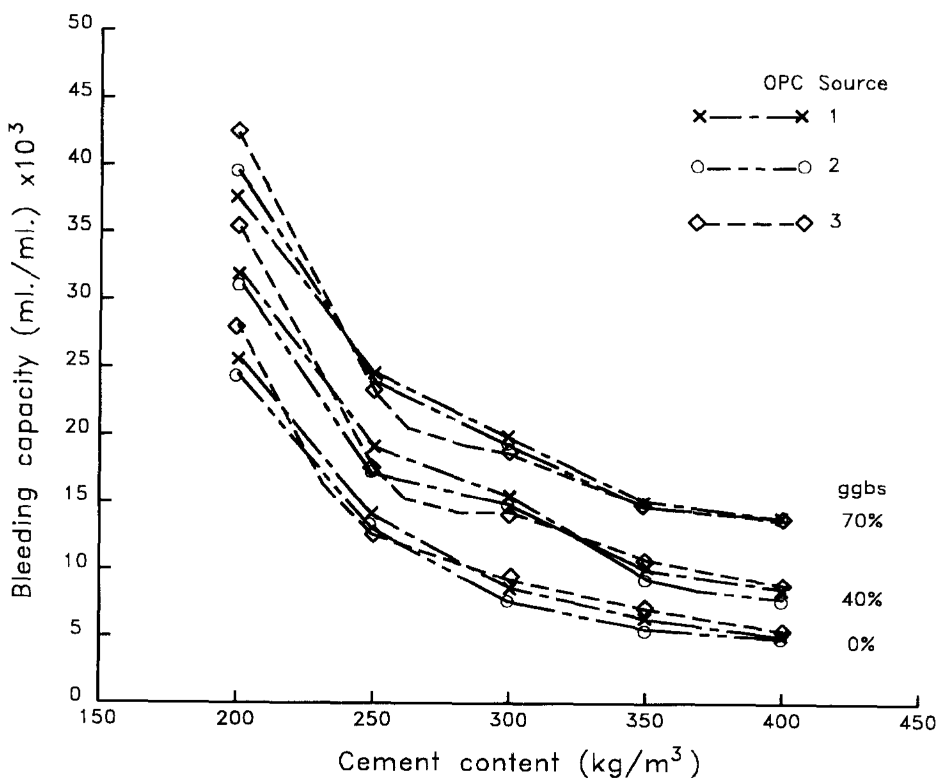

FIG. 4
Bleeding Capacities for OPC/ggbs Concretes

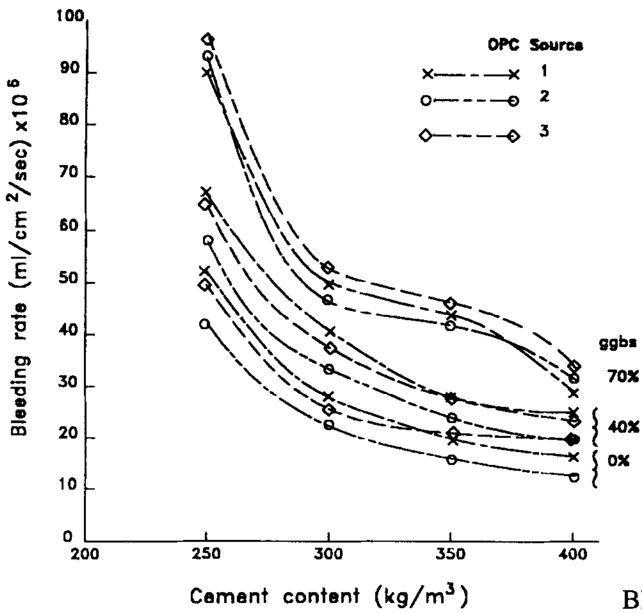

FIG. 5
Bleeding Rates for OPC/ggbs Concretes

A lowering of the reactivity means a reduction in the rate at which hydration products are formed particularly in the early ages. The hydration products play a significant role in reducing bleeding by physically restricting the movement of water to the surface. Any delay in the formation of these hydrates will therefore result in an increase in bleeding.

The influence of cement source is not as obvious as that of slag addition which is not surprising in view of the earlier discussion (see 4.1) on the OPC mixes. The one clear trend is that the cement from source 2, when combined with 40% ggbs, produced lower bleed characteristics than the other two cements. For example the bleed rates were, on average, 21% lower than with the cements from the other two sources. Such trends are in keeping with those discussed earlier in relation to the OPC mixes. As might be expected the influence of cement source becomes less significant as the slag level increases and at 70% addition the bleed characteristics for all three cements are very similar. One other point of interest is that the bleed rates for concretes made with a combination of 40% ggbs and 60% OPC from source 2 are similar to those of concretes made from 100% OPC from sources 1 and 3.

Comparison at Equal 28 Day Strength

As mentioned earlier compressive strength measurements were made on all mixes at the ages of 7, 28 and 90 days the results of which are shown in Figure 6. In most cases the source of the OPC was shown to have little effect on the compressive strength at constant water/cement ratio (cement content); what differences there are get less as the age of test increases. In view of these small differences and to aid clarity individual points have not been shown on this graph.

Partial replacement of OPC with ggbs results in a reduction in the rate of gain of strength; for example at a cement content of 350 kg/m^3 the 28 day strengths of concretes containing 40% and 70% ggbs are on average 20% and 46% lower than those of the OPC controls. At 90 days however the differences between the respective mixes are very small.

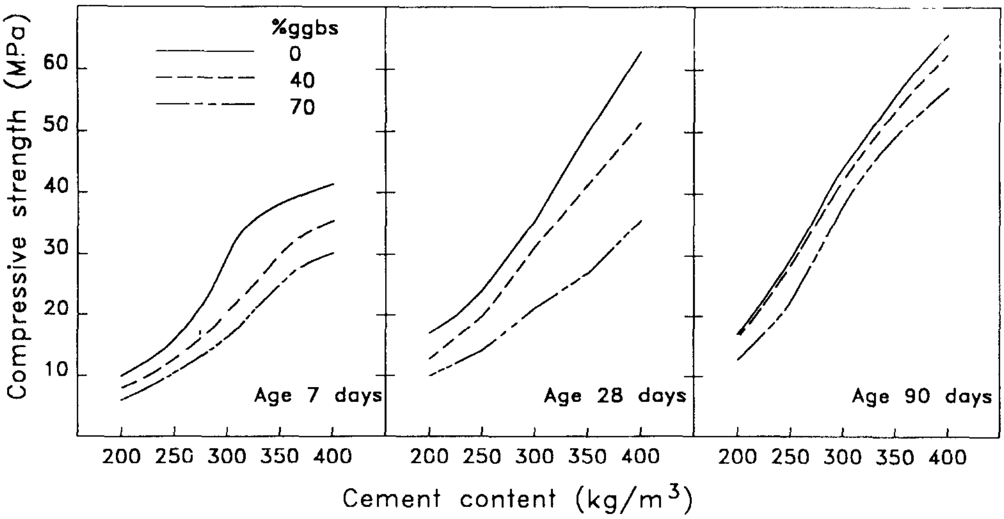

FIG. 6
Compressive Strength of All Concretes at 7, 28 and 90 Days

In most practical situations concrete is specified in terms of its 28 day compressive strength and its workability. From Figure 6 it can be seen that the partial replacement of OPC by ggbs will lead to a reduction in 28 day strength and if equality in strength is to be achieved the overall cement content of the slag cement concretes will need to be increased. As mentioned earlier it is likely then that the reduction in bleeding resulting from the increase cement content will compensate to some degree for the increase in bleeding arising from the addition of the slag. To verify this the results of bleeding rate and capacity have been plotted against the 28 day compressive strength and are shown in Figures 7 and 8. As can be seen, for a given 28 day compressive strength there is little if any difference between the bleed characteristics of the slag cement or the OPC concretes. For compressive strengths greater than about 20 MPa the slag cement concretes show slightly higher bleed rates but the maximum difference is no more than about 25%. For bleeding capacities the differences are even smaller and in most cases they cannot be considered to be significant.

On the same basis similar conclusions may be drawn when examining the influence of cement source on the bleed characteristics. It would appear then, from the results presented here, that the premise stated earlier regarding the compensating effects of increasing cement content and slag additions is true and that when compared on the basis of equal 28 day compressive strengths there are no significant differences between the bleed characteristics of OPC and slag cement concretes.

Conclusions

An investigation has been carried out to examine the influence of the composition of OPC and the addition of up to 70% ggbs on the bleed characteristics of concrete. The following conclusions have been drawn from the results presented in this paper.
When making comparisons on the basis of an equal water/cement ratio (cement content):-

(1) Significant reductions in all aspects of bleeding were observed with an increase in cement content.

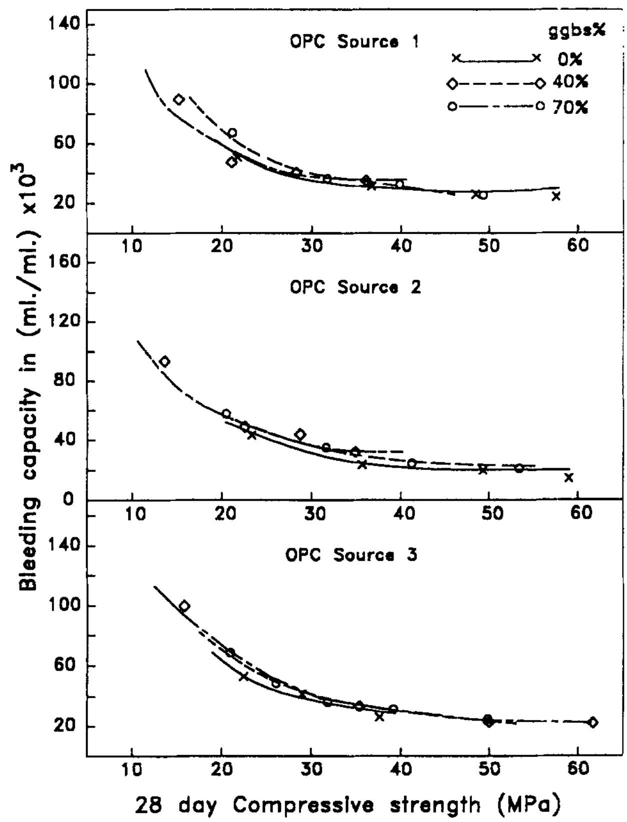

FIG. 7
Bleed Rate - Strength Relationship for All Concretes

(2) Portland cements from three different sources were used, only one of these behaved differently from the other two showing reductions of up to 28% and 13% in bleeding rate and capacity respectively. The only property of the cement examined by the author that such differences could be attributed to was its narrower particle size distribution. However other factors, details of which were not available, such as the crystallographic form of the cement constituents could also have had an influence.

(3) The partial replacement of OPC with 40% and 70% of ggbs lead to increases in the bleeding of the concretes, these increases were more pronounced at the higher replacement levels.

(4) In one case a change in the source of the OPC was shown to have as large an influence on bleeding as the partial replacement of cement with up to 40% of ggbs.

When making comparisons on the basis of equal 28 day compressive strength:-

(5) Neither the source of the OPC or the partical replacement with up to 70% of ggbs had any significant effect on the bleed characteristics of all the concretes tested.

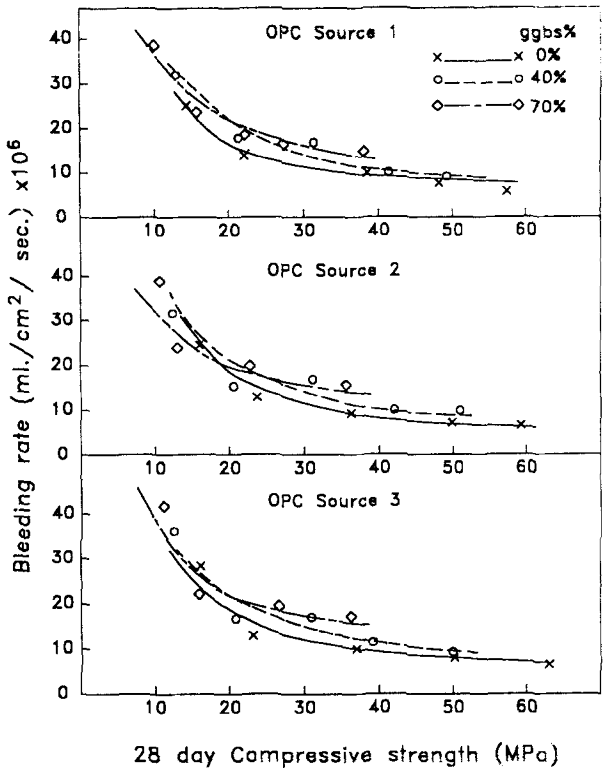

FIG. 8
Bleed Capacity - Strength Relationship for All Concretes

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