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The properties of slag cement mortar incorporating ggbs of different fineness were investigated. Four additional slag samples were obtained by grinding a commercially available slag. The properties investigated on all the mortar mixes were workability, bleeding characteristics, compressive strength and drying shrinkage. Mortar mixes containing 70% ggbs at 0.45 water/cement ratio were studied.

The results showed that increasing the slag fineness from 4320 to 7500 cm^2/g (Blaine) had an insignificant effect on workability, but improves the bleeding characteristics of the mortar mixes. Furthermore, the results showed that increasing the slag fineness led to an increase in the compressive strength and drying shrinkage values of the mixes at all ages of testing.

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TECHNICAL PAPER

PROPERTIES OF SLAG CEMENT MORTAR INCORPORATING GGBS OF DIFFERENT FINENESS

*by Folarin T. Olorunsogo**

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ABSTRACT

The properties of slag cement mortar incorporating ggbs of different fineness were investigated. Four additional slag samples were obtained by further grinding a commercially available slag. The properties investigated on all the mortar mixes are workability, bleeding characteristics, compressive strength and drying shrinkage. Mortar mixes containing 70% ggbs at 0,45 water/cement ratio were studied. The results showed that increasing the slag fineness from 4320 to 7500 cm^2/g (Blaine) had an insignificant effect on workability but improves the bleeding characteristics of the mortar mixes. Furthermore, the results showed that increasing the slag fineness led to an increase in the compressive strength and drying shrinkage values of the mixes at all the ages of testing.

INTRODUCTION

Ground granulated blastfurnace slag (ggbs) has been in use as a cement extender in the construction industry for more than forty years in South Africa and a century in Europe. The reason for its use is that the material is economical in certain areas and possesses some advantageous properties in relation to the durability of concrete. Slag is produced as a by-product of pig iron manufacture. When the molten slag is cooled down rapidly, a granulated glassy material which possesses latent hydraulic properties is formed. The granulated material is ground to cement fineness. In blended cements the calcium hydroxide and alkalies liberated by the hydration of ordinary Portland cement are adequate for the slag to be activated.

Portland cement-slag blends can be prepared in two different ways, namely by intermixing cement and slag (ground to cement fineness) or by intergrinding cement clinker, gypsum and granulated slag. Intermixing is commonly used in South Africa, Japan and the United Kingdom because it has the advantage of flexibility of choice of replacement levels. Another advantage of grinding separately and intermixing is that the components can individually be ground to different finenesses so as to obtain a blended cement with particular hydraulic properties (Frigione and Murolo 1985).

Various methods are employed by different investigators in considering the influence of slag fineness on the performance of cement pastes, mortar and concrete mixes incorporating slag. Helmuth *et al* 1986 and Seo *et al* 1986 investigated the performance of slag by stating the percentage of particle size fractions of a known size range. For example Helmuth *et al* described slag fineness as 95% coarser than 15µm. Harada *et al* (1986) and Sao *et al* (1986) described slag fineness by specifying the specific surface area. However, they considered slag samples with extreme values of fineness. An attempt is made in this study to investigate the effect of slag fineness on some properties of mortar mixes containing ggbs of fineness ranging from 4320 cm^2/g (for a commercially available slag) to 7500 cm^2/g (a super fine slag). Three additional slag samples with fineness of 5300, 6500 and 7500 cm^2/g (Blaine) were also included.

MATERIALS AND PROCEDURES

Materials

The properties of the ggbs which was ground to different fineness and the ordinary Portland cement are shown in Table 1, while Table 2 shows the physical properties of the sand. For each mix, the five different size fractions of the sand in Table 2 were recombined such that the resulting combination conformed with the *zone M* grading of the British Standard BS 882:1983.

Experimental Procedure

Four additional slag samples were prepared by grinding the original slag sample (4320 cm^2/g) using a 10 kg capacity ball mill. The fineness of the ground samples ranged from 5300 to 7500 cm^2/g (Blaine). The properties of mortar which were examined on all the mixes are workability, bleeding characteristics, compressive strength and drying shrinkage. Based on the results obtained from a previous investigation (Olorunsogo 1990), tests were carried out on the mortar mixes containing ground slag samples at 70% level of replacement and 0,45 water/cement ratio.

Determination of packing density

Apart from determining the chemical composition of the cementitious materials, the packing density of the OPC and all the slag samples were determined following the procedure specified by the British standards BS 812:1975 Part 102.

Mixing procedure

All the mortar mixes were made using a 25 kg capacity Cretangle mixer. The cement (i.e. OPC and ggbs) and sand for each mix were first mixed in a dry state for about 30 seconds before water was added. The entire mixture was then mixed for another 90 seconds, after which the mortar was left in the mixer undisturbed for approximately

15 minutes before performing any tests on the mix.

Workability

After mixing, determination of the workability of each mix was carried out employing the German flow Table Test described in German standard DIN 1048:1978.

Casting of cubes and prisms

Twelve 50 mm cubes and two pairs of 25 mm by 25 mm by 200 mm prisms were cast from each mix. The cubes were used for the determination of the compressive strength while the prisms were made for the measurement of the drying shrinkage. After casting and subsequently demoulding, all the cubes and a pair of the prisms were kept in a curing room which was maintained at a temperature of 22°C and relative humidity of 100% until tests were conducted at 3, 7 and 28 days since casting. The remaining pair of the prisms were kept in a humidity and temperature controlled room at 22°C and 70% RH.

Bleeding characteristics

The method described by ASTM C232:1977 was employed for the determination of the bleeding rate and capacity of all the mixes prepared using a modified version of the recommended apparatus. The apparatus, made from a plastic material instead of steel, consists of a cylindrical container having an inside diameter of 254 mm and an inside height of 267 mm. Water on the surface of the mortar was collected at intervals of 10 minutes within the first 40 minutes, and half an hour intervals afterwards until cessation of bleeding water.

Compressive strength

Three 50 mm cubes from each mix which were cured at 100% RH and a temperature of 22°C, and the compressive strength determined at the ages of 3, 7 and 28 days. A 3000-kN Dartec machine was used to crush the cubes at a loading rate of 6/mm^2/s.

Table 1 – Properties of GGBS and OPC

(a) Chemical Analysis		
Oxides	GGBS	OPC
	Percentage (%)	
CaO	40,12	64,01
SiO_2	37,28	21,06
$A1_2O_3$	10,79	5,09
Fe_2O_3	0,43	3,01
MgO	8,83	2,58
MnO	0,68	-
TiO_2	0,58	-
K_2O	0,37	0,80
Na_2O	0,27	0,33
S(total)	1,04	-
SO^{2-}	0,98	-
SO_3	0,15	2,92
$C1^-$	-	0,03
C	0,12	-
Free CaO	0,06	1,20
L.O.I.	1,03	-
Insoluble Residue	0,22	0,40
(b) Physical Properties		
Specific Surface Area (cm^2/g, Blaine)	4320	3880
Relative Density	2,930	3,105

Table 2 – Properties of Fine Aggregate

(a) Particle size distribution	
Size Range	Percentage Passing (%)
> 2,36 mm	100
1,18 mm - 2,36 mm	85
600 μm - 1,18 mm	65
300 μm - 150 μm	35
< 150 μm	15
(b) Physical properties	
Relative Density	2,62
Water Absorption	0,13%

Table 3 – Fineness and Packing Density of the Slag Samples Ground to Different Fineness

Sample Identification	Fineness Blaine (cm^2/g)	Percentage Void	Relative density
OPC	3880	35	3,11
N	4320	34	2,93
W	5300	30	2,96
X	6500	37	2,97
Y	7100	38	2,97
Z	7500	40	2,99

Drying shrinkage

Aside from curing a pair of the prisms made for the monitoring of the drying shrinkage in the fog room at 100% RH and a temperature of 22°C as the control specimens the remaining pair was kept at 70% RH and 22°C. Drying shrinkage was measured at 3, 7 and 28 days using the apparatus suggested by BS1881:1970; Part 5.

RESULTS AND DISCUSSION

Fineness and packing density of the slag samples ground to different finenesses.

The fineness and packing density of the OPC and all the ggbs samples are shown in Table 3. The results show that the percentage voids in the slag powders increased with increases in fineness except from sample N to W.

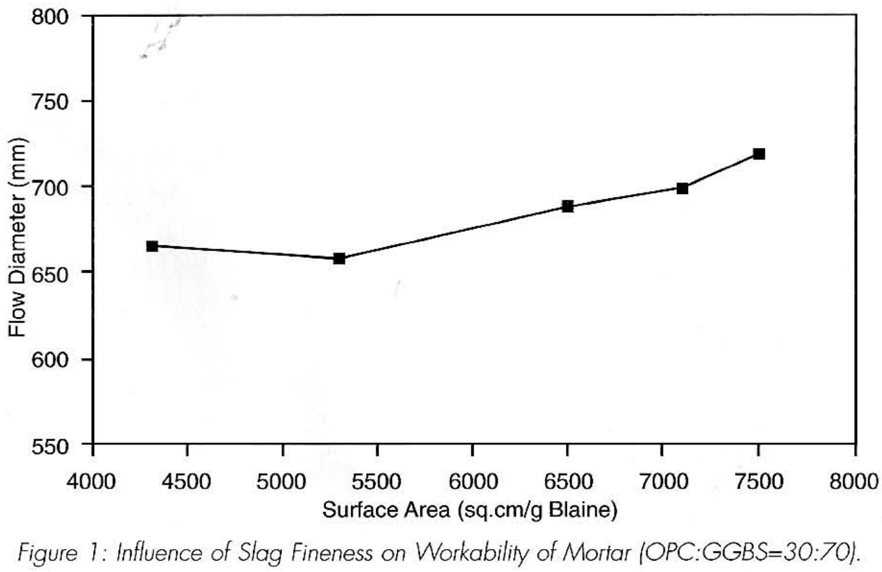

Figure 1: Influence of Slag Fineness on Workability of Mortar (OPC:GGBS=30:70).

Workability

Figure 1 illustrates the effect of increasing fineness of the slag on workability. The figure shows that the flow diameter of mortar mixes increased by 52,5mm (or 8%) when the slag fineness increased from 4320 to 7500 cm^2/g. However, this is an insignificant increase when compared to the 12,5% coefficient of variation for the repeatability of measurement of workability in this study. Investigating the influence of the slag fineness on cement pastes containing up to 80% ggbs Harada *et al* (1986) found that there was a negative linear relationship between the slag fineness and flow values of the pastes. Harada and his co-workers did not explain their findings, but it is thought to be due to an increase in water demand associated with increasing fineness of cementitious materials (Sprung *et al* 1985).

The reasons for the observations made in this study could be attributed to the fact that, apart from the ggbs having different finenesses they also had varying percentages of voids as shown in Table 3. According to the results of Sumner *et al* (1984), increasing the "voidage" of cements led to an increase in water demand for the pastes made to the same consistency (i.e. at a constant water/cement ratio the flow of the cement paste decreased with and increase in the percentage of voids). In fact increasing the fineness tends to lead to an increase in the percentage of voids which in turn should mean a reduction in workability. However, Figure 2 shows the opposite trend, i.e. the flow diameter increased with an increase in the percentage of voids. Therefore, it is possible that the slag grains themselves may act as a lubricant to the mortar matrix which may lead to masking the dual effects of increasing fineness and voidage thereby, resulting in no significant change in workability.

Bleeding characteristics

Figure 3 shows the results of the bleeding characteristics of the mortar mixes. The results presented in Figure 3(b) show that for the slag cement mortars made with 70% ggbs at 0,45 water/cement ratio, an increase in fineness from 4320 to 7500 cm^2/g (Blaine) resulted in reductions of 74 and 43% in bleeding rate and bleeding capacity respectively. Coefficients of variation for the repeatability of measuring bleeding rate and capacity are 6,4 and 9,5% respectively. The figure also shows that within the fineness ranges tested the relationships in both cases are curvilinear. Representing the fineness of the slag sample by the position parameter of the Rosin-Rammler distribution function, such an increase in fineness is equivalent to reducing the position parameter from 18,5 to 11,0 μm.

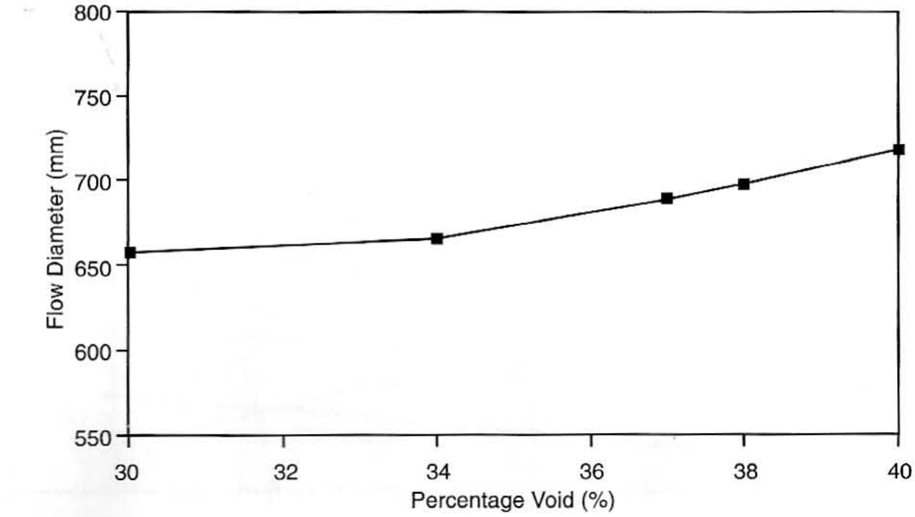

Figure 2: Percentage Voids and Workability of Mortar (OPC:GGBS=30:70).

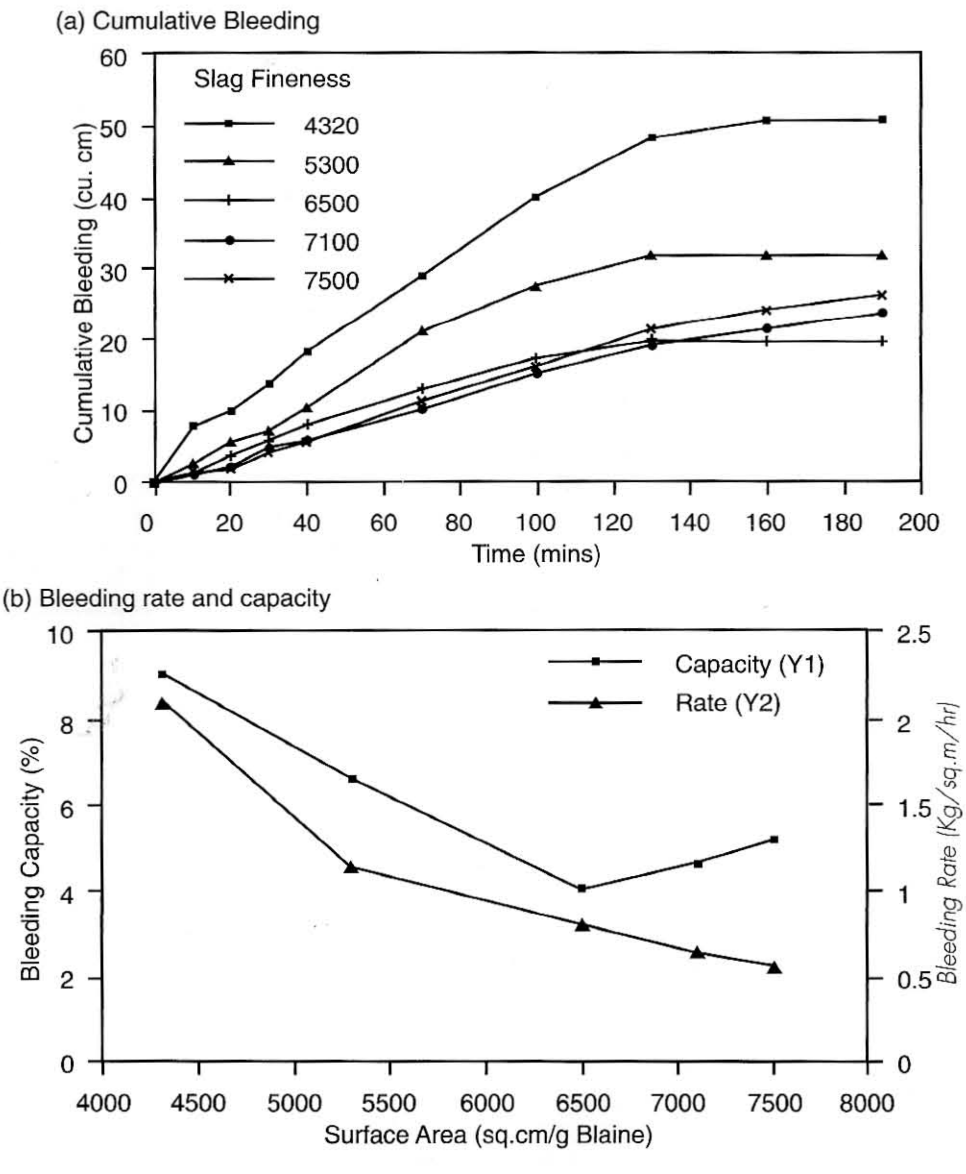

Figure 3: Effect of Slag fineness on the Bleeding Characteristics of Mortar (OPC:GGBS=30:70).

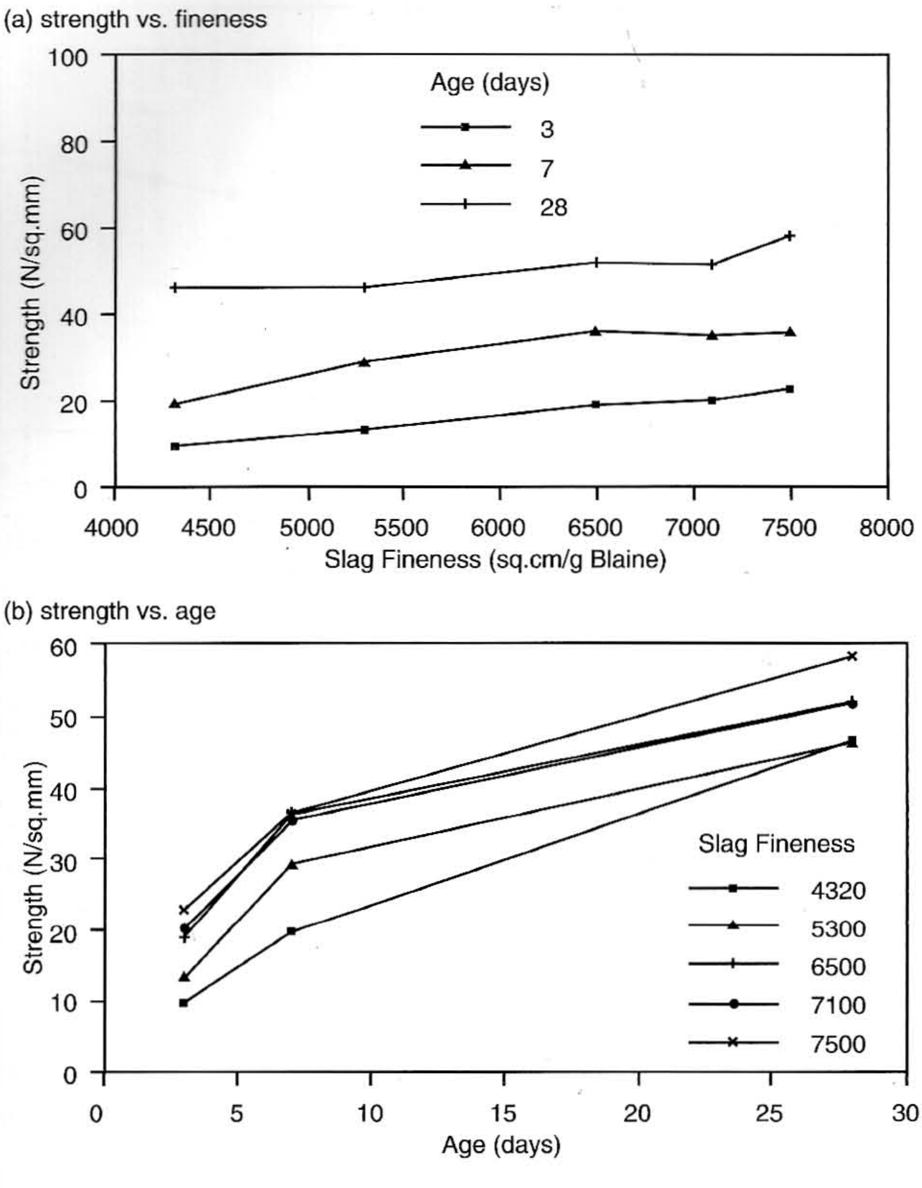

Figure 4: Effect of Slag Fineness on the Compressive Strength Development of Mortar (OPC:GGBS=30:70).

A comparison with the results of an earlier investigation (Olorunsogo 1990) suggests that for the 70% slag mix at 0,45 water/cement ratio, reducing the position parameter from 18,5 to 11,0 μm affects bleeding characteristics more than reducing it from 23,0 to 15,0 μm. Olorunsogo also confirmed that the relationship between change in position parameter (i.e. the slag fineness) and bleeding characteristics is nonlinear. Similarly, studies by Higginson (1970) and Hwanf and Lin (1986) revealed that increasing the fineness of cements led to decreases in both the bleeding capacity and bleeding rate of cement paste, mortar and concrete mixes.

Explanations about why increasing the fineness of the ggbs reduces the bleeding characteristics of the mixes can be associated with the fine particles having larger surface areas which tend to use larger amounts of water for both physical and chemical reasons (Bensted and Bye 1966). For physical reasons, water will be used for the initial wetting of the surface of the particles and chemically, larger surface areas demand more water for early hydration. The effect of early hydration may not be significant here since the OPC portion had the same surface area and chemical composition throughout. Therefore, it is likely that the reasons for the reduction in bleeding are largely physical, relating to the surface of the slag powder.

Compressive strength

The results of the compressive strength tests are shown in Figure 4. Generally, increases in the fineness of the slag resulted in increases in compressive strength at all the ages (i.e. 3, 7 and 28 days) for which the specimens were tested. Although, only marginal differences were observed with the three finest samples, increasing the slag fineness from 4320 to 7500 cm^2/g led to increases of 135, 84 and 25% in strength at 3, 7 and 28 days respectively. For the repeatability of measuring the compressive strength in this study, the coefficient of variation was 3,4%. As expected the magnitude of the increase reduces with age. This is so because most of the hydration processes which are enhanced by increased surface area are expected to have taken place at the early age (Olorunsogo and Wainwright 1996). Many researchers including Harada *et al* (1986), Sato *et al* (1986), Numata *et al* (1986) and Seo *et al* (1986) investigated the strength development of cement mortars incorporating slags of different fineness. They concluded that compressive strength increased with an increase in the slag fineness. Ritzmann (1968) and Sprung *et al* (1985) also reported similar findings with OPC cement pastes. The increase in strength of both the cement paste and slag mortar mixes as a result of an increase in the fineness of the cementitious materials are attributed to the increase in the surface area of the particles leading to an increase in reactivity.

Drying shrinkage

Figure 5 shows that in general, at all ages at which the specimens were tested, drying shrinkage increased with an increase in the fineness of the ggbs samples. As can be seen, the relationship between fineness and shrinkage is approximately linear. Increasing the fineness of the slag sample from 4320 to 7500 cm^2/g led to increases of 180, 170 and 121% in the shrinkage at 3, 7 and 28 days respectively. Although, the coefficient of variation for measuring drying shrinkage was as high as 15%, the changes observed here are still significant. This observation is in line with the results of other investigators such as Sato *et al* (1986), Numata *et al* (1986) and Harada *et al* (1986).

Harada *et al* investigated the drying shrinkage of 30, 50 and 70% slag cement mortars which contained slag with finenesses of 3470, 6090 and 9830 cm^2/g. They reported that the drying shrinkage increased with an increase in the fineness of the slag powders. The increases they observed were most apparent with the 30% slag mixes but the values remained constant after about the age of eight weeks. For the 50 and 70% slag mixes however, there was little or no difference between the shrinkage of the mixes incorporating the 6090 and 9830 cm^2/g slag. Similarly, Sato *et al* considered 40% slag mortar specimens and found that although the two slag powders (3700 and 8000 cm^2/g) investigated showed higher shrinkage over the the OPC mix, the mixes containing the finer slag showed higher shrinkage up to the age of four weeks. After this time both specimens showed similar shrinkage up to the age of one year.

The tendency for the drying shrinkage of the slag mixes to become higher the higher the slag fineness could be attributed to the lower bleeding capacity resulting from the finer slag powders (Olorunsogo 1990). Plotting the values of the bleeding capacity and drying shrinkage obtained in this study (as shown in Figure 6) revealed that drying shrinkage increased initially until the bleeding capacity reached 5,16%. This value corresponds to the bleeding capacity of the mortar mix containing the finest slag sample (i.e. 7500 cm^2/g). Afterwards, the shrinkage values decreased with increasing bleeding capacity. Another reason shrinkage increased with increasing slag fineness is that, in general finer cementitious materials tend to exercise less restraining effects on the shrinking paste than the coarser ones (Neville 1986).

CONCLUSIONS

Increasing the slag fineness from 4320 to 7500 cm^2/g (Blaine) had an insignificant effect on the workability of the mortar mixes. However, increasing the fineness (by increasing the grinding time) of the ggbs resulted in an improvement in the bleeding characteristics of the five slag mixes investigated. The highest bleeding rate and capacity were associated with the coarsest slag mix.

The strength development of the slag cement mortars shows that, compressive strength increased with increasing degree of fineness of the ggbs. However, only marginal

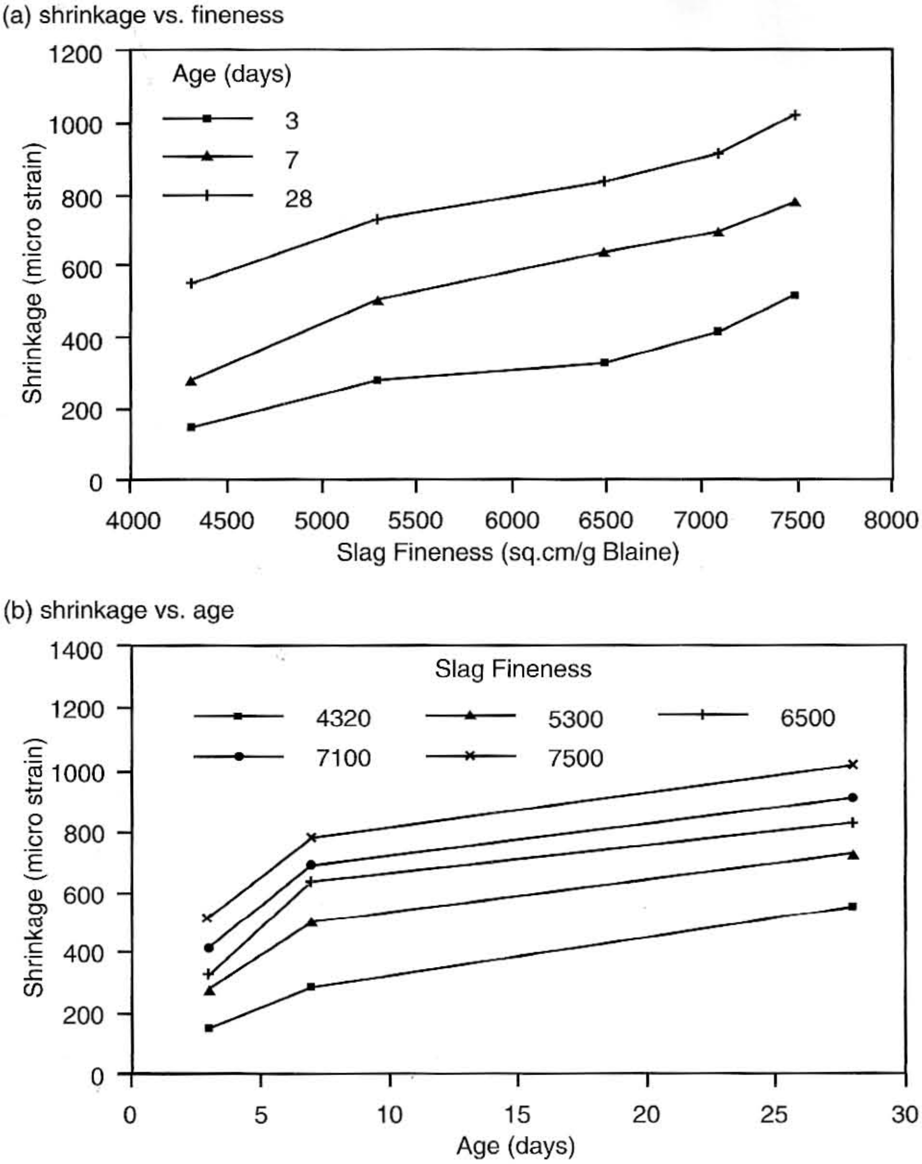

Figure 5: Effect of Slag Fineness on Drying Shrinkage of Mortar (OPC:GGBS=30:70).

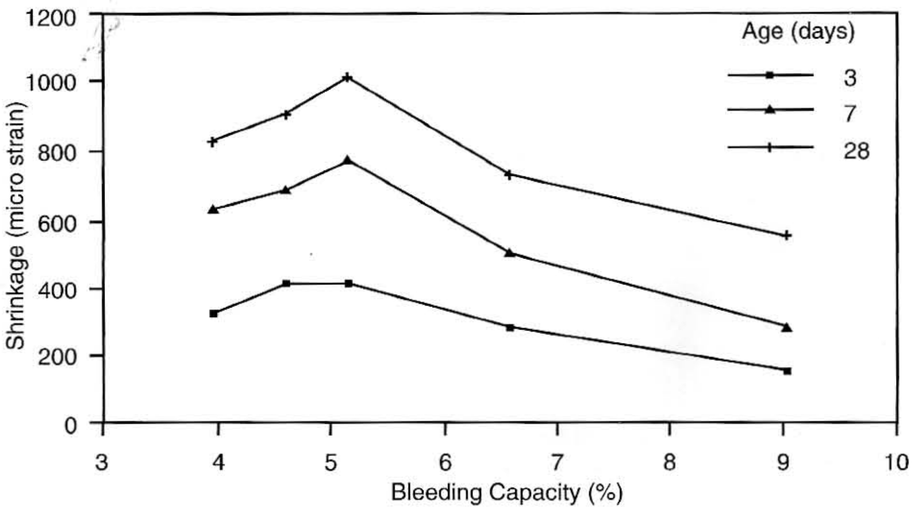

Figure 6: Bleeding Capacity and Drying Shrinkage of Mortar (OPC:GGBS=30:70).

differences were observed in the values of the compressive strength of the mixes incorporating the three finest slag samples. The increased strength as a result of the increase in the slag fineness has been attributed to the increase in the surface area of the slag samples which contributes to the rapid early hydration of the slag cement.

Similarly, the results showed that increasing the slag fineness led to increased drying shrinkage. The phenomenon of the drying shrinkage becoming higher the higher the slag fineness, could be due to the lower bleeding capacity which resulted from the finer slag powders.

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