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TESTING OF BINDERS FOR HIGH PERFORMANCE CONCRETE

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ABSTRACT

Powders for binders for high performance concrete have been investigated using a simple flow spread test. Test on pastes made with individual powders at increasing water content give two parameters; the retained water ratio and the deformation coefficient. Values of these for powder mixtures can be obtained by a simple law of mixtures. Values of yield stress and plastic viscosity from concentric cylinder tests are shown to be related to the flow spread test results, which gives confidence for their use in selection of the constituents and materials for high performance concrete. © *1997 Elsevier Science Ltd*

Introduction

Many high performance concretes incorporate binders consisting of blends of cement, cement replacement materials, inert fillers and admixtures, particularly superplasticizers. As with normal concrete, the binder constituents and their proportions are often chosen according to the requirements of the hardened (e.g. strength) or hardening (e.g. heat of hydration) concrete. However, the use of low water/binder ratios and relatively high binder contents leads to a need for the rigorous consideration of fresh properties, and makes the achievement of adequate workability more demanding (1).

The large number of possible combinations of binder constituents can lead to extensive and time consuming series of trial mixes. Some preliminary testing of the binder itself is therefore desirable. For example, de Larrard uses a flow cone test to determine the required dosage of superplasticizer for pastes for high strength concrete (2).

A simple flow spread test, analogous to the slump flow test for concrete, has been used by Okamura et al. (3) when selecting the binder constituents for self compacting concrete. This paper presents some results obtained from using this test on individual binder powders and some combinations of these. Comparisons are made with fundamental rheological properties of the pastes obtained with a concentric cylinder viscometer. Although the tests were carried out with the aim of investigating suitable binders for the authors' study of self compacting concrete (4), the test method employed will be useful for assessing binders for other types of high performance concrete.

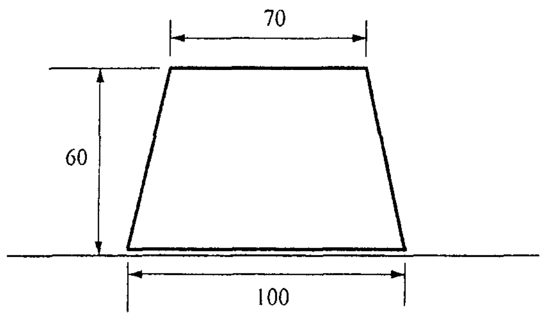


FIG. 1.
Dimensions of flow spread test.

The Flow Spread Test and Its Interpretation

The apparatus for the flow spread test consists of a mould in the form of a frustum of cone, 60 mm high with diameters of 70 mm at the top and 100 mm at the base (Fig 1). The cone is placed at the centre of a glass plate, and is filled with the cement paste in two layers, each layer being compacted with 15 strokes of steel rod. Immediately after filling, the cone is lifted and the paste spreads over the table. The average diameter (D) of the spread is measured, the the relative flow area (R) is then calculated using:

$$R = \frac{(D^2 - 100^2)}{100^2} = (D/100)^2 - 1 \tag{1}$$

Values of R are typically in the range from 0.2 to 15.

The test has similarities to that specified in JIS 5201 (5), ASTM C230 (6) and BS4551 (7). The initial spread is obtained in the same way, but is measured without the paste being subjected to any jolting; hence the flow is solely due to self-weight. The test is therefore simpler and more convenient.

Okamura et al. (3) found that, for a paste made with any particular powder, the relative flow area (R) and the water powder ratio by volume (V_w/V_p) are linearly related, as shown in Figure 2. Their expression for this was:

$$V_w/V_p = \beta_p + R.\ E_p \tag{2}$$

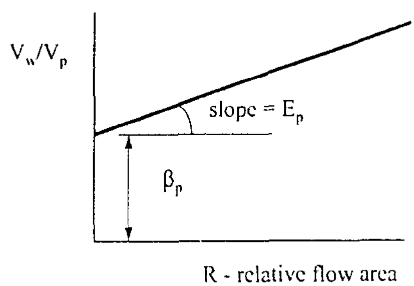


FIG. 2.
Typical relationship from flow spread test.

TABLE 1

Physical Properties of Powders

	Portland cement	pfa	ggbs	limestone powder
particle size	SSA 376m²/kg	87.5% <45μm	SSA 420m²/kg	90% < 53μm 30% < 10μm
specific gravity	3.15	2.40	2.90	2.68

where:

- β_p (the intercept with the V_w/V_p axis) is the *retained water ratio*, which can be thought of as comprising the water adsorbed on the powder surface together with that required to fill the voids in the powder system and to provide sufficent dispersal of the particles for flow to be about to commence.
- E_p (the slope of the line) is the *deformation coefficient*, which is a measure of the sensitivity of the fluidity characteristics of the paste to increasing water content.

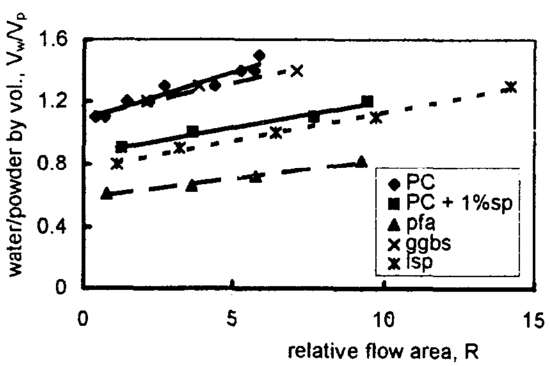
Flow Spread Tests on Single Powders and Powder Combinations

A series of flow spread tests was carried out using the flow test to characterize pastes made from Portland cement, pulverized fuel ash, ground granulated blast furnace slag and limestone powder. The physical properties of these are given in Table 1.

All the pastes were mixed with a high-shear high-speed mixer for 5 minutes; this had been shown to produce efficient dispersion of the particles and reproducible properties (8).

The flow table results for pastes made with the above four materials, and for the Portland cement in combination with a constant dosage of a naphthalene-based superplasticizer are shown in Figure 3. The linear behaviour obtained by Okamura was confirmed, and the resulting values of β_p and E_p, obtained by regression analysis, are shown.

The relative performances of the powders were as expected. The portland cement and the ggbs had the highest β_p values, which is presumably due to their similar particle size and



powder/mixture	β_p	E_p
portland cement	1.08	0.061
pfa	0.59	0.024
ggbs	1.10	0.046
lsp	0.77	0.037
pc + 1% sp	0.86	0034

FIG. 3.
Flow spread test results for single powders.

TABLE 2

Flow Spread Results for Powder Mixtures

powder mixture	measured values		values calculated from single powder values	
	β_p	E_p	β_p	E_p
35%PC+30%pfa+35%ggbs	0.95	0.056	0.94	0.045
70%PC+30%pfa	0.94	0.049	0.93	0.050
50%pfa+50%lsp	0.72	0.047	0.68	0.031
25%PC+25%pfa+50%ggbs	1.01	0.036	0.97	0.044
35%PC+20%pfa+45%ggbs	0.99	0.042	0.99	0.047

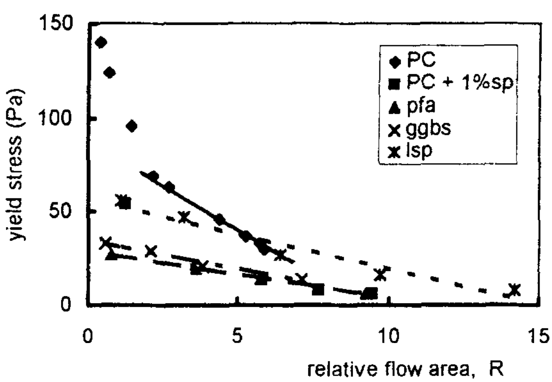
shape. However the ggbs had a lower E_p value, indicating its greater sensitivity to increasing water content. The pfa having the lowest values of both β_p and E_p which can be attributed to its particle shape. The limestone powder had intermediate values of both β_p and E_p. The superplasticizer reduces the values of both β_p and E_p for the portland cement, with a proportionally greater change in the latter.

Powder combinations which would be useful for the development of self-compacting concretes were also tested, as listed in Table 2. As with the single powders, all mixes showed a linear relationship between relative flow area and water/powder ratio by volume; the resulting values of β_p and E_p are given in Table 2.

Also shown are values of β_p and E_p calculated from the results for the individual powders (Fig. 3) using a simple law of mixtures. The agreement between the calculated and measured values of β_p is excellent, and that for the E_p values is good. This shows that it is possible to estimate values of β_p and E_p for powder mixtures from those for the individual powders, thus obviating the need for tests on each potential powder mixture.

Viscometric Tests

It was thought valuable to examine the relationship between the characteristics as measured by the flow spread test and fundamental rheological parameters. The yield stress and plastic



PC: $\tau_y = 91 - 10.2\,R\ (R > 2)$ ..(3)

pfa: $\tau_y = 29 - 2.5\,R$ ..(4)

ggbs: $\tau_y = 35 - 3.1\,R$ ..(5)

lsp: $\tau_y = 58 - 3.8\,R$ ..(6)

PC + 1% sp

$\tau_y = 26 + 2.1\,R\ (R > 2)$ ..(7)

(τ_y = yield stress)

FIG. 4.
Yield stress vs. relative flow area for single powders.

TABLE 3

Calculated Relationships between R and τ_y for Powder Mixtures

powder mixture	relationship calculated from eqns 1-4
35%PC+30%pfa+35%ggbs	$\tau_y = 52.8 - 5.41R$
70%PC+30%pfa	$\tau_y = 72.4 - 7.89R$
50%pfa+50%lsp	$\tau_y = 43.5 - 3.15R$
25%PC+25%pfa+50%ggbs	$\tau_y = 47.5 - 4.73R$
35%PC+20%pfa+45%ggbs	$\tau_y = 53.4 - 5.47R$

viscosity values of all of the pastes were therefore measured, using a concentric cylinder viscometer with bob and cup diameters of 45 mm and 48.8 mm respectively. Before obtaining the flow rheological parameters were measured, the paste was sheared in the viscometer at a high strain rate (704/sec) for one minute to ensure full structural breakdown (9,10).

In the flow spread test the flow is induced by self weight of the paste and the flow rate is small, so it might be expected that the relative flow area and yield stress as measured with the viscometer are related. Figure 4 shows that this is indeed the case, and the relationship for the single powders is approximately linear over the whole range of R for the pfa, ggbs and lsp, and for values of R greater than 2 (the larger part of the range tested) for mixes containing Portland cement. The corresponding regression lines are also shown.

As with the flow spread test results, it is possible to obtain equations relating R to yield stress (τ_y) for the powder mixtures from the equations for individual powders (eqns 3-6) by a simple law of mixtures. The resulting equations are given in Table 3.

Values calculated from these for each of the measured R values are plotted against the measured values in Figure 5. The agreement is good, and shows that a reasonable estimate can be made of the yield stress of a powder mixture from the results of the flow spread test, provided that the relationship between R and τ_y for the individual powder is known.

A relationship between the plastic viscosity (μ) of the mix and the water/powder ratio might also be expected. Figure 6 shows that each powder has a different curve, with the ranking with increasing viscosity being similar to that from the relative flow area shown in

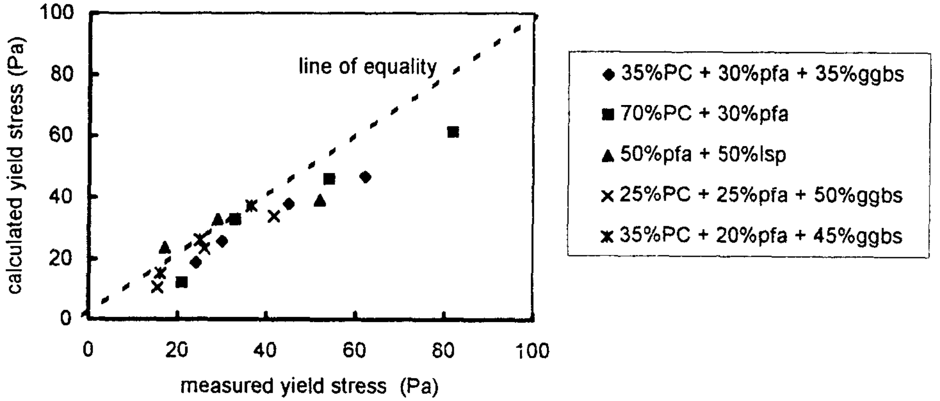


FIG. 5.
Calculated vs. measured values of yield stress for powder mixtures.

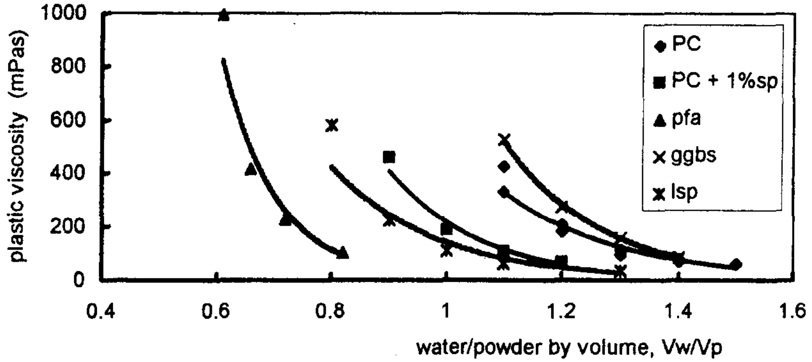


FIG. 6.
Plastic viscosity vs water powder ratio for single powders.

Figure 3. Further analysis shows that if the data are plotted as values of $V_w/V_p.1/\beta_p$ against $\mu.E_p$ then all results fall on or very close to a single curve (Figure 7). The shape of this curve suggests a power law relationship of the form:

$$\mu.E_p = k_1(\frac{V_w}{V_p} \cdot \frac{1}{\beta_p})^{k_2} \quad (7)$$

where k_1 and k_2 are constants. Regression analysis gives a correlation coefficient of 0.97 for values of k_1 and k_2 of 22.63 and -6.25 respectively. Also shown in this figure are the corresponding data for the powder mixtures, which conform to the same relationship, with a little more scatter. The existence of this single curve for all powders gives confidence that the flow spread test is measuring properties that are related to fundamental rheological properties, and that with further work it might be possible to predict the fundamental properties of the paste from the flow spread test.

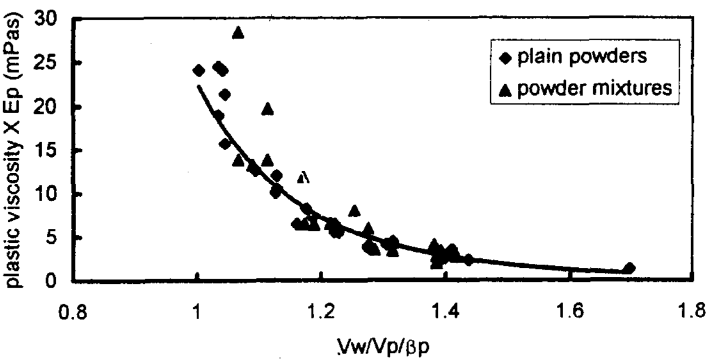


FIG. 7.
Combined results from flow spread and viscometer tests.

Conclusions

The simple flow spread test can be used to obtain the retained water ratio, β_p, and the deformation coefficient, E_p, of powders, which are important parameters characteristizing their performance when used in binders for high performance concrete.

Comparison of the results of the spread flow test with yield stress and plastic viscosity measured in a concentric cylinder viscometer gives confidence that spread flow test is measuring a useful rheological characteristic. It is possible to predict with reasonable confidence the values of β_p and E_p for pastes containing mixtures of powders from results of powders tested singly; this is extremely useful in the early stages of mix design of high performance concrete, for example, when high workability is required at minimum water content.

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