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by J.J. Beaudoin

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COMPARISON OF MECHANICAL PROPERTIES OF COMPACTED CALCIUM HYDROXIDE AND PORTLAND CEMENT PASTE SYSTEMS

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ABSTRACT

Mechanical properties of $Ca(OH)_2$ are compared with those of portland cement paste at different porosities. Intrinsic values of modulus of elasticity (E) and microhardness (H) for $Ca(OH)_2$ compacts were obtained by extrapolating to zero porosity log E and log H versus porosity curves. The values for the $Ca(OH)_2$ and portland cement paste systems are of similar magnitude. Flexural strength values for both systems were also determined to be of similar magnitude for the porosity range studied. Fracture terms (K_c, J_c, G_c, γ_T) were determined. K_c and γ_T versus porosity plots for both systems revealed that these fracture terms are of similar magnitude in the porosity range common to both.

Introduction

Hydrated portland cement at normal temperatures contains approximately 20-26% $Ca(OH)_2$ by weight. Crystal sizes are dependent on temperature and hydration time and vary from a few μm to several hundred μm (1). Not all $Ca(OH)_2$ in cement paste, however, is crystalline. Amorphous $Ca(OH)_2$ may be present in different amounts (2). There is evidence that some $Ca(OH)_2$ in cement paste may also be porous (3,4).

The role of $Ca(OH)_2$ in the fracture of cement paste is unresolved. Some indication of the importance of this phase in the fracture process of Ca_3SiO_5 paste has been obtained by optical microscopy (5). These studies have shown that cracks can propagate around and through $Ca(OH)_2$ particles or be arrested by them, depending on the degree of hydration of the system.

There is a paucity of data on the mechanical properties of $Ca(OH)_2$ alone. Such data are important for following the role of $Ca(OH)_2$ in cement pastes in terms of crack propagation in hydrated cements. A literature search revealed only two studies that give modulus of elasticity values, viz., 3.5 to 4.5 × 10^3 MPa (6) and 8.84 × 10^3 MPa (7), values that were obtained for compacts made by pressing $Ca(OH)_2$ powder at 136 and 340 MPa, respectively.

The present paper compares the mechanical properties of compacts of $Ca(OH)_2$ and of portland cement paste made at different pressures to obtain a range of porosities.

Experimental

Materials

Reagent grade $Ca(OH)_2$ powder was used. The analysis showed the following: $Ca(OH)_2$, 98.2%; chloride, 0.003%; sulphate, 0.05%; insoluble in HCl, 0.02%; heavy metals as Pb, 0.001%, Fe, 0.003%; Mg and alkalies as SO_4, 1.0%.

Preparation

Two series of compacted samples were prepared. One series was made in the form of compacted discs 3.18 cm in diameter by 0.127 cm thick. The discs were compacted at five different pressures in the range 136 - 680 MPa. Details of the compaction procedures are available (8). A second series of samples were compacted in the form of rectangular beams 9 cm × 1.2 cm × 0.127 cm thick. The ends of the beam were semicircular, with radius = 0.5 cm. Compaction procedures were similar to those used for the disc samples. Beam samples were prepared at four compaction pressures in the range 115 - 460 MPa. A mid-span notch was saw cut for beam samples used in fracture testing.

All testing was done in gloved boxes conditioned to 11% RH, a convenient reference state that minimizes the risk of carbonation, dissolution, and excess volume change.

Techniques

Porosity. Porosity was calculated from the weight and volume of the samples, using a solid density value of 2.24 g/cc.

Modulus of Elasticity. E values were calculated for both discs and beams without notches from load-deflection records. A description of the miniature loading device for the discs and the calculation based on central deflection of a circular plate supported at three equally spaced edge supports is given elsewhere (9).

Calculations using the beam were made as follows

$$E = \frac{P}{\delta}\left[\frac{\ell^3}{4bd^3} + \frac{1.2\ell}{2bd}\right]$$

where P = load, δ = mid-span deflection, ℓ = span, b = sample thickness, d = sample depth.

Microhardness. Hardness was measured with a Leitz miniload tester in a gloved box free of CO_2 using the Vickers pyramid indentor (10). Five determinations were performed on the surface of each sample.

Fracture Testing. An environmental chamber was mounted on the cross-head of an Instron testing machine. Notched and unnotched beam specimens conditioned to 11% RH were simply supported in it and loaded at the mid-point. The mid-span deflection was measured using an LVDT device with a readout accurate to 0.0001 mm. Cross-head speed was 0.005 mm/min. The following fracture terms were determined from the load deflection records: K_c (stress intensity factor), G_c (strain energy release rate), J_c (J-integral), γ_T (work of fracture). Further details of the determination are given elsewhere (11).

Flexural Strength. Flexural strength values for $Ca(OH)_2$ and portland cement paste were obtained using peak stress values obtained from load-deflection records of unnotched beam samples.

Results and Discussion

Logarithms of modulus of elasticity (E) values for $Ca(OH)_2$ are plotted against porosity in Fig. 1. The log E versus porosity curve contains results obtained from both the disc and beam samples. Figure 1 also shows a curve for compacted and in situ hydrated portland cement paste. The data for the hydrated portland cement paste curve (including corrections to porosities determined by water displacement) were obtained from previous work (10,12). Water is not considered a suitable medium for porosity measurement because of rehydration and interlayer penetration in C-S-H. Values for compacts of hydrated portland cement paste, made by grinding in situ hydrated cement paste into a powder and compacting it, lie along the same line as those for in situ hydrated portland cement paste.

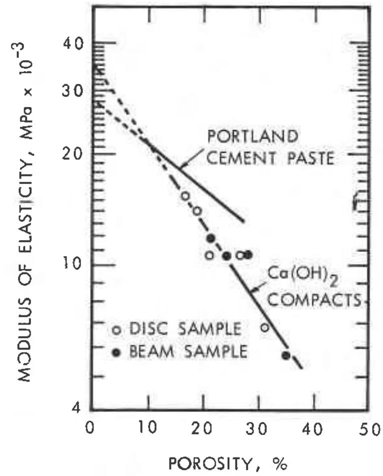

FIG. 1

Modulus of elasticity of $Ca(OH)_2$ compacts and portland cement paste vs porosity

A logarithm of microhardness versus porosity plot (not presented) gave a linear relation. Ramachandran (13) obtained similar microhardness data, but with a small difference in the slope of a log H versus porosity curve. Factors that may account for this difference include differences in crystallinity and particle size of the material. Regression analysis gives, by extrapolation, the following values of E and H for $Ca(OH)_2$ at zero porosity: $E_0 = 35.24 \times 10^3$ MPa; $H_0 = 2786$ MPa. The E_0 value for cement paste is 28×10^3 MPa, i.e., about 20% less than the value for $Ca(OH)_2$. The H_0 value for cement paste is 900 MPa, significantly less than the value for $Ca(OH)_2$. For portland cement paste there is some evidence for the validity of the extrapolation to zero porosity (14). Estimates of the modulus of elasticity of the non-porous cement paste samples, made by employing composite theory on cement paste samples completely impregnated with another phase, were similar to values determined by extrapolation. Similar extrapolations for the $Ca(OH)_2$ system, however, may not be valid.

It is evident that values of E and H for $Ca(OH)_2$ compacts in the porosity range studied are of the same order of magnitude as the values for portland cement paste. Further, most microhardness values for $Ca(OH)_2$ compacts are higher and modulus of elasticity values lower than those for portland cement paste over the porosity range studied. It is suggested that E and H values for these compacts are influenced by the intrinsic properties of the particles themselves and by the nature of the interparticle contacts. Microhardness measurement of $Ca(OH)_2$ compacts may have been influenced to a greater degree than modulus of elasticity by the properties of the particles themselves. The curve for $Ca(OH)_2$ compacts (Fig. 1) intersects the curve for cement paste at 10% porosity. At porosities >10% the curve for $Ca(OH)_2$ lies below the curve for cement paste. At porosities <10% the increase in the interparticle contact area for pressed $Ca(OH)_2$ particles is sufficient (assuming that extrapolation is valid) to give E values greater than those for portland cement paste. Similar differences in E and H values have been reported for other cement systems (12).

Flexural strength data are given in Table I. The values for $Ca(OH)_2$ compacts are of a magnitude similar to those for portland cement paste (range of all values is 3.0 - 14.2 MPa) over a similar porosity range (17.0 - 34.2).

Fracture terms for $Ca(OH)_2$ and portland cement paste are given in Table II. A range of values for portland cement paste is given to indicate differences between first drying and wetting. Comparison at 21% porosity reveals that values of K_c, J_c, G_c and γ_T are generally higher for portland cement paste. Ratios of the terms for portland cement paste to corresponding terms for $Ca(OH)_2$ are as follows: K_c (1.34 - 1.62); J_c (0.64 - 1.61); G_c (2.81 - 3.63); γ_T (1.53 - 2.40).

Fracture terms K_c and γ_T for $Ca(OH)_2$ compacts and portland cement paste are plotted against porosity in Fig. 2. K_c and γ_T values for $Ca(OH)_2$ compacts decrease with porosity. The values of K_c and γ_T for both systems are of the same order of magnitude over the range of porosity common to both data sets. Values of K_c for $Ca(OH)_2$ are less than those for cement paste (first drying and wetting) at porosity values <30%. Values of γ_T for $Ca(OH)_2$ are similar to those for portland cement paste (first drying) between 20 and 25% porosity.

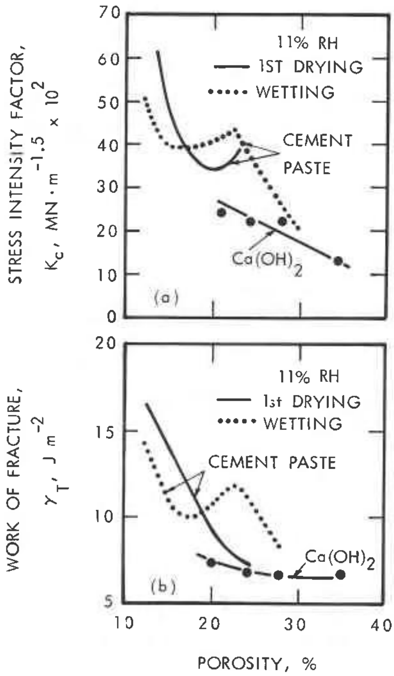

FIG. 2

Fracture terms, K_c and γ_T vs porosity for $Ca(OH)_2$ compacts and portland cement paste

TABLE I

Flexural Strength Values of $Ca(OH)_2$ and Portland Cement Paste

Material	Flexural Strength (MPa)	Porosity, %
	14.20	21.0
$Ca(OH)_2$ compacts	14.00	23.9
	12.84	27.7
	5.89	34.2
Portland cement paste	3.00 - 10.00	17.0 - 30.0

There is evidence to support the application of linear elastic fracture mechanics to the $Ca(OH)_2$ and portland cement paste systems. Measured values of G_c approach those of 2 γ_T within a factor of 2 or 3 (see Table II); whereas for metallic and polymeric materials, which fracture according to a plastic crack-tip separation process, G_c is several orders of magnitude in excess of 2 γ_T. This paper provides data on the fracture of both $Ca(OH)_2$ and cement paste containing $Ca(OH)_2$. Further work on fracture of lime-depleted cement paste is in progress.

TABLE II

Fracture Terms for $Ca(OH)_2$ Compacts and Portland Cement Paste

Material	Fracture Terms					Porosity
	K_c $(MNm^{-1.5})10^2$	J_c (Jm^{-2})	G_c (Jm^{-2})	γ_T (Jm^{-2})	G_c/γ_T	%
$Ca(OH)_2$ compacts	24.74	6.21	6.06	4.59	1.32	21.0
	22.52	3.58	4.65	3.93	1.18	23.9
	22.70	1.94	5.61	3.08	1.82	27.7
	14.50	4.60	5.59	3.17	1.76	34.2
Portland cement paste	40 - 50	8 - 9	15-17	12.5-14	1.2-1.5	14.0
(11% RH first	33 - 40	4-10	17-22	7-11	2-2.42	21.0
drying and wetting)	36 - 38	6-13	15-28	5-12	2.3-3.0	25.0

Conclusions

1. Samples formed by pressing $Ca(OH)_2$ powder can be used to determine its mechanical properties.
2. Microhardness and modulus of elasticity values of $Ca(OH)_2$ compacts are porosity dependent and of similar magnitude to those of portland cement paste.
3. The modulus of elasticity of non-porous $Ca(OH)_2$ extrapolated from the plot of log modulus of elasticity versus porosity has a value similar to that for non-porous cement paste.
4 Flexural strength values for $Ca(OH)_2$ compacts are of similar magnitude to those for portland cement paste over the porosity range studied.
5. Values of fracture terms K_c, J_c, G_c and γ_T for $Ca(OH)_2$ compacts are of the same magnitude but generally lower than the corresponding fracture terms for portland cement paste.

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