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EFFECTS OF TRANSITION ZONE MICROSTRUCTURE ON BOND STRENGTH OF AGGREGATE-PORTLAND CEMENT PASTE INTERFACES

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ABSTRACT

A relationship between interfacial bond strength and electrical conductivity of the transition zone has been developed. Microstructural factors affecting the bond strength of a non-porous aggregate-portland cement paste interface are elucidated. The results indicate that two principal factors affect the interfacial bond strength, i.e. the thickness of the water layer on the aggregate surface at the beginning of the mixing and w/c ratio. Decreasing the thickness of the water layer and w/c ratio are two methods to increase the bond strength.

INTRODUCTION

A description of the microstructural features and formation process of the transition zone between non-porous aggregate and portland cement paste has been developed by the authors using an electrical conductivity model[1,2]. This approach can used to relate interfacial bond strength to the microstructural features of the transition zone.

The objective of this contribution is to develop a relationship between interfacial bond strength and transition zone microstructure. Microstructural factors affecting the bond strength will be elucidated. Methods to increase bond strength will be suggested. Experimental phenomena obtained by others will be discussed in terms of the relationships developed[3].

INTERFACIAL BOND STRENGTH

General Equation

No current strength theory has been applied directly to the interface between aggregate and cement paste due to the complexity of the microstructure. As a first approximation, interfacial bond strength can be considered to be directly proportional to the total area fraction of solid phases associated with fracture surface in the transition zone, i.e.

$$\mathbf{P}_{f} \propto \Psi_{fs}$$

or

$$\mathbf{P}_{\mathbf{f}} = \mathbf{P}_{\mathbf{f}\mathbf{o}} \, \psi_{\mathbf{f}\mathbf{s}} \tag{1}$$

where, P_f is the interfacial bond strength, and ψ_{f_f} is the total area fraction of solid phases along the fracture surface in the transition zone, and P_{f_0} is the interfacial bond strength in the case, $\psi_{f_f}=1$, or zero-porosity bond strength. P_{f_0} however, can not be conceptually considered as the "intrinsic strength" of the interface since both composition and development of microstructure in the transition zone are time-dependent.

Since $\psi_{fs} = 1 - \sigma_f / \sigma_1$ (reference[2])

where, σ_f , σ_l are the electrical conductivities of the transition zone and the pore solution in a specimen saturated with pore solution, equation (1) can be expressed as

$$\mathbf{P}_{f} = \mathbf{P}_{fo} \left(1 - \sigma_{f} / \sigma_{l} \right) \tag{2}$$

Equation (2) relates bond strength and electrical conductivity of the aggregate-cement paste interface, viz. the interfacial bond strength is linearly dependent on the ratio of interface and pore solution conductivity.

Interfacial Bond Strength of Non-Porous Aggregate-Portland Cement Paste System

Equation (2) is a general equation expected to hold for any aggregate-cement paste interface. The conductivity ratio, σ_f/σ_i , in equation (2) for the non-porous aggregate-portland cement paste system can be expressed as follows[2]:

$$\frac{\sigma_{f}}{\sigma_{l}} = A_{f} \, \phi^{\circ}_{c} + B_{f}$$

$$A_{f} = -\left(\frac{\delta_{e}}{\delta}\right) \left[\lambda_{e}(1-m) + \lambda_{gel} \eta_{gel}m + \lambda_{CH} \eta_{CH} \cdot m\right],$$

$$B_{f} = 1 - \psi_{fo} ,$$
(3)

where, ϕ_c^* is the initial volume fraction of cement expressed as a ratio of the volume of cement to cement + water, δ is the thickness of the transition zone, δ_c is the thickness of "effect region" which is a part of transition zone and contains a few layers of cement particles between the water layer and bulk paste[2], m is the degree of hydration, and ψ_{fo} is the area fraction of hydrates other than C-S-H gel and CH in the transition zone, and λ_i , η_i are constants, where i=c for unhydrated cement, gel for C-S-H gel, CH for solid Ca(OH)₂.

Substituting equation (3) into equation (2) yields:

$$\mathbf{P}_{f} = \mathbf{P}_{fo} \left[\Psi_{fo} + (\delta_{c}/\delta) \mathbf{A}_{f}' \boldsymbol{\phi}_{c}^{*} \right]$$
(4)

where, $A'_f = \lambda_c(1-m) + \lambda_{gel} \eta_{gel} m + \lambda_{CH} \eta_{CH} \cdot m$.

Since $\delta_e = \delta - \delta_w$ [2], with δ_w being the thickness of the water layer on the aggregate surface at the initial mixing of aggregate and fresh cement paste, equation (4) becomes:

$$\mathbf{P}_{f} = \mathbf{P}_{fo} \left[\Psi_{fo} + (1 - \delta_{w} / \delta) \mathbf{A}'_{f} \boldsymbol{\phi}^{*}_{c} \right], \tag{5}$$

or

$$P_{f} = P_{fo} \left[\psi_{fo} + \frac{(1 - \delta_{w}/\delta)}{1 + (w/c)\rho_{c}} A'_{f} \right]$$

with $\varphi_{c}^{*} = 1/[1+(w/c)\rho_{c}], \text{ where } \rho_{c} \text{ is the density of cement}[2].$

It can be inferred from equation (5) or (5') that there are two microstructural factors that affect the interfacial bond strength:

(5')

(1). Interfacial structure factor, δ_w/δ (or δ_0/δ): interfacial bond strength decreases with δ_w/δ , the thickness of the water layer relative to the thickness of the transition zone.

(2). Bulk paste structure factor, ϕ_c^* (or w/c ratio): increasing ϕ_c^* (or decreasing w/c ratio) will increase the bond strength.

EXPERIMENTAL RESULTS AND DISCUSSION

Experimental results obtained by Liu were used to validate the relationship given by equation (5)[3].

Plots of both tensile strength and shear strength of limestone- and quartz-portland cement paste interfaces vs φ_c^* are given in figure 1 and figure 2 respectively.





It can be seen that interfacial bond strength(tensile and shear), is directly proportional to ϕ_{c}^{*} , or inversely proportional to w/c ratio.

Interpretation as equation (5) or (5') and the experimental results, it suggests that there are two possible ways to increase the interfacial bond strength. One is to decrease the thickness of the water layer on the aggregate surface at the beginning of mixing. An excellent example is given by R.Zimbelmann[4]. It was shown that the bond strength was increased by 100 to 180% by adding some tensides into the mixing water to reduce the thickness of the water film. The other way to increase the bond strength is to use low w/c ratio. It is well known that w/c ratio determines the initial porosity of cement paste and a low w/c ratio is an essential prerequisite for preparing high strength concrete. Equation (5) or (5') indicates that low w/c ratio is also a necessary condition to enhance the interface between non-porous aggregate and portland cement paste.

CONCLUSIONS

(1). There are two principal factors affecting bond strength at the interface between nonporous aggregate and portland cement paste, i.e. the thickness of the water layer on the aggregate surface at the beginning of the mixing and w/c ratio. There are, therefore, two possible ways to increase the bond strength, i.e. decreasing the thickness of the water layer and w/c ratio.

(2). The interfacial bond strength is linearly related to the electrical conductivity of the transition zone. Bond strength for the non-porous aggregate-portland cement paste system is proportional to the negative thickness ratio of the water layer and transition zone and inversely proportional to w/c ratio.

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