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DEGREE OF DISPERSION OF LATEX PARTICLES IN CEMENT PASTE, AS ASSESSED BY ELECTRICAL RESISTIVITY MEASUREMENT

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ABSTRACT

The degree of dispersion of latex particles in latex-modified cement paste was assessed by measurement of the volume electrical resistivity and modeling this resistivity in terms of latex and cement phases that were partly in series and partly in parallel. The assessment was best at low values of the latex-cement ratio; it underestimated the degree of latex dispersion when the latex/cement ratio was high, especially > 0.2 .

Introduction

Admixtures in the form of polymers, fine particles and short fibers are used in concrete mixes in order to improve the mechanical properties of the concrete. In particular, polymer admixtures improve both the flexural strength of the concrete and the bond strength between reinforcement (fibers or rebars) and the concrete [1-3]. In addition, polymer admixtures reduce permeability [1] and improve the vibration damping ability [4] and flexural toughness [5]. Among the various types of polymers, latex in the form of styrene butadiene is particularly common for use in cement [1-9].

In spite of the practically valuable properties of latex-modified cement [6-9], the microstructure of this material (an organic/inorganic hybrid material) has not been clarified. Most attention regarding the microstructure has been given to the voids, the content of which decreases with increasing latex/cement ratio [1,5]. The polymer (latex) is a distinct phase, but its observation by microscopy is difficult, partly due to the water in the cement paste and partly due to the small particle size ($0.2\ \mu\text{m}$) of latex. An obvious question regarding the microstructure relates to the degree of dispersion of this phase. The use of microscopy to assess the degree of dispersion globally is difficult and tedious. In this work, through electrical resistivity measurement, we have been able to assess the degree of dispersion of latex in cement paste. This technique is based on the fact that latex is essentially non-conducting compared to cement, so that the degree of latex dispersion strongly affects the resistivity of the latex-modified cement paste. Although the mechanical properties are also affected by the degree of dispersion, they are strongly affected by the polymer/cement bonding and the void content, so they cannot serve as indicators of the degree of dispersion.

Experimental Methods

The cement was portland cement (Type I) from Lafarge Corp. (Southfield, Michigan). No fine or coarse aggregate was used. The water/cement ratio was 0.23, except that it was 0.45 when latex was absent. The slump was around 160 mm, as determined conventionally using a 77 mm-diameter and 58 mm-high plastic cylinder. No water reducing agent was used. The latex was a styrenebutadiene dispersion (Latex 460NA from Dow Chemical Corp., Midland, Michigan; 48 wt.% solid, density 1.01 g/cm³, particle size 0.19-0.21 μ m); it was used in the amount of 0.05-0.30 of the weight of the cement, and was used along with an antifoam (Dow Corning 2410), which was in the amount of 0.5% of the weight of the latex. The latex and antifoam were first mixed by hand for about 1 min. Then this mixture, cement and water were mixed in a Hobart mixer with a flat beater for 5 min. After pouring the mix into oiled molds, a vibrator was used to decrease the amount of air bubbles. Then specimens were demolded after 1 day and then allowed to cure at room temperature and room relative humidity (33%) in air for 28 days.

The air content was measured using ASTM C185-91a, modified for the absence of sand and the presence of latex. This method also gave the latex volume fraction and the density. Six specimens of each type were tested.

The volume electrical resistivity was measured by the four-probe method, using silver paint for the electrical contacts. The DC current used ranged from 0.1 to 4 A. The specimen size was 160 $\times$ 40 $\times$ 40 mm. Six specimens of each type were tested.

Flexural testing was performed on all specimens by three-point bending (ASTM C348-80), with a span of 140 mm. The specimen size was 160 $\times$ 40 $\times$ 40 mm. Six specimens of each type were used. The hydraulic Material Testing System (MTS) was used for flexural testing with a cross head speed of 1.27 mm/min and the load-deflection curve was automatically recorded. The flexural toughness was calculated from the area under the stress/displacement curve obtained in flexural testing.

Results and Discussion

Table 1 shows that the density decreases with increasing latex/cement ratio, in spite of the fact that the void content decreases with increasing latex/cement ratio (Fig. 1). This is because the

TABLE 1
Latex Content, Void Content and Density of Cement Pastes
with Various Values of the Latex/cement Weight Ratio

Latex*/cement weight ratio	Latex* vol. %	Void vol. %	Density (g/cm ³)
0	0	2.32	1.99
0.05	3.64	2.07	1.95
0.10	7.35	1.88	1.90
0.15	11.07	1.70	1.87
0.20	14.91	1.53	1.83
0.25	18.81	1.25	1.79
0.30	22.55	1.10	1.76

*Dispersion.

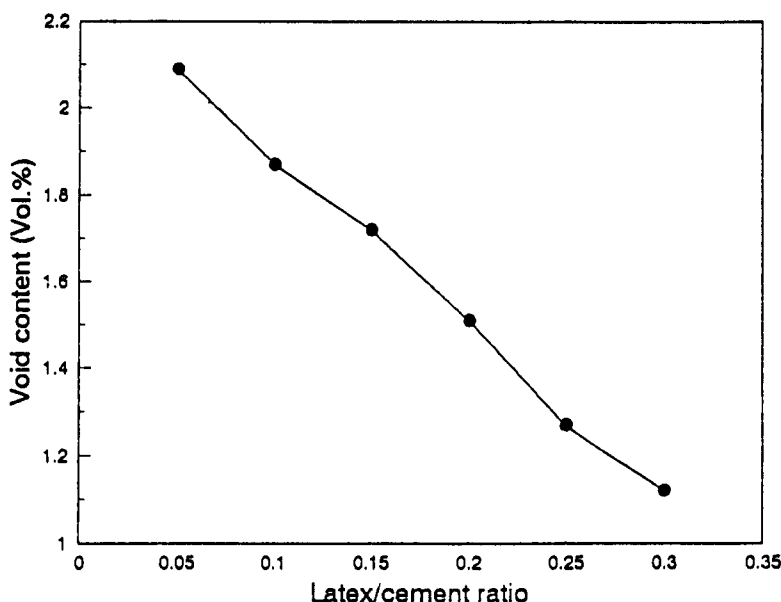


FIG. 1.
Effect of the latex/cement ratio on the void content.

density of the latex dispersion (1.01 g/cm^3) is lower than that of cement (3.15 g/cm^3). The latex volume fraction obviously increases with increasing latex/cement weight ratio. Fig. 2 shows that the volume electrical resistivity increases with increasing latex/cement ratio.

Assuming that the latex and cement phases are in parallel (Fig. 3(a)) and neglecting the conductivity of latex compared to that of cement, the volume resistivity of the latex-modified cement ρ_l is given by

$$\rho_l = \frac{\rho_c}{V_c} \quad (1)$$

where ρ_c is the volume resistivity of the cement phase and V_c is the volume fraction of the cement phase. Assuming that the latex and cement phases are in series (Fig. 3(b)) and neglecting the conductivity of latex, the resistivity of the latex-modified cement ρ is ∞ . In reality, the situation is in between these two extremes, so that the real resistivity is between ∞ and the value given by Eq. (1). Fig. 3(c) is an electrical conduction model of the real situation. In this model, the latex and cement phases are partly in parallel (e.g., sections 1, 3 and 4 of Fig. 3(c)) and partly in series (e.g., sections 2 and 5 of Fig. 3(c)). The sections which are in series do not contribute to electrical conduction, so the effective volume fraction of the cement phase V_c^{eff} is given by

$$V_c^{\text{eff}} = (1 - f) V_c \quad (2)$$

where f is the volume fraction of the cement phase which belongs to the sections that are in the series configurations. Thus, the resistivity of the latex-modified cement ρ is given by

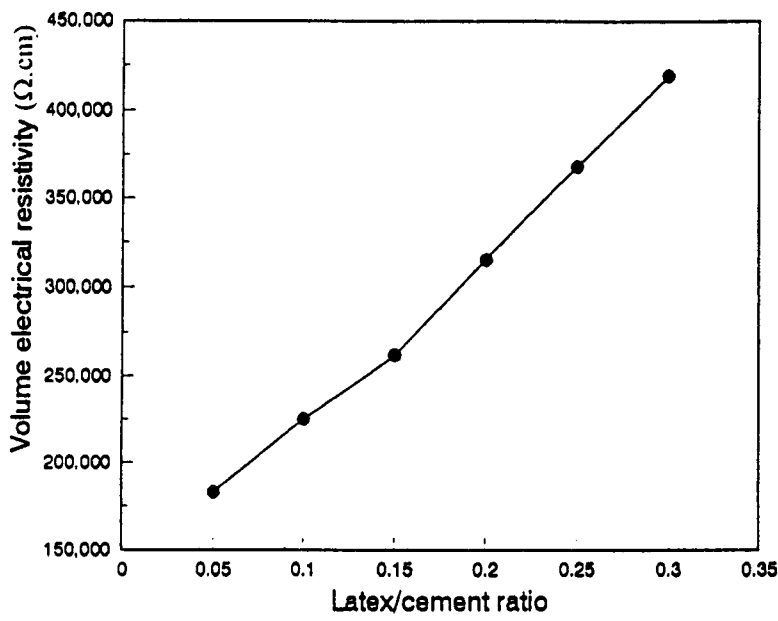


FIG. 2.
Effect of the latex/cement ratio on the volume electrical resistivity.

$$\rho = \frac{\rho_c}{V_c^{eff}} \tag{3}$$

Combining Eq. (2) and (3),

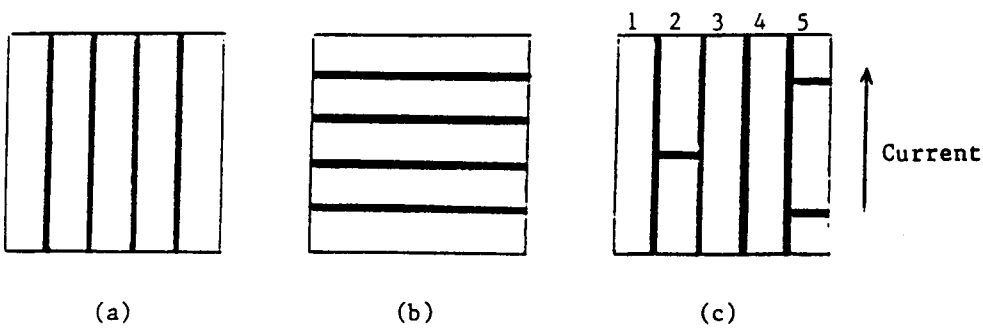


FIG. 3.
Electrical conduction model of in latex-modified cement paste. (a) Latex and cement phases in parallel. (b) Latex and cement phases in series. (c) Latex and cement phases partly in series and partly in parallel. Dark bands: latex phase. Remaining areas: cement phase.

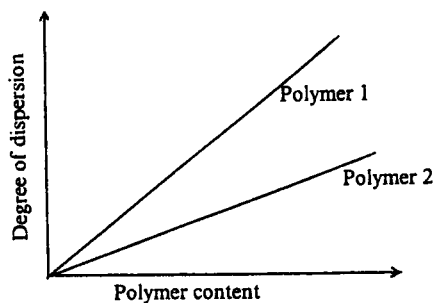


FIG. 4.

Schematic illustration of the effect of polymer species and content on the degree of dispersion (f) of polymer in cement paste.

$$\rho = \frac{\rho_c}{(1 - f)V_c} \quad (4)$$

The quantity f provides a description of the degree of dispersion of the latex phase.

The greater is f , the greater is the degree of dispersion, as illustrated in Fig. 4, where Polymer 1 has a higher degree of dispersion than Polymer 2 and, for a given polymer, f increases with the polymer content. The value of f is obtained from Eq. (4), if ρ , ρ_c and V_c are known. The

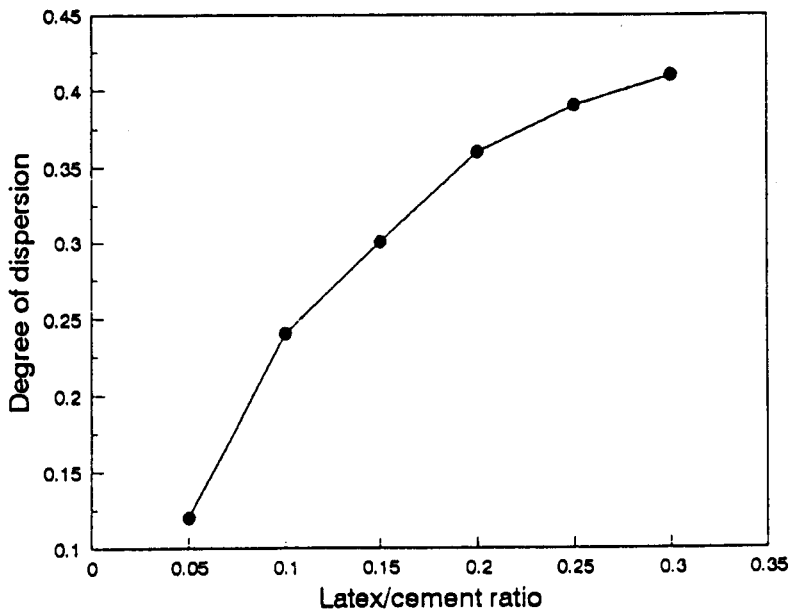


FIG. 5.

Degree of dispersion (f) of latex as a function of the latex/cement ratio.

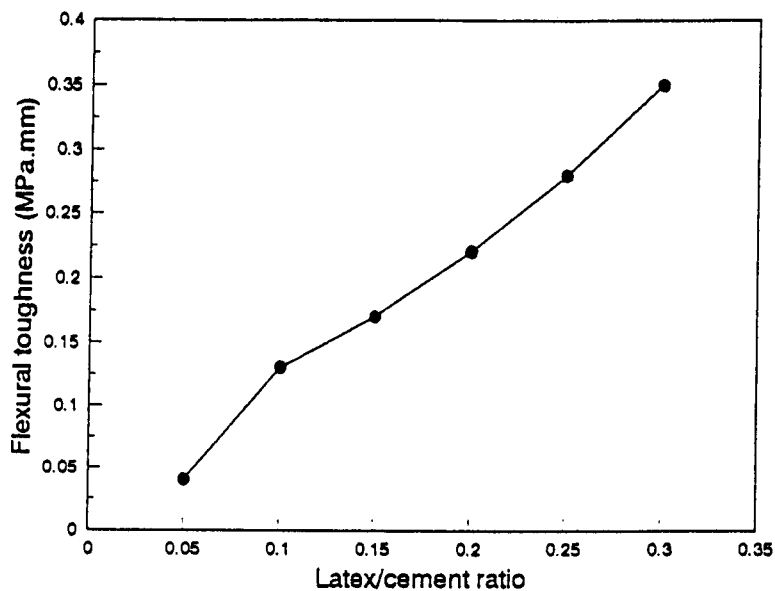


FIG. 6.

Effect of the latex/cement ratio on the flexural toughness.

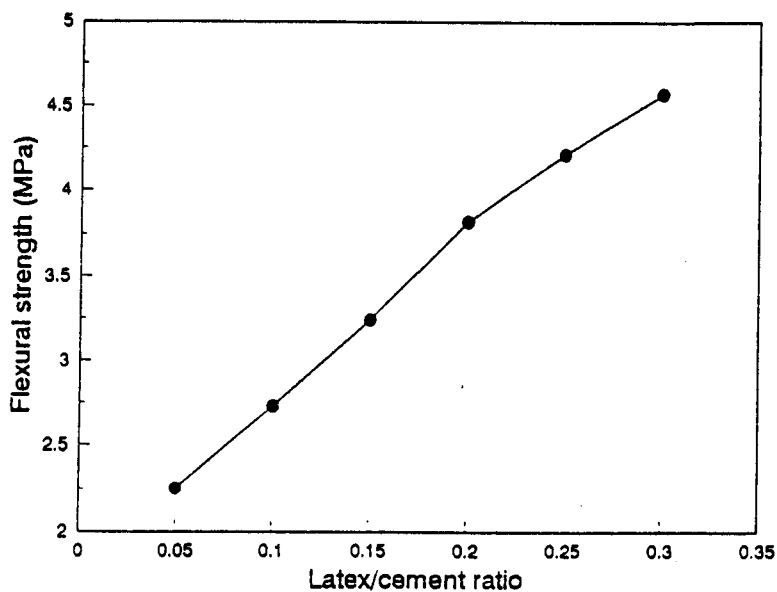


FIG. 7.

Effect of the latex/cement ratio on the flexural strength.

quantity V_c is obtained by deducting the latex volume fraction and void volume fraction (Table 1) from unity. The quantities ρ and ρ_c are measured (Fig. 2).

Fig. 5 gives the variation of f with the latex/cement ratio; f increases more rapidly with the latex/cement ratio at low values of this ratio than at high values of this ratio. This is because a high latex/cement ratio corresponds to a situation in which some of the sections of Fig. 3(c) (such as Section 5) have more than one horizontal band of latex. A section does not contribute to conduction as long as it has at least one band. Therefore, f underestimates the true degree of dispersion when the latex/cement ratio is high, particularly > 0.2 .

Fig. 6 shows that the flexural toughness increases with increasing latex/cement ratio. Fig. 7 shows that the flexural strength increases with increasing latex/cement ratio. The trends in Fig. 6 and 7 are roughly linear (not convex like the trend for f , Fig. 5). This is because f underestimates the degree of dispersion when the latex/cement ratio is high.

Conclusion

The degree of dispersion of latex particles in latex-modified cement paste was assessed by measurement of the volume electrical resistivity. The resistivity was modeled by considering the latex and cement phases to be partly in series and partly in parallel and by neglecting the conductivity of the latex phase compared to that of the cement paste. This assessment was best at low values of the latex-cement ratio; it underestimated the degree of latex dispersion at high values of the latex/cement ratio, especially > 0.2 .

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