of hydration of the silicate phases. The non-evaporable water is also believed to be an indication of the extent of cement hydration in the system.

The amount of CH and non-evaporable water were markedly reduced for the M-0.8% and M-1.5% specimens at 6 hours. This is consistent with the calorimetric results (Fig. 13a) and the electrical response (Fig. 2a and 3a) indicating retardation at increased PNS dosages during early hydration. After three days, the differences became generally insignificant (for each paste and mortar) with age. The smaller CH contents at 28 days for the mortar specimens could be a result of lime leaching upon immersion curing. It is noted in Table 3 that the hydration process appears to be little affected by the sand inclusions. Winslow and Liu (26) have reported that for mature specimens, the paste in the mortar was more porous than the corresponding plain paste.

CONCLUDING REMARKS

The effect of varying dosages of a PNS superplasticizer on the microstructure of a portland cement paste and on the microstructural and transition zone characteristics of a mortar was investigated, using AC impedance spectroscopy and other techniques. The impedance behavior of both cement paste and mortar systems was altered by the presence of the superplasticizer, implying that the use of superplasticizer has an influence on both the cement/sand interfacial region and the bulk paste component in the mortar. The transition zone was more porous at 4 hours for mortars with high dosage of superplasticizer because of the improved dispersion of cement particles and the set retarding effect. It was also established that the ionic concentration in the pore solution had a significant role in determining the electrical properties of the fresh mortar specimens but a markedly reduced effect when the specimens hardened. A greater electrical resistivity and larger high frequency arc was detected for all the superplasticized mortars after one-day hydration. This was attributed to the modification of the interfacial zone microstructure and density as well as in the pore structure and porosity of the bulk matrix due to presence of the superplasticizer. Results from mercury porosimetry, TGA and conduction calorimetry support this interpretation.

Interestingly, it was found that even a low dosage of PNS superplasticizer (0.1%, 0.3%) can change the impedance response, pore size distribution and porosity of hydrated cement systems. At higher PNS dosages, greater electrical resistance, lower total porosity and modified pore size distribution (relative to the control mortar and low-dosage mortars) were obtained. The dosage levels also appeared to influence the morphology of hydrates.

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TABLE 1—MIX PROPORTIONS (BY MASS).

Mixtures	Portland cement	Silica sand	Superplasticizer	Water
P-0%	1	0	0	0.35
P-0.1%	1	0	0.001	0.35
P-0.3%	1	0	0.003	0.35
P-0.8%	1	0	0.008	0.35
P-1.5%	1	0	0.015	0.35
M-0%	1	0.3	0	0.35
M-0.1%	1	0.3	0.001	0.35
M-0.3%	1	0.3	0.003	0.35
M-0.8%	1	0.3	0.008	0.35
M-1.5%	1	0.3	0.015	0.35

TABLE 2—POROSITY AND PORE SIZE DISTRIBUTION DATA OF MORTARS WITH VARYING DOSAGES OF PNS SUPERPLASTICIZER.

Mixtures	Overall porosity (vol. %)		Threshold pore diameter (nm)		Pore size distributions (vol. %)			
					> 50 nm		50 – 3.2 nm	
	1d	28d	1d	28d	1d	28d	1d	28d
M-0%	22.6	15.4	50.0	29.2	37.9	12.5	62.1	87.5
M-0.1%	22.1	14.6	38.9	25.0	37.5	12.5	62.5	87.5
M-0.3%	23.9	15.1	50.0	25.0	43.6	10.9	56.4	89.1
M-0.8%	20.9	13.8	38.9	25.0	22.9	10.6	77.1	89.4
M-1.5%	19.5	14.3	38.9	25.0	29.6	10.7	70.4	89.3

TABLE 3—$Ca(OH)_2$ AND NON-EVAPORABLE WATER CONTENTS DETERMINED BY TGA METHOD.

Mixtures	$Ca(OH)_2$ (%)						Non-evaporable water (%)					
	6h	1d	3d	7d	14d	28d	6h	1d	3d	7d	14d	28d
P-0%	2.5	9.2	12.7	13.2	13.7	13.1	6.1	11.1	14.9	13.6	14.0	13.9
P-0.1%	2.1	8.7	13.1	13.4	14.0	13.3	6.1	11.0	15.1	14.2	14.9	14.4
P-0.3%	2.0	9.0	13.0	13.2	13.4	14.0	5.5	12.4	14.8	14.7	14.3	15.1
P-0.8%	1.2	8.4	11.7	11.7	12.1	12.6	4.9	10.9	14.7	14.3	13.9	13.7
P-1.5%	1.4	6.7	11.2	11.1	11.4	12.0	4.8	10.7	15.1	14.5	14.3	14.8
M-0%	2.1	10.4	12.4	12.7	14.5	12.2	4.9	12.3	13.3	14.4	14.3	16.0
M-0.1%	2.4	9.9	12.6	13.1	14.9	13.4	4.6	12.3	13.8	14.2	14.4	15.8
M-0.3%	2.2	10.3	13.0	12.9	14.5	12.2	4.8	12.9	13.8	14.3	14.3	15.9
M-0.8%	1.4	9.8	11.8	12.2	14.0	12.1	4.0	12.5	13.7	14.1	15.1	15.9
M-1.5%	1.3	9.7	12.9	12.1	12.6	11.3	4.0	13.1	16.1	14.3	13.5	16.8

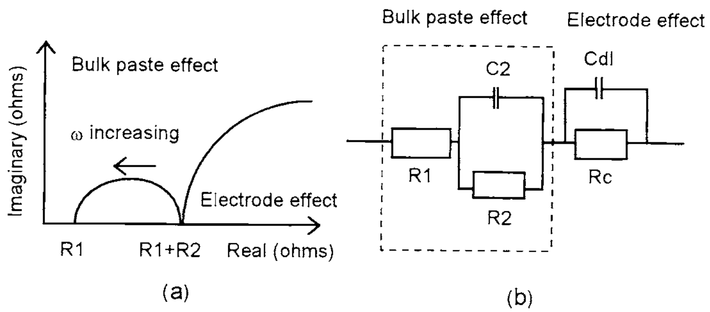

Fig. 1—(a) Schematic plot of an AC impedance spectrum in the real-imaginary complex plane for cement pastes; (b) equivalent electrical circuit model.

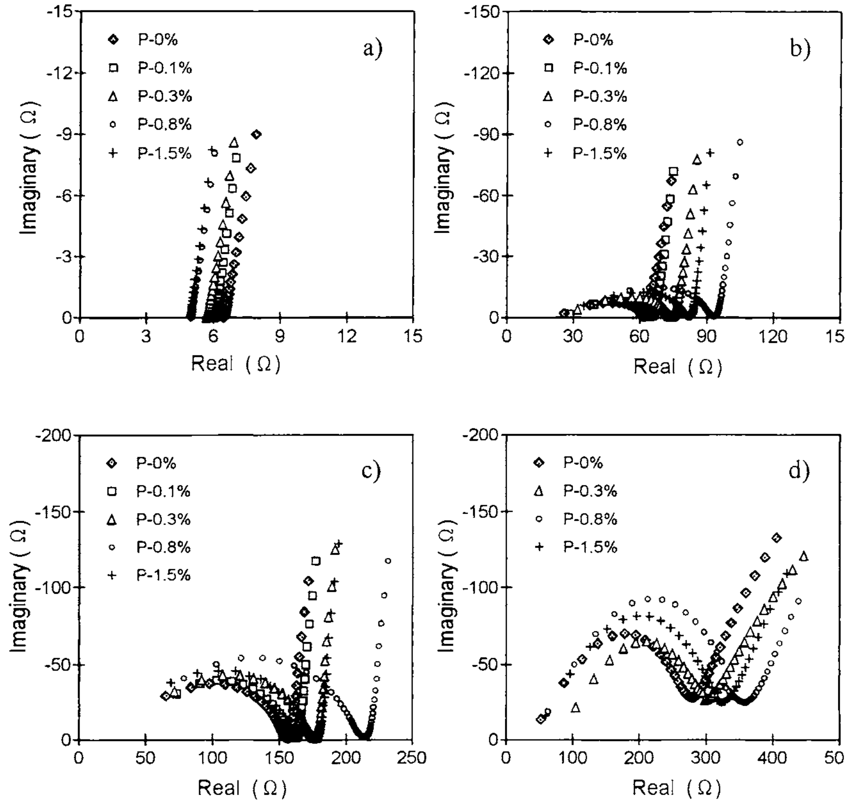

Fig. 2—AC impedance spectra of cement pastes prepared with and without PNS superplasticizer at various hydration times. *W/C* = 0.35. (a) 4 hours; (b) 1 day; (c) 28 days; (d) 120 days.

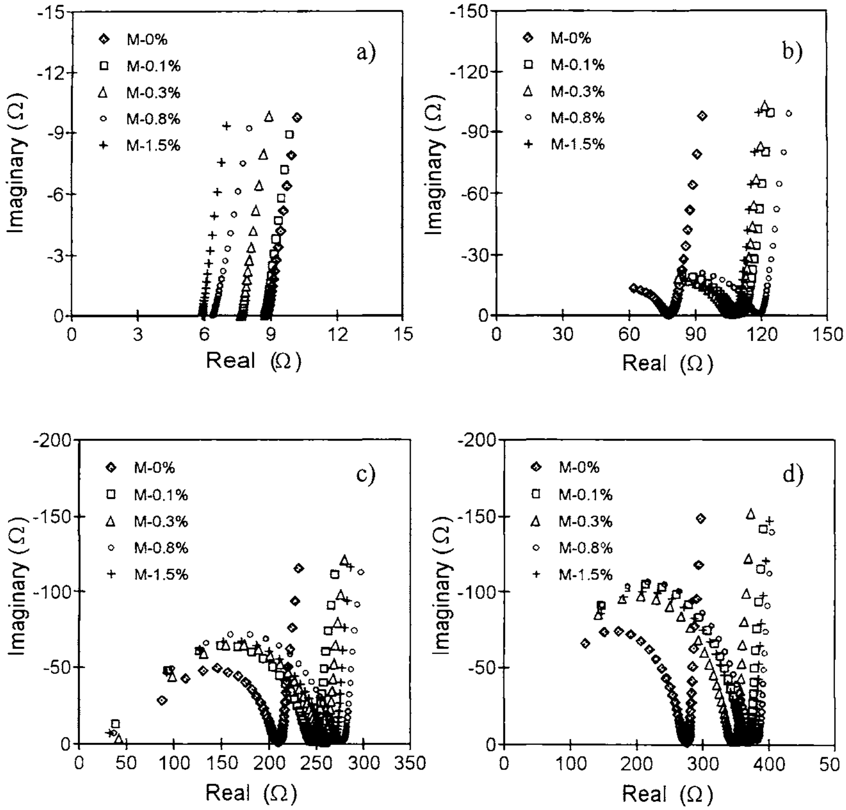

Fig. 3—AC impedance spectra of mortars prepared with and without PNS superplasticizer at various hydration times. *S/C* = 0.3, *W/C* = 0.35. (a) 4 hours; (b) 1 day; (c) 28 days; (d) 120 days.

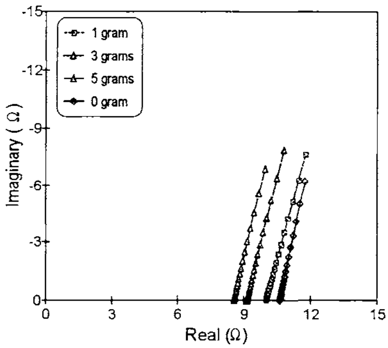

Fig. 4—AC impedance spectra of limewater with different PNS superplasticizer contents.

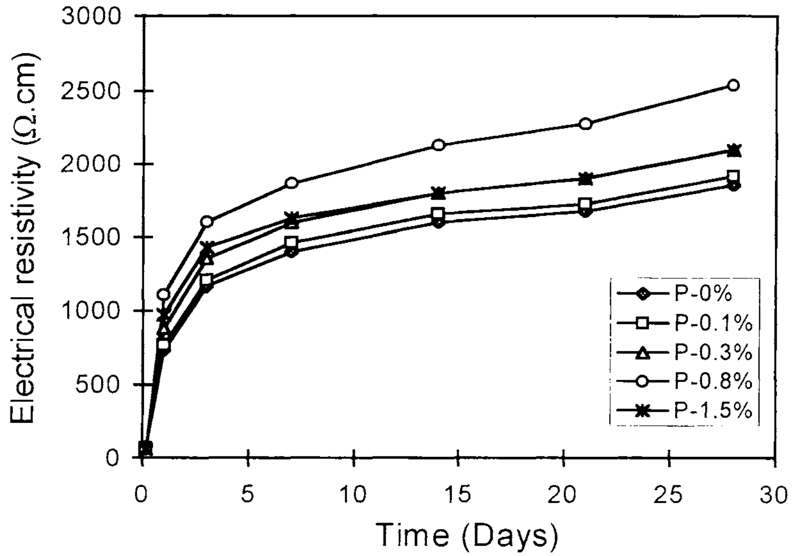

Fig. 5—Effect of PNS superplasticizer of varying dosages on electrical resistivity of cement pastes. *W/C* = 0.35.

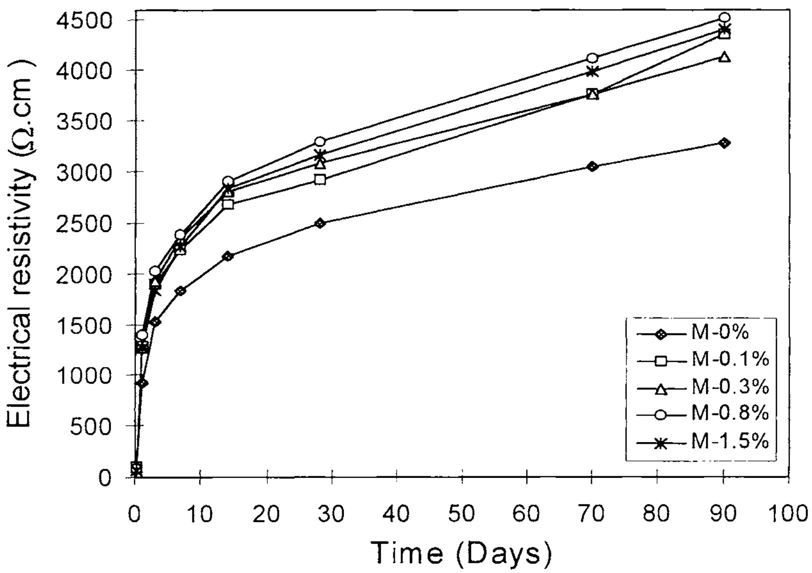

Fig. 6—Effect of PNS superplasticizer of varying dosages on electrical resistivity of mortars. *S/C* = 0.3, *W/C* = 0.35.

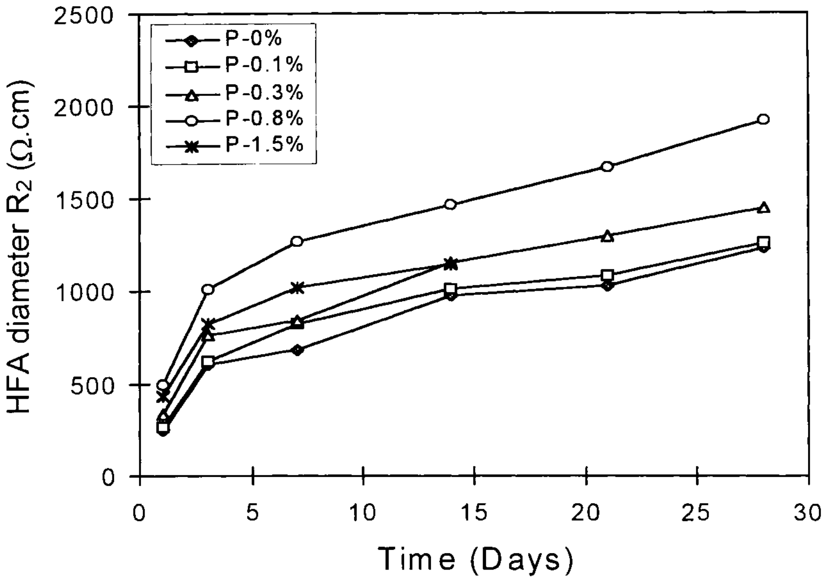

Fig. 7—Effect of PNS superplasticizer on high frequency arc (HFA) diameter, R_2 of cement pastes. *W/C* = 0.35.

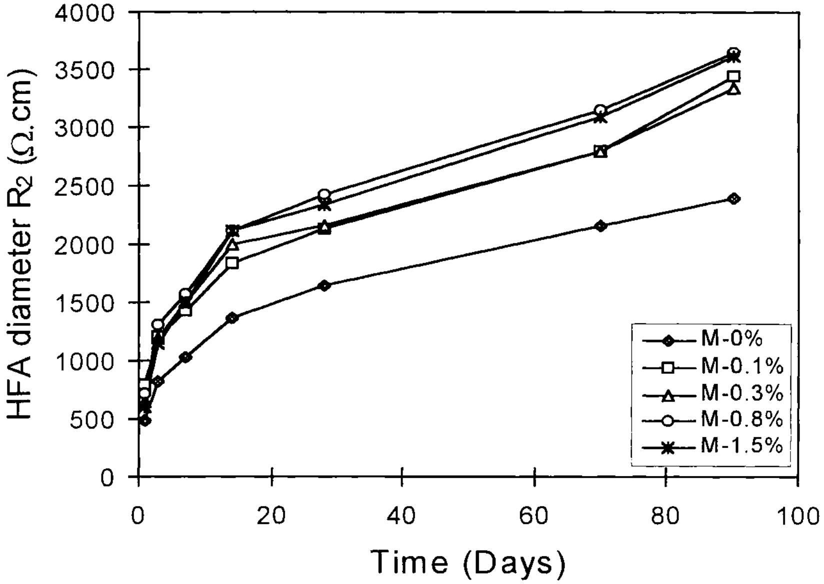

Fig. 8—Effect of PNS superplasticizer on high frequency arc (HFA) diameter, R_2 of mortars. *S/C* = 0.3, *W/C* = 0.35.

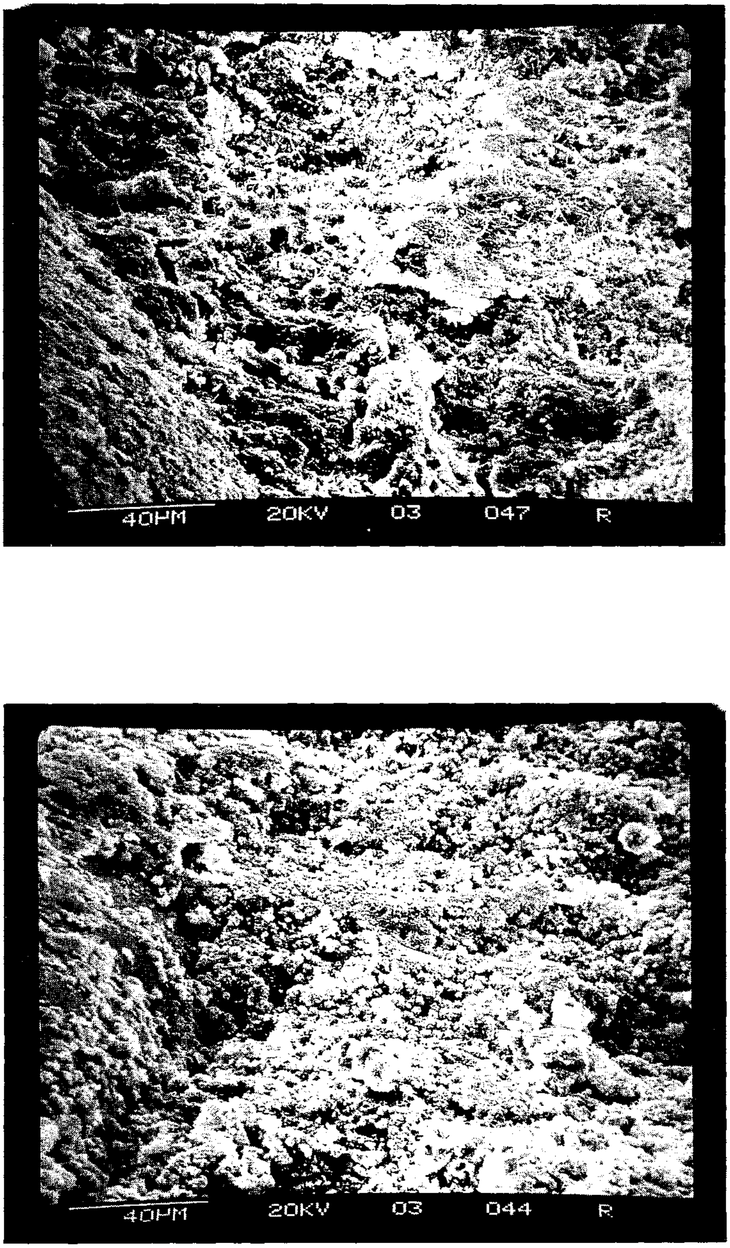

Fig. 9—Sand grain-paste interfacial zone of portland cement mortars at one day—top: 0.8 percent PNS superplasticizer; bottom: without superplasticizer.

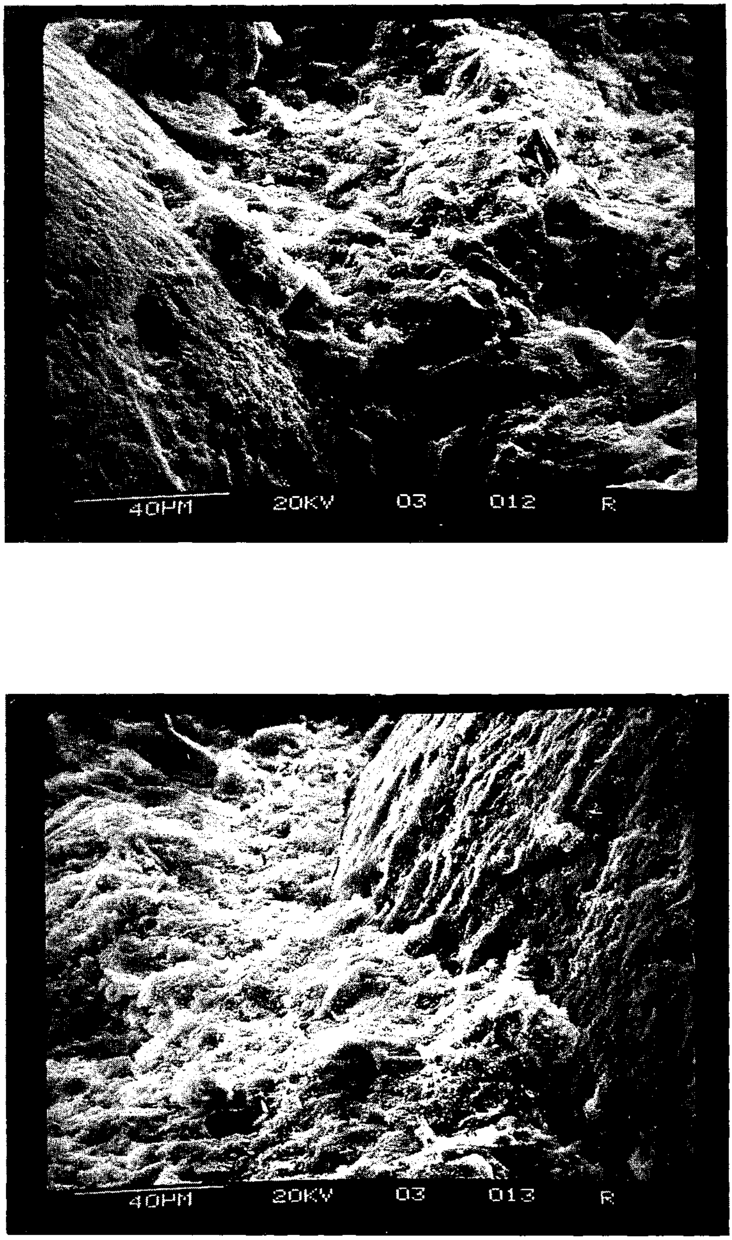

Fig. 10—Sand grain-paste interfacial zone of portland cement mortars at 28 days—top: 0.8 percent PNS superplasticizer; bottom: without superplasticizer.