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SPATIAL DISTRIBUTION OF MECHANICAL AND ELECTRICAL PROPERTIES OF CEMENT MORTAR PRIOR TO LOADING

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ABSTRACT

The hardness was found to be lower (by ∼10 in Rockwell H scale) and the volume electrical resistivity was found to be higher (about doubled) at the edge (up to a depth of ∼5 cm for curing at 100% relative humidity) than at the center of a cement mortar specimen prior to loading. This is attributed to the faster drying at the edge and the resulting poorer bond between cement paste and sand at the edge than the center. © *1998 Elsevier Science Ltd*

Introduction

Although much work has been conducted by numerous workers for decades concerning the properties of concrete or cement mortar before and after loading, much less attention has been given to the spatial distribution of the properties, i.e., how a property varies within a single piece of concrete or mortar. For the purpose of detecting damage in a concrete structure after loading or aging, the spatial distribution of the elastic modulus and of the electromagnetic, acoustic, and thermal behavior has been previously measured in a macroscopic scale (e.g., meter scale) (1–10). However, little attention has been given to the spatial distribution of a property prior to loading, especially in a less macroscopic scale (e.g., cm or mm scale) that reflects the material behavior. In this paper, we report on the spatial distribution of the mechanical and electrical properties of mortar prior to loading. Information on the spatial distribution is fundamental to the study of concrete properties and is technologically useful to the design of concrete structural components.

Experimental Methods

The cement used for mortar specimens was Portland cement (Type I) from Lafarge Corp. (Southfield, MI). Natural sand was used as the fine aggregate (all passing #4 US sieve, 99.9% SiO_2). The sand/cement ratio was 1.0. The water/cement ratio was 0.45 unless noted otherwise. Cement, sand, and water were mixed in a Hobart mixer for 5 min. After pouring

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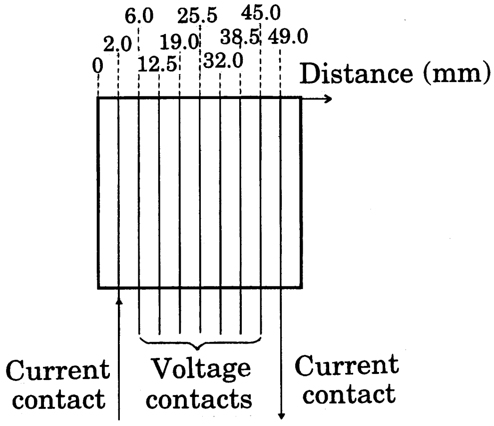

FIG. 1.
Specimen configuration for measuring the horizontal resistivity and its distribution in the horizontal direction. All distances are in mm.

the mix into oiled molds of size 2 in. × 2 in. × 2 in. (51 mm × 51 mm × 51 mm) or size 160 mm × 40 mm × 40 mm, a vibrator was used to decrease the amount of air bubbles. The specimens were demolded after 1 day and then allowed to cure in a moist room (humidity 100%) for 28 days.

The DC volume electrical resistivity distribution was determined by using the four-probe method (unless noted otherwise), using silver paint in conjunction with copper wires as electrical contacts and using a Keithley 2002 multimeter. In this method, the outer two probes were for passing the current, while the inner two probes were for voltage measurement.

In order to measure the resistivity in the horizontal direction and determine its spatial variation in the horizontal direction, nine electrical contacts were made on a mortar cube, such that each contact was around the whole perimeter of the cube in the plane perpendicular to the direction of resistivity measurement, as illustrated in Figure 1. The

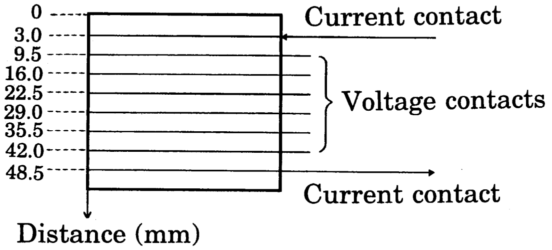

FIG. 2.
Specimen configuration for measuring the vertical resistivity and its distribution in the vertical direction. All distances are in mm.

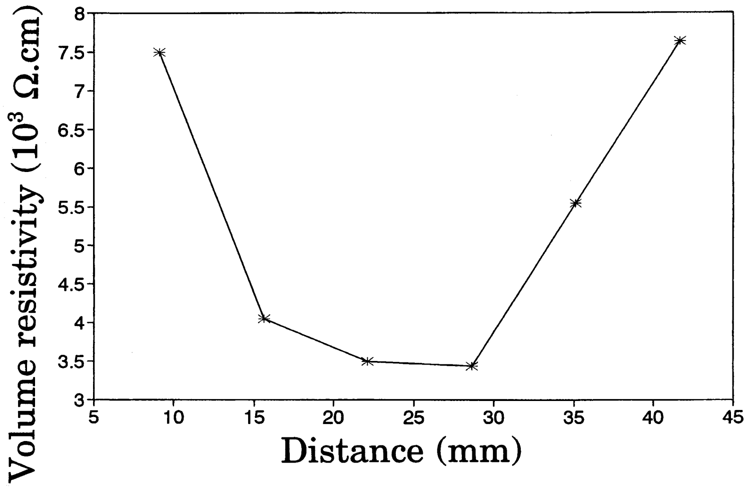

FIG. 3.
Resistivity distribution in the horizontal direction of a 2 × 2 × 2 in. mortar cube, measured by the four-probe method.

outermost two contacts were for passing current. All the remaining contacts were successively used in pairs as voltage contacts. For example, by using the second and third contacts as voltage contacts, the resistance between these two contacts was measured; by using the third and fourth contacts as voltage contacts, the resistance between these two

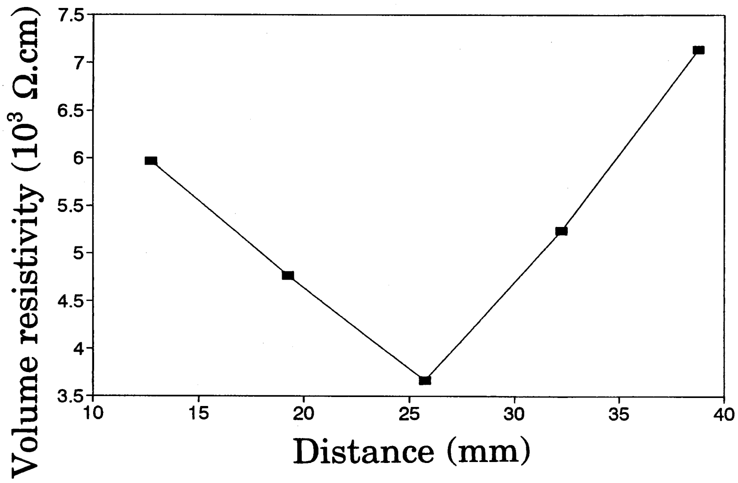

FIG. 4.
Resistivity distribution in the vertical direction of a 2 × 2 × 2 in. mortar cube, measured by the four-probe method.

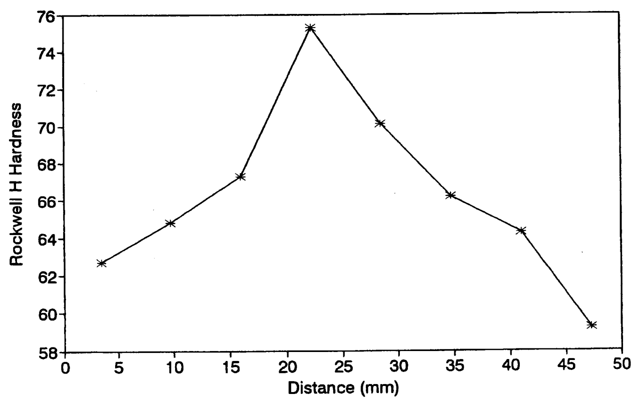

FIG. 5.
Hardness distribution in the horizontal direction of a 2 × 2 × 2 in. mortar cube.

contacts was measured. The nine contacts allowed the resistivity to be measured at six points along the horizontal direction.

In order to measure the resistivity in the vertical direction and determine its spatial variation in the vertical direction, eight electrical contacts were made on a mortar cube, such that each contact was around the whole perimeter of the cube in the plane perpendicular to the direction of resistivity measurement, as illustrated in Figure 2. The outermost two contacts were for passing current. All the remaining contacts were successively used in pairs as voltage contacts. The eight contacts allowed the resistivity to be measured at five points along the vertical direction.

To further support the results obtained by the four-probe method; the two-probe method was also used. In this method, each of two probes was both for passing the current and for measuring voltage. The resistivity of any portion of the mortar was measured by applying the

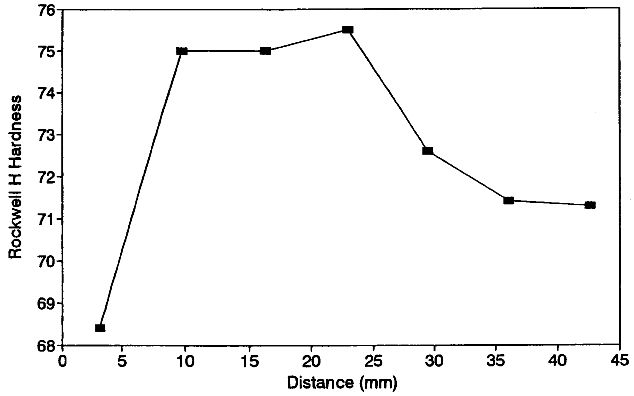

FIG. 6.
Hardness distribution in the vertical direction of a 2 × 2 × 2 in. mortar cube.

two probes to that portion. The configuration for the electrical contacts was similar to Figure 1, except that there was no distinction between current and voltage contacts. The contacts were successively used in pairs in order to measure the resistivity distribution in the horizontal direction.

Hardness testing (Rockwell H scale, i.e., indentor being 1/8 in. steel ball at 60 kg load) was performed at points along a straight line parallel to an edge of a 2 in. $\times$ 2 in. $\times$ 2 in. mortar cube, such that the line was in the middle of the middle plane, which was exposed by cutting the cube in half.

The mechanical and electrical property distributions were measured for at least three specimens of each configuration. The results for each configuration were found to be consistent. Although the results presented in this paper are for one specimen for each configuration, the results are reproducible in general.

Results and Discussion

Figures 3 and 4 show the resistivity distribution of 2 $\times$ 2 $\times$ 2 in. specimens in the horizontal and vertical directions, respectively. In both directions, the resistivity was lower at the center than at the edges. The difference in resistivity between center and edge was large; the resistivity at the edge was about double that at the center. As the resistivity of mortar increases by only 63% when the curing time increases from 1 to 28 days (11) and the extent of cure (at 100% humidity) is either the same at the center and edge of the cube or slightly higher at the center than the edge, the results in Figure 1 and 2 cannot be explained by a difference in the extent of cure between the center and the edge of a cube.

The resistivity distribution of a 2 $\times$ 2 $\times$ 2 in. specimen in the horizontal direction, as measured by the two-probe method, has the same shape as that obtained by the four-probe method (Fig. 3), though the absolute resistivity values are much higher.

The resistivity distribution of a 160 $\times$ 40 $\times$ 40 mm mortar bar (water/cement ratio = 0.32) in the horizontal (160 mm long) direction, as measured by the two-probe method, is similar to that for a cubic specimen, except that there is a 60 mm long region at the center of the bar where the resistivity is uniform. Thus, the increase in resistivity from the center to the edge is an edge effect, which affects the mortar up to 50 mm from the edge.

Figures 5 and 6 show the hardness distribution at the mid-plane of 2 $\times$ 2 $\times$ 2 in. mortar cubes in the horizontal and vertical directions respectively. The hardness was higher at the center than the edge (whichever edge) of the cube.

The increase in resistivity from center to edge is too large to be accounted for by the residual stress resulting from a difference in drying shrinkage rate between the center and the edge. It is also too large to be accounted for by a difference in void or microcrack content between the center and edge. We attribute this to the faster drying at the edge than the center and the resulting poorer bond between cement paste and sand at the edge than the center. A poorer bond is associated with a higher contact electrical resistivity. This explanation is supported by the observation that the hardness is lower at the edge than the center. The depth of penetration of this edge effect is $\sim$5 cm for the case of curing at 100% relative humidity. At a lower humidity, the difference in property between edge and center is expected to be larger than those reported here.

Conclusion

The hardness was found to be lower and the volume electrical resistivity was found to be higher at the edge (up to a depth of ~5 cm for the case of curing at 100% relative humidity) than the center of a mortar specimen. This is attributed to the faster drying at the edge and the resulting poorer bond between cement paste and sand at the edge than the center.

References

1. M.P. Luong, ASME-ASCE-SES Joint Summer Meeting, pp. 199–213, ASCE, New York, 1997.
2. O. Buyukozturk and H.C. Rhim, Constr. Build. Mater. 11, 195–198 (1997).
3. P. Mallinson, Insight-non-Destructive Testing & Condition Monitoring 39(12), 874–877 (1997).
4. S.W. Hearn and C.K. Shield, ACI Mater. J. 94, 510–519 (1997).
5. D. Tarchi, E. Ohlmer, and A. Sieber, Nondestructive Evaluation 9, 213–225 (1997).
6. V. Vavilov, T. Kauppinen, and E. Grinzato, Research in Nondestructive Evaluation 9, 181–200 (1997).
7. M. Sansalone, ACI Struct. J. 94, 777–786 (1997).
8. W. Uddin and F. Najafi, Proc. Speciality Conf. Infrastructure Condition Assessment: Art, Science, Practice, pp. 524–533, ASCE, New York, 1997.
9. D.J. Transue, K.L. Rens, and M.P. Schuller, Proc. Speciality Conf. Infrastructure Condition Assessment: Art, Science, Practice, pp. 415–424, ASCE, New York, 1997.
10. S.K. Park and T. Uomoto, Insight-non-Destructive Testing & Condition Monitoring 39(7), 488–492 (1997).
11. X. Fu and D.D.L. Chung, Cem. Concr. Res. 25, 689–694 (1995).