Dielectric measurement and modeling of cementitious composite panels using a coaxial probe

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ABSTRACT

Dielectric properties of construction materials have become a valuable information in the condition assessment of civil infrastructure using microwave and radar nondestructive evaluation (NDE) techniques and sensors. Multi-phase dielectrics are usually encountered when structures are made of cementitious composites (e.g., Portland cement). In this paper, the dielectric dispersion of cement paste panels in the frequency range of 0.5 GHz and 4.5 GHz is studied. Cement paste panels of various water-to-cement (w/c) ratios (0.35, 0.40, 0.45, 0.50) were manufactured and their relative complex permittivity (dielectric constant and loss factor) was measured by a coaxial probe in room temperature (77°F). Contact dielectric measurements were collected at different locations on each panel to study the dielectric heterogeneity of the cement paste panels. The relaxation time in Debye's model was calculated for each panel. It is found that the measured relative complex permittivity varies even within one cement paste panel. The measured relative complex permittivity decreases with the increasing w/c ratio, both the real (dielectric constant) and imaginary (loss factor) parts.

Keywords:

1. INTRODUCTION

The complex permittivity of cement paste depends on many factors such as curing time, w/c ratio, relative humidity. The cement paste has a heterogenic structure that consists of hydrated cement, and voids which are partially filled with water and air. This heterogenic property of cement paste makes it very challenging to measure the dielectric properties especially when contact measurements are used to determine it. Point readings on the surface of the panels do not represent the whole panel, so more than a few measurements are required to observe the panels. By increasing the number of measured spots on a panel, statistically a more reliable average value is obtained which represents the overall property of the panel.

In this paper we discuss the reliability of measured complex permittivity of cement paste panels using contact measurements, and the effect of using different frequencies and w/c ratios panels to the reliability of the measurements.

2. REVIEW

Several radar NDT techniques for assesing the condition of cementitious specimens.[1] The dielectric properties of cement paste has been studied by many researches with different methods. El Hafiane et al.(1999)[2] used cement paste samples with 0.4 w/c ratio, and the measurements were collected after 10 hours of curing time, up to 8 hours after curing. The frequency range was from 1 MHz to 1.8 GHz. Relaxation time has been calculated at early stages of hydration process. El Haffiane et al. (2000)[3] also used aluminous cement paste and conducted the experiments within 10 Hz - 1GHz frequency range. Al-Qadi et al. (1995)[4] used a parallel plate capacitor setup for dielectric measurements of portland cement concrete. The complex permittivity have been measured over 28 days of moist curing within 0.1 - 40 MHz. The decrease of dielectric constant over frequency and curing time has been shown. Wen and Ching (2002)[5] used carbon filaments and steel fibers as stress sensors embedded in cement paste to relate the dielectric constant with stress level. Hu et al (1999)[6] studied the variation of dielectric

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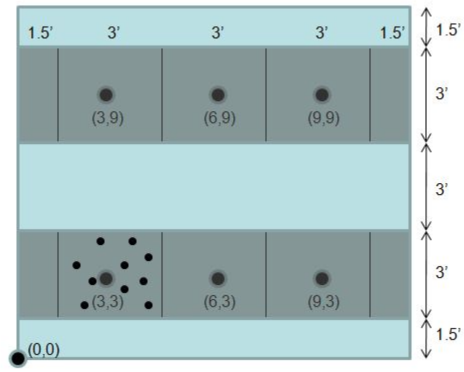

Figure 1. 60 readings have been collected from 6 different regions of the panel surface.

constant of cement densified with small particles from 0 to 93 % relative humidity. The variation is modeled within 1 MHz to 1 GHz frequency. Miura et al. (1997)[7] conducted microwave dielectric relaxation measurements via the time-domain reflectrometry method on portland cement paste. The relaxation process due to hydrated water in the cement paste structure has been observed at frequencies of 100 MHz and 1 MHz because of different orientation of water. Mubarak et al. (2001)[8] used Monopole probe to estimate the w/c ratio of fresh portland cement based materials at 3 GHz frequency. Using other methods, different w/c ratios, curing times, humidity and frequency range more research have been conducted by many groups.[9–12]

3. EXPERIMENTAL SETUP

The measurements were carried out between 0.1 GHz and 4.5 GHz with E5071C Agilent Technologies ENA Series Network Analyzer. Coaxial Performance Probe apparatus have been used for measurements. Since contact method have been used, a perfect contact between the specimen and the probe is necessary. The required smooth surface has been obtained during the casting procedure of the samples. The inner surface of the molds have been covered with flexi glass which provides a very smooth surface. The dimensions of the samples that have been used for the experiments are 1 in. by 1 ft. by 1 ft. Cement paste samples have been used which has only water and cement in the mixture (no sand or aggregates). Four different water to cement ratios (w/c = 0.35, 0.40, 0.45, 0.50) have been measured during the experiment. After casting the specimens, they have been held in room conditions for one day within the molds and then removed from the molds. The panels have been cured in water for seven days. After the curing process, the panels are kept in room conditions 3 months before the measurements.

The measurements are collected from six main regions of a panel with the shown coordinate locations on each region (Figure 1). 10 measurements are collected randomly from each region which adds up to 60 measurements for one panel.

4. DATA ANALYSIS AND INTERPRETATION

As seen on Figure 2 both the dielectric constant and the loss factor decrease as the w/c ratio increases. This is due to the higher void ratio in the panels with high w/c ratio. But the void ratio is not the same for every section in a single panel. This heterogenic structure of cement paste results in different dielectric constant values at different points of the same panel. The values shown on Figure 1 are the average values of 60 measurements for each panel. Statistically, we have calculated that the average value of 60 measurements have an error less than 3 % with 95 % confidence level.

With more measurements on a panel a more reliable dielectric constant is obtained. In Figure 3 a simulation is run which selects the 60 measurements randomly at 2 GHz frequency. As the number of data set increases the average value of the selected data converges to the average value of 60 measurements. When other simulations are run similar trends are observed. To see the relation between the error and the number of measurements more

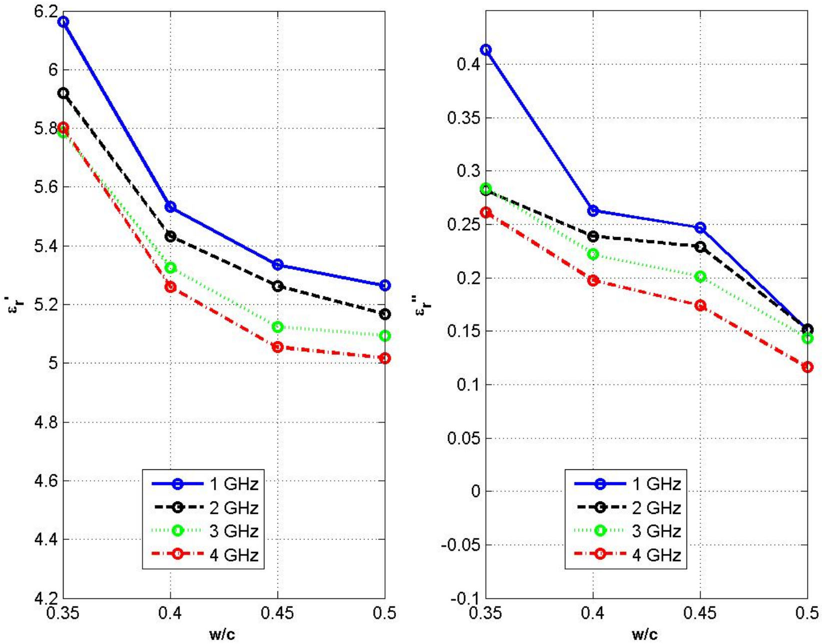

Figure 2. As the frequency of the measurements increases, a decrease in both the dielectric constant and loss factor is observed. Also as the w/c ratio increases, the dielectric constant and loss factor decrease.

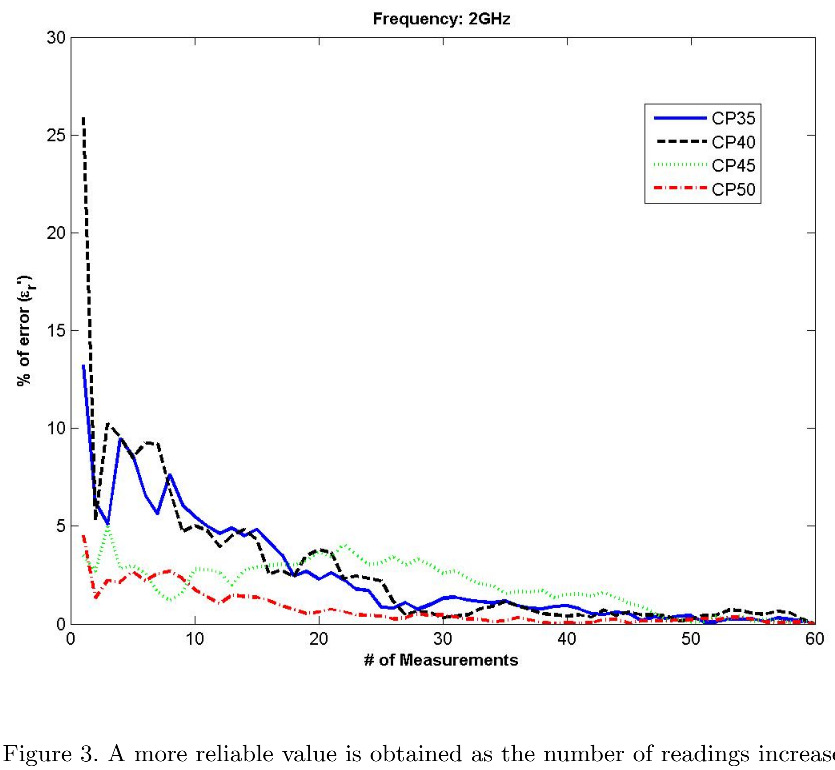

Figure 3. A more reliable value is obtained as the number of readings increase.

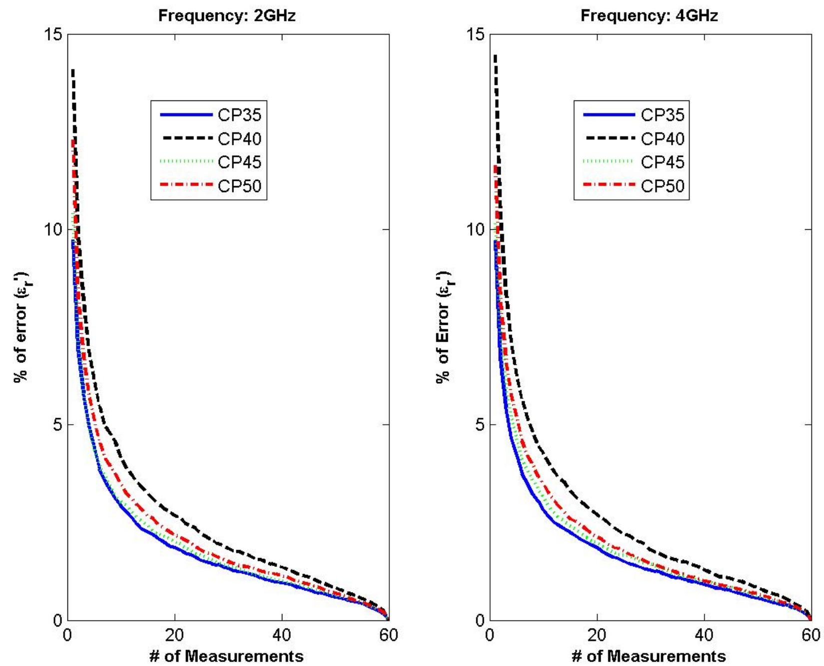

Figure 4. The average of 1000 random simulations are obtained at different frequencies (2 GHz and 4 GHz). The percentage of error is independant of the measurement frequency.

clearly Monte Carlo simulations have been used. A simulation such as the one used in Figure 3 has been run 1000 times and their average is obtained. The results are shown in Figure 4.

This way a smoother curve is obtained. We have also compared the results of measurements at 2 GHz with 4 GHz frequency (Figure 4), and we have seen that the reliability of the data is independent of the frequency used for the measurements. Also the error levels are very close to each other for different w/c ratios. So while we were modeling the relation we have used the average of four different w/c ratio cement paste panels at 2 GHz frequency.

Using power equation fit the relation between the number of measurements and the percentage of error is modeled. The model fits fine to the measured data as seen in Figure 5. The calculated coefficients are shown below where y is the percentage of error, and x is the number of measurements.

$y = a/timesx^b + c$

Coefficients; a = 12.8100, b = - 0.3214, c = - 3.029

5. SUMMARY

Dielectric constant of cement paste panels have been calculated using coaxial contact probe. It has been shown that a single measurement is not enough to approximate the dielectric constant of cement paste. The relation between the error and number of measurements is modeled using power equation. The required number of measurements can be found for desired error percentage using the model. The frequency of the measurement and w/c ratio of the cement paste being measured has very little effect on the reliability of the measurements, so can be neglected.

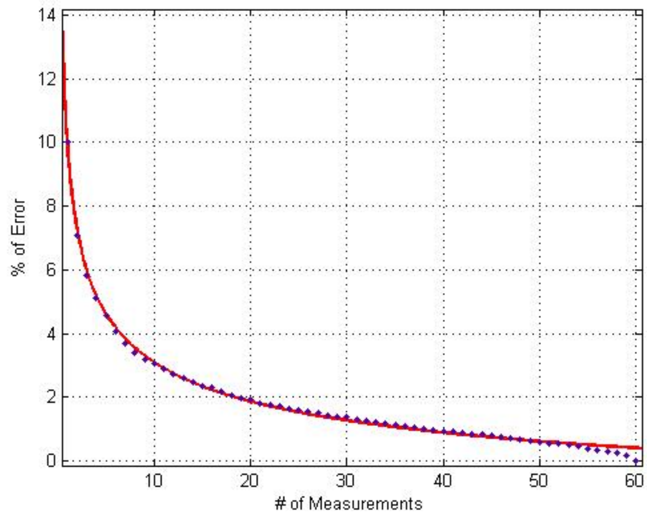

Figure 5. The relation between the percentage of error and the number of readings is modelled using power equation.

6. ACKNOWLEDGMENTS

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