Nondestructive Monitoring Technique Based on Electrical Resistivity for Moisture Condition in Containment Structures

M. Shekarchi[1], G. Debicki[2], Y. Billard[2] and R. Briot[3]

1) University of Tehran, Iran
2) Insa de Lyon, URGC Structures, France
3) Insa de Lyon, Génie Electrique et Ferroélectricité, France

ABSTRACT

In present study, the variation of electrical resistance of material with water content was used to obtain the variation of water content throughout the tests. In doing so, water content measurements were performed by embedded electrical resistance water meters. These consist of a autoclaved mortar cube containing two stainless steel drill plates. These meters permit to obtain locally water content measurement and its variation with time. Test results showed that this method can be used in the case of study of heat and mass transfer in concrete, especially to detect the plugging the pores by the liquid phase during testing. This method has been used in order to assess the leaktightness integrity of containment wall.

INTRODUCTION

Water content in concrete is closely related to the development of the strength of concrete, progress of shrinkage and creep in concrete and carbonatation of concrete. Moisture in concrete also influences durability such as the corrosion of reinforcing bars, deterioration due to freezing and thawing action and the progress of alkali-aggregate reaction. Thermal behaviour of concrete depends strongly to moisture condition of concrete [1,2]. In the case of study of leak tightness integrity of the reactor containment wall susceptible to accident conditions, the knowledge of water containing in the capillary pores and its variation with time permits to detect the plugging the pores by the liquid phase, which leads to improve the leak tightness integrity of containment wall. Moreover, pore pressure and temperature distributions are effected by moisture propagation [3]. Accordingly, the assessment of the water will lead to provide useful information for elucidating mechanism of those phenomena.

The assessment of the free water variation with time while the specimen is under test requires essentially the use of a non destructive technique, since all destructive methods involve the removal of a sample of the concrete. The measurements made by several different non-destructive techniques as Neutron Probe, Microwave Method and Infrared Process have been reported by workers [4, 5]. But the use of some technique as Neutron Probe is expensive, requires radio protection and it is not suitable for continuously measurements. Two others (Microwave Method and Infrared Process) being without contact methods, give only the water content of surface of specimen.

Another non-destructive method is the use of electrical properties of material. The application of electrical properties of material to studies of cement paste microstructure has been increased in recent years. These studies have been based on interpretations relating electric properties as resistance, capacitance and dielectric constants to the pore structure of the material. Topics have been included such diverse applications as cement setting time [6], hydration degree, dry-rewetting of cement paste [7], developing micro structure of fresh and hardened concrete [8], mechanical properties [9], and water content in concrete [10, 11, 12].

ELECTRICAL CONDUCTION THROUGH CONCRETE

In order to relate material properties to electrical measurements some investigators used impedance method and two type of approaches have been proposed:

1. The assembly of concrete + electrodes has been presented by Fig. 1 [13].. By drawing complex impedance diagram, there exists a frequency for which the electrode effects (Re, Ce) and bulk polarisation effect (Cb) are eliminated. Ri thus obtained is the true resistance for concrete alone.
2. The microstructure of material as a heterogeneous medium is considered as being composed of three main components [8], a) Solid particles surrounded by an ion atmosphere behaving as integral units b) Solid particles in contact with each other c) Pore spaces mostly filled with water containing dissolved compounds. When a voltage is applied to such a system (Fig. 2), the conduction of electrical current through material can be conducted along three possible paths: solid-liquid (a), solid-solid (b) and liquid (c).

The impedance of these circuit elements are determined by the geometrical parameters (a, b, c and d), representing the fractional cross-sections of paths and by the dielectric constants. The results of this method including a proportion of path in function of age of cement permit to obtain information during the cement hydration process.

The use of impedance method is mostly essential in the case of hydration process study of fresh concrete. In this present study, the major finding is that the resistance measurement of material in an C&R parallel equivalent circuit could give an good means of determining moisture propagation in concrete exposed to accident conditions (high temperature and vapour pressure), provided that moisture meter cast in concrete is autoclaved and stabilised. The variation of resistance measurement thus obtained depends mostly to moisture content evolution than solid structure [10, 14].

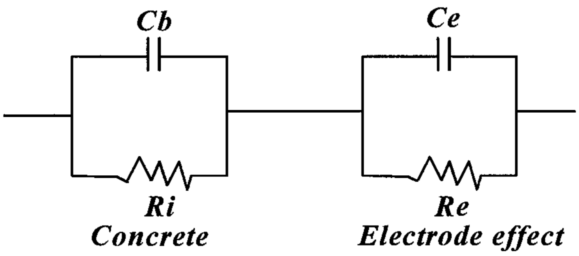

Fig. 1 Assembly Concrete+Electrode [13]

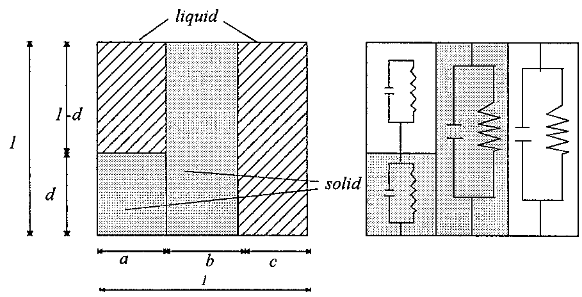

Fig. 2 Model of current paths [8]

A MOISTURE METER

Moisture meter consists of mortar cub (25x20x20 mm) containing two stainless steel drills plates (Fig. 3). The mortar mixture proportion has been designed in such a way that gives the same adsorption kinetic as testing concrete. It permits to assure a close link of the equilibrium humidity between moisture meter and concrete specimen during the tests. It should be noticed that hydraulic equilibrium between moisture meter and concrete during testing is translated by the similar relative humidity of two materials (mortar and concrete), however water content of material depends on pore distribution and especially the accessible pores to water of each material.

The meters were cast in a batch. Following removal from the moulds, moisture meters have been stored in lime water for six days. After this period they were autoclaved in saturated steam at 200°C and P=15MP for 48 hours. By DRX Analysis it was found that autoclaving permits to accelerate hydration reactions and stabilise pore structure. By this means, ageing effects and material decomposition due to high temperature were minimised. Electrical resistance was measured with an LCR Meters (SR715 Standard Research System). The test conditions were as following: Drive voltage: 1.0 Vrms, Test frequency: 1KHz, Measurement mode: C&R, Equivalent Circuit: parallel. In fact this circuit is a simplified one of circuit shown by Fig. 1, where electrode effects are eliminated using a small amplitude alternating current. The variation of capacitance element representing bulk polarisation was relatively low comparing to resistance one.

After autoclaving, weight and resistance were measured and moisture meters whose resistance varied greatly from the average were rejected outright. It should be noticed that electrical resistances were made also for 100KHz and it was found that at 100Hz electrical resistance was higher than one for 1KHz.

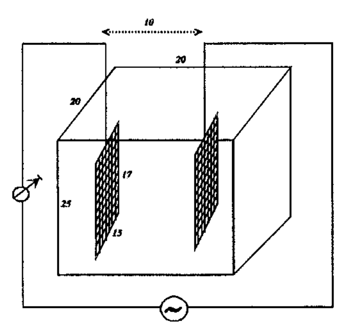

Fig. 3 Moisture meter SDB (Shekarchi, Debicki, Billard) [2]
(Dimensions in mm)

MOISTURE METER CALIBRATION TESTS

The resistance of moisture meter is connected with: the free water content of the mortar (released at 105°C), the temperature and the age of meter. So, three calibration tests were required. Furthermore, to determine concrete moisture in concrete specimen, a ratio between the water content in concrete and the water content in the moisture meter was evaluated.

Humidity Calibration Test

Due to electrical conduction from solution in electrical system of material, electrical resistance decreases for high water content and increases considerably in the case of dry material. The first calibration test was made to establish the relationship between the resistance of the meter and its water content at 20°C. The water content of autoclaved meters were obtained by drying them at 105°C (for 4 days). The meters were then stored in lime water until they ceased to adsorb any water. They were then left to stand in the laboratory at 20°C, their weights and resistances were made at intervals that varied from 3 hours at first to 12 hours at the end of the test, which ended when they stopped losing weight (after 12days). The results of the moisture meters of one batch are shown in Table 1 and Fig. 4. Basing these results, following relationship between water content and resistance could be obtained:

$$W = a - b.\exp(-c.R_{20}^{d})$$

This continuously curve gives the best fitting for each moisture meter, as well as for all the meters from one batch. The values of the constants a, b, c and d, experimentally obtained change slightly from one batch to another.

Table 1 Values of electrical resistances during the drying for a moisture meter

Stage	R20(KOhms)	W(%)
After autoclaving	**0.354**	**9.537**
After re-saturation	0.726	9.300
Drying at 20°C	2.058	7.856
"	3.049	6.707
"	3.889	5.864
"	4.944	5.232
"	12.087	3.641
"	21.490	3.051
"	31.980	2.735
"	36.960	2.629
"	44.800	2.534
"	66.360	2.366
"	81.040	2.308
"	108.760	2.266
"	116.370	2.234
"	181.330	2.176
"	192.530	2.171
"	536.600	1.876
"	625.000	1.844
"	788.500	1.786
End of drying at 20°C	981.400	1.776
After drying at 105°C (measured at T=20°C)	**300000**	**≈ 0**

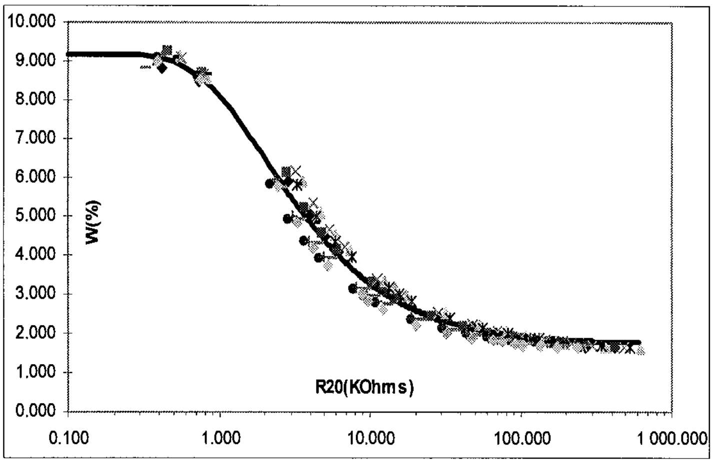

Fig. 4: Humidity calibration test

Temperature Calibration Test

The possibility of the large effect of temperature on the resistance measurements has already been mentioned [15]. The second calibration test that was made was to establish the relationship between resistance of a meter and its temperature. One meter from each batch having Resistance-Water content curve near to average curve of all meters was selected. To ensure that moisture content of material was maintained during the experiment, moisture meter was cast into a cylindrical concrete (D=75 and H=94mm), this was placed inside a steel envelope (D=81 and H=100mm) 10mm thick. The injection of silicon rubber compound of 3-mm thickness between this metallic envelope and the concrete insures the leak tightness.

The specimen containing moisture meter was then placed in an oven and temperature increased up to 200°C (7.5°C/hr) and then decreased back to room temperature, recording of resistance and temperature during the cycle. This cycling process was repeated and it was observed that it did not exhibit any noticeable hysterisis and the curve of resistance in function of temperature was effectively one line. This observation highlights that autoclaving process could stabilise the material and avoid its decomposition for temperature up to 200°C. Using values taken the plot of resistance against temperature, it is possible to plot a graph of resistance (R_T) against the corresponding resistance at 20°C (R_{20}) for various temperatures (Fig. 5). It was found that relationship between R_{20} and R_T could be written as following:

For T<175°C:
$$R_{20}=a_1+b_1\, R_T+c_1\, /(R_T)^2$$

For T>175°C:
$$R_{20}=(a_2+b_2.R_T)/[1+c_2\, .R_T+d_2\, .(R_T)^2]$$

It should be noticed that the relationship between resistance (R_T) and the corresponding resistance at 20°C (R_{20}) was obtained by [10, 15] and they indicated that there is a linear relationship between the logarithm of resistance (R_T) and the logarithm of the corresponding resistance at 20°C (R_{20}). In present study, only for T<100°C the proposed relationship [10, 15] gives satisfactory results.

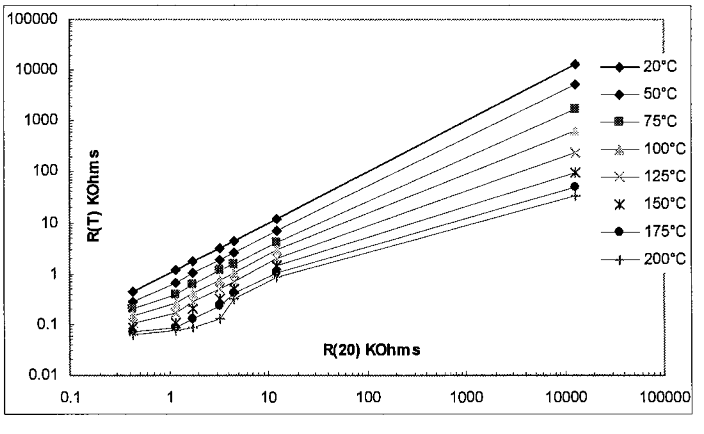

Fig. 5 Temperature calibration test

Ageing Calibration Test

As it was mentioned above, autoclaving process minimises pore structure evolution. However it has been observed that at constant temperature and water content, electrical resistance of moisture meter increases slightly (about 0.32 Ohm/day). This correction was made in order to taking into account the age effects.

Ratio between Water Content of Moisture Meter and Free Water of Concrete

Concerning to *ratio* it should be considered that the results of humidity calibration test obtaining during the drying of moisture meters in laboratory are useful provided the material surrounding the moisture meter has not more water content. Otherwise, current path will not remain in moisture meter volume and resistance measurement thus taken does not correspond to water content of moisture meter. Since for mortar mixture design it should be attempted to free water of mortar is higher than concrete one.

In present study, as a first approach, the ratio between the saturation water content of two materials (5.66% for concrete against 9.5% for mortar leading to *ratio* = 0.55) has been used.

Practical Procedure

In practical purpose, during testing electrical resistance at temperature (R_T) and temperature corresponding (T) are measured by moisture meter and thermocouple embedded in concrete specimen. Using Fig. 5 the value of R_{20} is obtained. The correction for ageing effects is applied. Using R_{20} thus obtained, Fig. 4 gives water content of moisture meter. Finally water content of concrete is obtained, applying the ratio between water content of the mortar and free water of the concrete.

EXEMPLE OF USE

In the scope of study of heat-mass transfer in reactor containment wall exposed to *sever accident* (Tmax=200°C and vapour pressure=15MPa) following by *heating test* (T=200), some tests have been carried out on the concrete specimen thickness 1.3 m containing the moisture meters at INSA de Lyon [16].

Some results concerning moisture propagation during two tests obtained by moisture meters are shown by Figs 6 and 7. Fig. 6 indicates the plugging zone and its migration towards cool face in the case of *sever accident*. The migration of drying front during the *heating test* is shown by Fig. 7.

SUMMERY AND CONCLUSIONS

The obtained results are summarised as follows:

1.Electrical Resistance Method appears to be a useful and inexpensive technique for detecting moisture propagation in concrete wall exposed to high temperature and high vapour pressure. The use of this method is still easier at room temperature.

2.Different stages of fabrication and calibration of moisture meter have been explained, especially the essential points to moisture meter mixture design are identified. It has been shown that autoclaving of material could stabilise pore structure of material and thus, variation of electrical resistance depends strongly on water content (at room temperature).

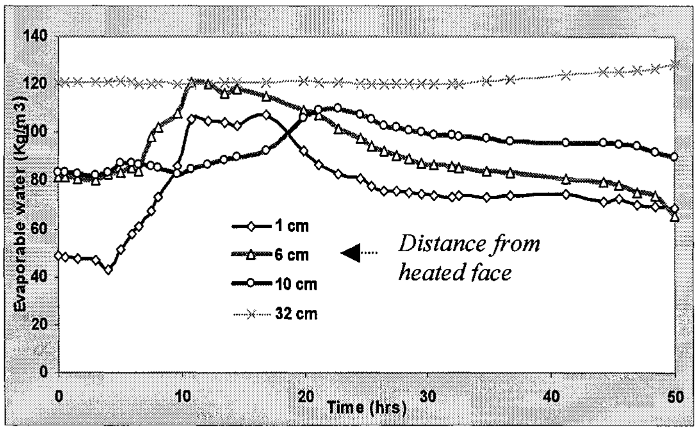

Fig. 6 Variation of water content in concrete during severe accident

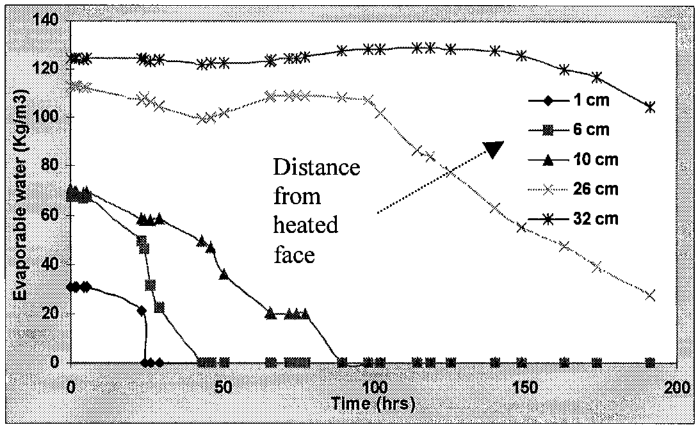

Fig. 7 Water content in concrete during heating test

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