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Estimation of concrete's porosity by ultrasounds

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Abstract

Durability of concrete depends strongly on porosity; this conditions the intensity of the interactions of the concrete with the aggressive agents. The pores inside the concrete facilitate the process of damage, which is generally initiated on the surface. The most used measurement is undoubtedly the measurement of porosity accessible to water. The porosimetry by intrusion with mercury constitutes a tool for investigation of the mesoporosity. The relationship between concrete mixtures, porosity and ultrasonic velocity of concrete samples measured by ultrasonic NDT is investigated. This experimental study is interested in the relations between the ultrasonic velocity measured by transducers of 7.5 mm and 49.5mm diameter and with 54 kHz frequency. Concrete specimens (160 mm diameter and 320 mm height) are fabricated with concrete of seven different mixtures (various W/C and S/S+G ratios), which gave porosities varying between 7% and 16%. Ultrasonic velocities in concrete were measured in longitudinal direction. Finally the results showed the influence of ratio W/C, where the porosity of the concretes of a ratio W/C ≥ 0,5 have correctly estimated by ultrasonic velocity. The integration of the concretes of a lower ratio, in this relation, caused a great dispersion. Porosity estimation of concretes with a ratio W/C lower than 0,5 became specific to each ratio.

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Kewyordsots : concrete, porosity, ultrasounds, correlation, mixtures.

1. Introduction

The porosity conditions the intensity of the interactions with the aggressive agents. It is established that the density as well as the elastic modulus are correlated to ultrasonic velocity. The correlation between the porosity and ultrasonic parameters can thus be established. It is indicated that the ultrasonic velocity decreases and ultrasonic attenuation increases as porosity increases [1]. However, these tendencies can differ for saturated materials. Hernandez et al. [2] have obtained evaluations of porosity by non destructive tests. Their evaluation is based on the micromechanical model established by Jeong and Hsu [3]. However, this model requires many parameters, which can be unknown and the precision would require knowledge of the granulometry. Marc Goueygou [4] has also worked to connect the ultrasonic properties to the porosity and the permeability of the mortars. This study showed the difficulty to obtain precise evaluations of the ultrasonic parameters, caused by the variability of studied materials. This work focuses in measure porosity on seven concretes of different mixtures (water/cement W/C,

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sans/sand+gravel S/S+G) to establish the influence of mixture on porosity and thereafter on the ultrasonic velocity in the concrete. Consequently to estimate concretes porosity.

2. Materials and experimentation

2.1. Concrete's mixtures

Materials used for the different concretes are:

- a silicocalcareous sand rolled SCr. (0/4mm),
- two gravels crushed lime stones CC (5/15mm and 15/25mm)
- two rolled silicocalcareous gravels SCr. (5/15mm and 15/25mm)
- cement CEM II-A 42.5

Seven compositions of concrete are used in this study (table 1), while varying the gravels/sand ratios (G/S) and water/cement (W/C). The tests were carried out on cylindrical samples 16/32 (the samples (16/32) are cylinders of 16 cm in diameter and 32 cm high) [5] after curing in water for 28 days.

Table 1. Compositions of concretes

Concrete Composition (kg/m^3)	B1	B2	B3	B4	B5	B6	B7
Sand	500	750	1000	617.31	539.39	500	500
Gravel 5/15 Cc	232	307	130	275.42	508.70	---	307
Gravel 15/25 Cc	928	613	520	899.74	524.57	---	613
Gravel 5/15 SCr	---	---	---	---	---	307	---
Gravel 15/25 SCr	---	---	---	---	---	613	---
Cement	440	440	440	350	350	440	440
Water	186	186	186	212.12	221.51	220	220
S/S+G	**0.30**	**0.45**	**0.60**	**0.34**	**0.34**	**0.45**	**0.45**
E/C	**0.42**	**0.42**	**0.42**	**0.60**	**0.63**	**0.50**	**0.50**
f_{c28} (MPa)	32.64±3	33.16±3.1	26.20±1.1	27.55±1.7	26.24±1.3	20.47±2.10	32.07±2.2

2.2. Measurement of porosity

The most-commonly used method for characterization is undoubtedly the measurement of porosity accessible to water. This simple method is used for a variety of mortar, cements pastes or concrete and is considered as the base of any microstructural characterization or evaluation of the durability properties of a material. It provides a total result ("total" porosity), indicator of the material quality. Porosities were determined according to the procedure recommended by the AFREM [6].

2.3. Measurement of ultrasonic velocity

Measurements of ultrasonic velocities were determined with direct mode of transmission (fig. 1); this mode provides the maximum of energy. It is measured by an ultrasonic tester 58-E0048 (Controls mark) including a transmission transducer and a reception transducer of 54 kHz frequency [7].

Two types of transducers of diameters d=7.5 mm and D=49.5 mm were used. The transducers are put in contact of the samples faces by the intermediary of coupling matter (fig.2).

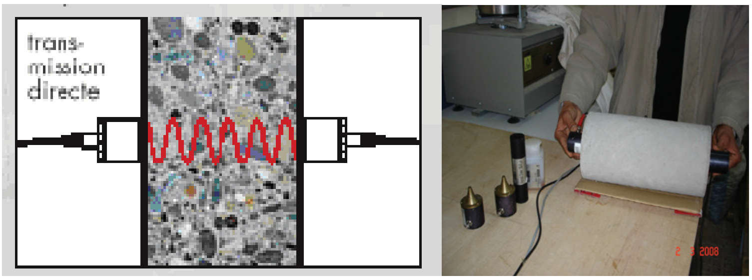

Figure 1. Positions of the transducers

The transducers are put in contact with the samples faces by the intermediary of coupling matter (fig.2). The length of the course is thus 320 mm (sample's length) and transverse dimension is 160 mm, this is higher than the minimum value required by the standard [8]. The ultrasonic velocities were determined by measurements of the course time for a series of three samples for each mixture. The samples remained in water until complete saturation with 20°C. That avoids the dispersion of the results caused by the variation of samples hygrometry.

3. Results and discussions

3.1. Effect of the transducers diameters on the ultrasonic velocity

The transducers used for non destructive testing can have variable dimensions adapted to the different applications. We have studied in this part the effect of the transducers diameter on the ultrasonic velocity. Two different transducers, of diameter d=7.5 mm and D = 49.5 mm (fig. 2), were used, table 3 and figure 3 gives the results acquired.

Ø =D = 49,5mm (b) Ø = d = 7,5mm

Figure 2. Ultrasonic equipment and transducers

Table 2. Ultrasonic velocity measured by the different transducers

Concrete	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
V_D (m/s)	3842 ± 205	3459 ± 101	3093 ± 115	3264 ± 190	3145 ± 100	3792 ±24	3736 ± 77
V_d (m/s)	2123 ± 90	2034 ± 88	1922 ± 70	1973 ±17	1885 ± 55	2401 ± 120	2126 ± 29
V_D/V_d	1.8	1.7	1.6	1.7	1.7	1.6	1.8
$(V_D/V_d)_{Moy.}$	**1.68 ± 0.08**						

It is noticed that the velocities determined by the transducers "D" are always higher than those determined by the transducers "d". This is explained that near the ultrasonic source, the beam is the object of rather complex vibratory interactions giving a maximum and minimum of energy on the axis of propagation. It is the close field or Fresnel's zone of which the length l is given by the relation [9]:

$$l = D^2/2\lambda \quad \text{avec} \quad \lambda = V / f \qquad (1)$$

D, is the source diameter and λ *is* the wavelength of the pulsations. Then, energy becomes monotonous and the beam diverges with an angle 2θ such as:

$$\theta = 1.22\, \lambda / D \qquad (2)$$

The relations between the properties of the transducers with diameters D and d are:

$$V_D = 1.66\, V_d \qquad (3)$$

and for a same frequency f

$$\lambda_D = 1.66\, \lambda_d \qquad l_D = 26.24\, l_d \qquad \theta_D = 0.25\, \theta_d \qquad (4)$$

This implies that the divergence of the beam for the small transducer is four higher than the large transducer. Where a better precision and a less disturbance of measurements by the transducers of diameters D in this precise case.

3.2. Porosity Measurement

The porosity measurement includes:
- Water vats for the conservation of the samples during 28 days,
- A digital balance of 30 kg ± 10 G, for the different weightings,
- A drying oven of 220 litters.

The porosity of the different concretes is given by table 3.

Table 3. Porosity of the different concretes

Concrete	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**
S/S+G	0.30	0.45	0.60	0.34	0.34	0.45	0.45
E/C	0.42	0.42	0.42	0.60	0.63	0.50	0.50
Porosity (%)	8.42± 1	10.62 ± 0.4	12.12± 0.9	15.49± 0.2	16.22± 0.5	12.43± 0.8	13.06± 0.1

From a ratio W/C=0.42 to 0.50, there is an increase in the porosity of 27% (for a same ratio S/S+G). Whereas all compositions included, an increase in W/C of 50% (from 0.42 to 0.60) are reflected by an increase in the porosity of 58% (from 10.26% to 16.22%). The porosity of the concrete is deduced from the loss of the water mass after passage to the drying oven (105°C) and stabilization of the samples mass. We prospect in this part, the effect of the mixture variation on the evolution of the concretes porosity.

3.3. Effect of the concrete mixture on porosity

It is noticed (Tab.3) that the highest values of porosity are obtained for the ratio W/C=0.63. Porosity grows with the increase in the ratios (S/S+G) and W/C (fig. 3).

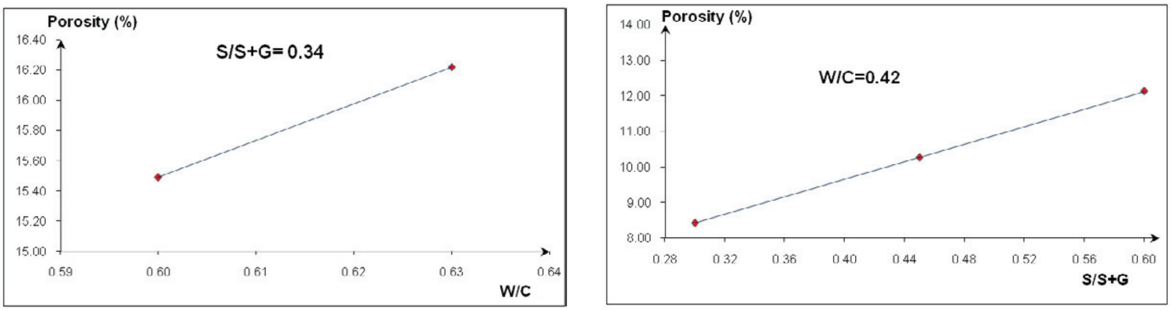

Figure 3. Evolution of the concretes porosity (effect of S/S+G and W/C)

The concretes B6 and B7 which present same the composition (Tab.1), except for the gravel nature (a peastone "silicocalcareous" for the B6 concrete and chippings gravel "calcareous" for the B7 concrete), present similar porosities. The porosity of the concrete B6 (12.43%) is slightly lower than that of the concrete B7 (13.06%), we can conclude that is a minim difference. it is equivalent to the variation of measurements (P_{B7}/P_{B6} = 1.05).

3.4. Relations between ultrasonic velocity and porosity

The velocities acquired by the transducers "D" are well correlated to porosities that those with transducers "d". It is noticed that for the two types of measurement the correlation coefficient approach to 1 for current and fluid concretes (fig. 4). Therefore, we can conclude that porosities can be deduced from ultrasonic velocities for concretes with a ratio W/C ≥ 0.5.

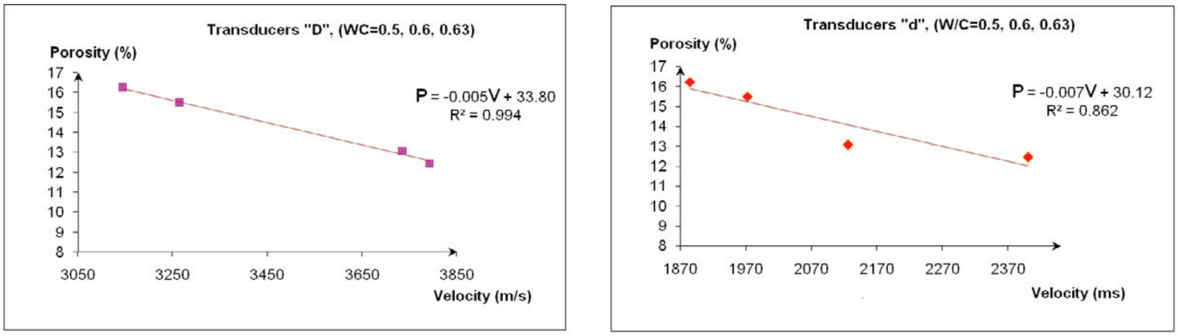

Figure 4. Evolution of porosity with ultrasonic velocity (concretes with W/C ≥ 0.5)

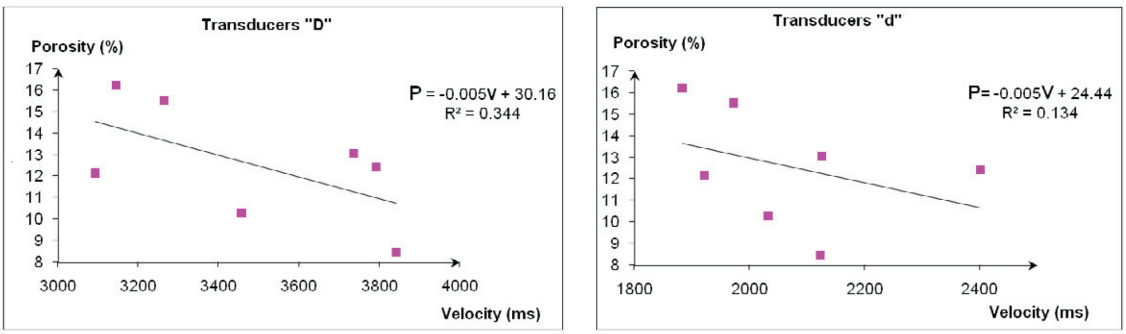

Figure 5. Evolution of porosity with ultrasonic velocity (concretes with W/C ≥ 0.42)

The correlations become less precise by integrating in these relations the concretes with a less ratio W/C (fig. 5). What seems to confirm the inaptitude of the ultrasounds to qualify the high performances concretes [9] [10] [11].

The Measured porosity is the porosity accessible to water. There is a porosity non accessible to the water, which represents the unconnected pores. This porosity is much lower than the first but when the porosity accessible to water decreases (for W/C < 0.5) the relationship between the two types of porosity increases what can influence the relations "velocity – porosity". By fixing the ratio "W/C", even for values lower than 0.5 (E/C=0.42 for example), we can estimate porosity with ultrasonic velocity.

4. Conclusion

We have integrated in this study the composition variation of concrete with an aim of having a beach of meaning porosity. The increase of W/C or S/S+G ratio led to an increase in porosity, the nature of the gravel (B6 and B7) have a less influence for porosity with a difference lower than 6% between the chippings gravel and rolled for the same composition. Ultrasonic velocities determined by the transducer of D=49,5mm diameter are on average 1,7 higher than those determined by the transducer of diameter d=7,5mm.

The relations between ultrasonic velocity and porosities of the concretes are described by linear relations for concretes with a ratio W/C ≥ 0.5. The correlation is better for the measurements determined using the transducer of large diameter (D=49.5 mm). They become less precise by integrating in these relations the concretes with a less ratio W/C. By fixing the ratio W/C, even for values lower than 0.5, we can estimate porosity from velocity. This relation always remains of linear type.

In final, we can conclude that we can estimate with acceptable accuracy porosity from ultrasonic velocity for ordinary or fluid concretes (W/C ≥0.5).

For the concretes with a ratio W/C <0.5, correlations are necessary for each ratio W/C.

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