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Possibilities of using ultrasound for the technological control of concrete of hollow-core slabs

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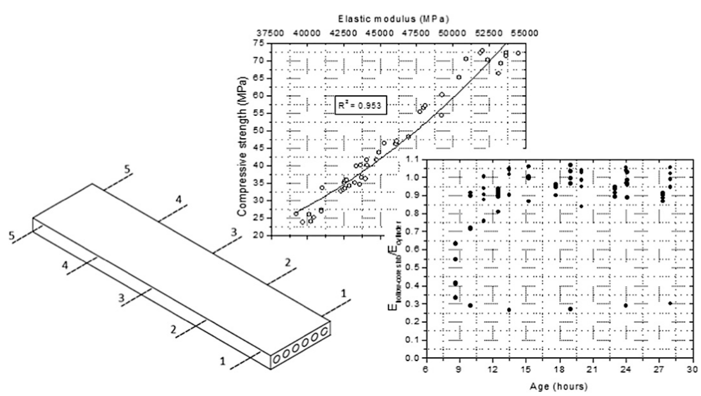
HIGHLIGHTS

- Ultrasonic tests provide reliable compressive strength vs. elastic modulus curves.
- Ultrasonic tests can improve the technological control in precast factories.
- The direct transmission method provides results with small dispersion.
- Elastic modulus of cylinders and hollow-core slabs were equivalents.

GRAPHICAL ABSTRACT

Ultrasonic test can be an interesting alternative to be applied in precast concrete industries complementing the existent methods in order to improve the technological control of concrete.



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ABSTRACT

This manuscript addresses the evaluation of possible applications of ultrasonic tests for the technological control of concrete of hollow-core slabs during the production phase. The study was divided into two phases. In the first, three different compositions of concrete were produced and ultrasonic tests were applied to cylindrical specimens for the obtaining of a correlation curve between compressive strength and dynamic elastic modulus. In the second phase, hollow-core slabs were constructed for a possible assessment of the variation of mechanical properties over time using the correlation curve obtained in the first phase. The results indicate ultrasonic tests can be an interesting alternative to be applied in precast concrete industries as a tool for the technological control of concrete without interference in the production line.

1. Introduction

Non-destructive tests (NDTs) have been widely applied to several industrial sectors, such as oil/petrochemical, chemical, aeronautical and electromechanical [1–3]. On the other hand, their use is still very limited in civil engineering. The main difficulties for their application include need for multidisciplinary expertise, interpretation of the results and incipient literature on civil

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engineering problems. At the same time, they are interesting procedures for inspection and maintenance activities, especially in the case of historic structures [4,5], since they do not damage the sample under testing and enable repetitions in the same sample at different times, which enables the testing of the proper structural element with no removal of drilled concrete cores. Therefore, non-destructive tests have been currently used in the evaluation of material properties [7–9]. According to ACI-228.2R-13 [6], NDTs can be applied for quality control, troubleshooting problems in new and old constructions, evaluation of conditions of older materials for rehabilitation purposes and quality assurance of repairs.

The ultrasonic pulse velocity (UPV) method has been largely applied for the characterization and quality monitoring of concrete structures [10–13]. According to Malhotra and Carino [14], it is a truly non-destructive method, as it uses mechanical waves and results in no damage to the concrete element under testing. Despite the ease of performing the test, the ultrasonic pulses can be affected by some factors, as pointed out by Popovics [15], such as surface condition, moisture, the presence of reinforcements and mainly the composition of concrete. The pulse velocity depends on the velocity through each constituent of concrete and consequently their relative proportions.

The principle of UPV is based on the dependence of the speed of propagation of stress waves (v) on the density (ρ) and elastic constants of the solid (elastic modulus, E and coefficient of Poisson, μ), see Eq. (1) for isotropic materials.

$$v^2 = \left(\frac{E}{\rho}\right)\left(\frac{1-\mu}{(1+\mu)(1-2\mu)}\right) \tag{1}$$

It is well known the elastic modulus of the concrete can be related to its compressive strength. The prediction of elastic modulus from compressive strength has been proposed by several standards [16–18] and the focus of several researchers [19–21]. Similarly, compressive strength can be predicted from elastic modulus measured from NDTs, as shown by Haach et al. [13]. However, special care should be taken in the determination of the correlation law between elastic modulus and compressive strength, since the elastic deformations of the concrete largely depend on its composition.

An interesting characteristic of the UPV method is it can be applied to very early-aged concrete [22,23]. The technological control of the concrete in early ages is one of the concerns of several civil engineering works, as construction of roller compacted dams, application of shotcrete and production of precast concrete elements. In the last case, cylindrical specimens of concrete are commonly molded during the production process for tests under compression prior to the prestress transference operation and demolding of the elements. The use of dry concretes with a very low slump is usual in the construction of hollow-core slabs when the extrusion system is applied as a manufacturing method [24]. According to ASTM C192 [25], in this case, the molding of concrete specimens is difficult due to the low water/cement ratio, which is approximately 0.3. Therefore, ultrasonic tests can be a reasonably accurate, reliable, and directly applicable in situ alternative for the characterization of concretes applied to precast industry.

A concern of the precast concrete industry regards the assurance of the strength of concrete in the early ages for the productivity optimization, anticipating tasks, like prestress transference and demolding of elements. Therefore, tests are mandatory for a proper characterization of the concrete applied. Ultrasonic tests are very interesting since they do not damage the sample under testing. As a result of this research, the obtaining of appropriate and reliable procedures for the application of ultrasonic tests in precast industry is expected.

2. Experimental program

The experimental program was divided into two phases that include the application of ultrasonic tests to cylindrical specimens of concrete and hollow-core slabs for the assessment of the test procedure and variation of mechanical properties over time.

2.1. Material properties

Portland cement, sand, gravel and 1% of a commercial policarboxylate superplasticizer were used in the preparation of the concrete. The Portland cement was type III with high early strength specified according to the ASTM C150 [26] classification. Sand has 2.4 mm maximum size and 1.95 fineness modulus, which is in accordance with ABNT NBR 7211:2009 [27], see Fig. 1. Gravel has 9.6 mm maximum size and 6.43 fineness modulus. Table 1 shows some physical properties of the materials.

In the first phase, three different compositions of concrete (M1 to M3) were produced (Table 2), whereas in the second phase, the hollow-core slabs were built with concrete composition M4.

2.2. Test specimens

In the first phase of the study, cylindrical specimens of 100 mm diameter and 200 mm height (height-diameter ratio of 2:1) were molded according to ABNT NBR 5738:1994 [28] and kept in the laboratory environment for one day. They were then removed from the molds, their ends were ground to obtain flat surfaces perpendicular to the axis of the cylinder and they were immediately stored in a moist chamber for curing until the age of testing. Eighteen specimens were molded from each concrete mixture. Destructive and non-destructive tests were performed at different ages from 18 to 57 h.

In the second phase, three hollow-core slabs of 500 mm × 100 mm cross section dimensions and 2000 mm length were built, as shown in Fig. 2. A welded mesh composed of four longitudinal bars of 6.3 mm diameter and thirteen transversal bars of 5.0 mm diameter with 500 MPa and 600 MPa nominal yield

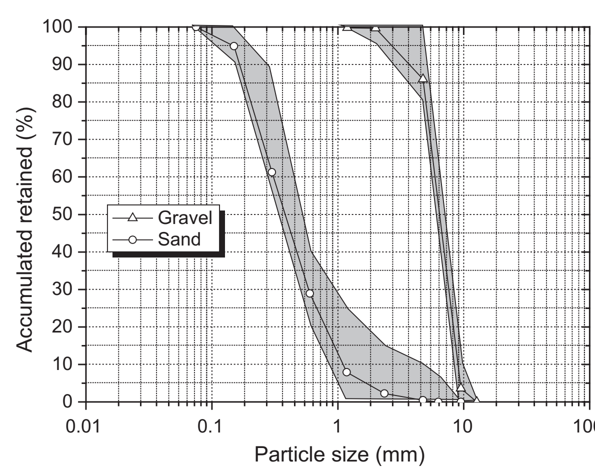

Fig. 1. Grading curve of aggregates.

Table 1
Properties of materials (kg/m^3).

	Cement	Sand	Gravel
Unit mass	1171	1565	1449
Density	3070	2625	2847