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In Situ Measurement of the Compressive Strength of Local Concrete: Correlation between Non-destructive and Destructive Tests

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Authors' contributions

This work was carried out in collaboration among all authors. Author SB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors DYKT and FZ managed the analyses of the study. Author MY managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The method used to evaluate the quality of concrete in structures includes, among other things, compressive strength testing of specimens cast on site. This method has shortcomings due to the non-uniformity in their formulation processes of the concrete studied in laboratories and that of the structure on site and the tardiness in obtaining test results. This is why the development of reliable methods of non-destructive assessment of the compressive strength of concrete in situ is essential for a better performance assessment of structures.There are a multitude of non-destructive methods, but in this article, the ultrasonic pulse velocity (UPV) and the rebound hammer (RH) are

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the methods used as they are easy to get manipulate, accessible and permit fast access to results. Analyses using single and multiple linear regression methods have been carried out with the results from compression tests and measurements of pulse velocity and rebound indices carried out between February and April 2018 on over 90 specimen samples in total. This resulted in correlation equations for the in-situ estimation of the compressive strength of the concrete studied.

Keywords: Non-destructive testing; sclerometer; ultrasound; combined method; compressive strength.

ABBREVIATIONS

V : Pulse velocity [m/s]
I_b : Rebound index [cm]
$F_{C.potential}$: Compressive strength with estimated error [MPa]
$F_{C.estimated}$: Estimated compressive strength [MPa]

1. INTRODUCTION

With the consequent increase in the number of projects, the non-respect of the execution deadlines, which can be economically attributable to the cost of the projects, it becomes more than necessary to find simple, economical and fast tools for the control and the evaluation of concrete strength on site [1-3]. Moreover, the specimens are not representative of structural concrete because of the difference in the installation, clamping and curing conditions, which are the main factors affecting the strength of the concrete [3,4].

This recurring problem, which resolution is essential to guarantee the quality of works at the local level, gives rise to reflections.That’s why in this article the objective is to establish correlation relations between the results of non-destructive tests and those of compression test of specimens cast on site and formulated in the laboratory. The combined method appears to be more suitable and it would contribute to providing building and public works stakeholders with a reliable, simple and rapid means of in situ non-destructive testing of local concrete [2,4]. To carry out this study, the cylindrical tube samples taken from nine (09) construction sites in the city of Ouagadougou and the cylindrical tube samples formulated in the laboratory LNBPT were tested on the 7th and 28th day of cure.

2. METHODOLOGY

2.1 Specimens Formulation

More than ninety (90) samples of cylindrical specimens with dimensions 15 cm /30 cm and 16 cm /32 cm were taken from the various sites. These are concretes formulated on the one hand on the sites of the various structures and on the other hand concrete developed in the laboratory. The laboratory specimens were formulated in accordance with the methods of Dreux-Gorisse, Bolomey and Faury [1]. We note that according to each of the formulation methods, the concrete specimens are similarly spoiled. The composition of their concretes per batch is given in Table 1.

The cure during this study took place in a laboratory environment. All specimens were submerged in water tanks for 7 days or 28 days.

2.2 Methods

2.2.1 Compressive test

The principle of the test is to subject a cylindrical (geometry used here), cubic or core specimen to an increasing pressure force and at constant speed until it ruptures in order to determine its compressive strength in accordance with the standards EN 12390-3 et EN 12390-2 [5,6].

The compression stress is given directly by the testing machine (hydraulic press) [7]. The test is carried out by placing the cylindrical specimen in accordance with Fig. 1.

Table 1. Concrete composition per cubic meter of laboratory specimens

Methods	Mixture composition			
	Gravel [kg]		Sand [kg]	Ratio Water/Cement
	5/15	15/25		
Dreux-Gorisse	273.4	590.2	578	0.61
Bolomey	528	506	816	0,63
Faury	511.2	616.6	701.74	0.50

Fig. 1. Compression test procedure

2.2.2 Ultrasonic Method (UPV)

The ultrasonic method has been used successfully to assess the quality of concrete for over 60 years [5,8]. It is a truly non-destructive method because its technique uses mechanical waves which do not cause any damage to the concrete examined [9]. The particular velocity of a wave in a medium depends on the elastic properties and the density of the medium [9,10].

The "Pundit Lab" device is the one used in this study to measure the pulse velocity through the diameters of the samples (Fig. 2).The following is the operating principle: the transmitting transducer of the pundit lab at one end of the specimen sends a wave into the concrete and the receiving transducer, at a distance L (in our case the diameter of the specimen), receives the pulse (Fig. 2) [3,7,11].

The pulse velocity of the mechanical (compression) wave V is therefore [3]:

$$V = \frac{L}{T} \tag{1}$$

V: the speed of sound propagation, in m/s;
L: the length of the route, in m;
T: the time it takes for the pulse to travel the length, in µs.

The test procedure is illustrated in Fig. 3.

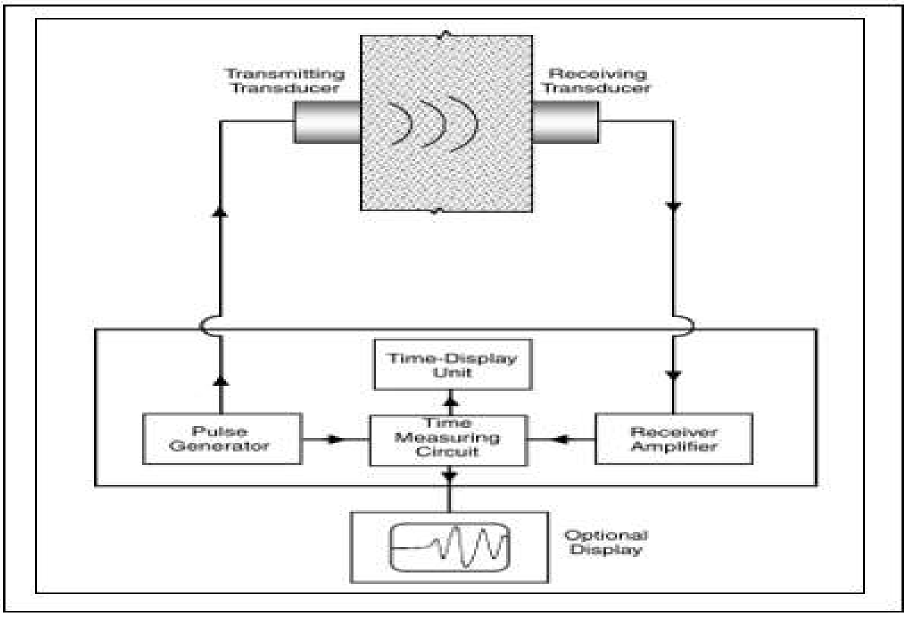

Fig. 2. Effect of different doses of aqueous extract of Folk Recipe (100, 200, 300 mg/kg) on blood glucose levels at different time intervals in normal rabbits
Diagrams of the pulse velocity measurement procedure with the Pundit-Lab device [10]

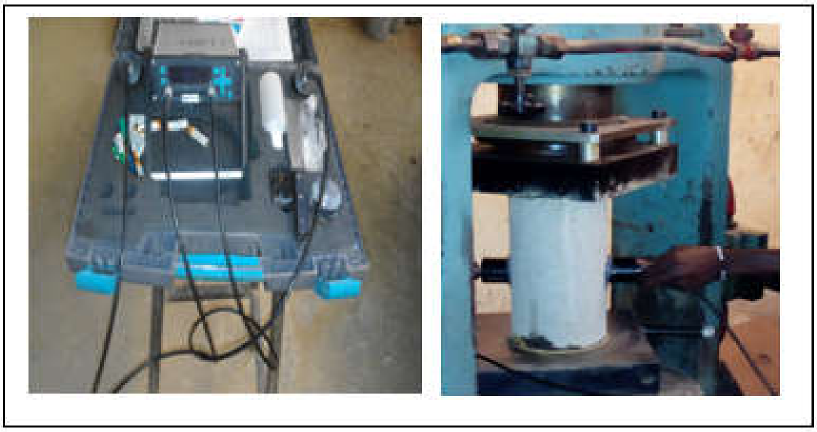

Fig. 3. Arrangement of transducers for pulse velocity measurement with Pundit-Lab

2.2.3 Rebound Hammer Method: Sclerometer

In 1948, a Swiss engineer, Ernst Schmidt, developed a test hammer to measure the hardness of concrete by the principle of rebound. Around 50,000 Schmidt's rebound hammers had been sold in 1986 worldwide [10]. The hammer test consists of projecting a mass onto the concrete surface with a constant initial energy (Fig. 4) [12]. Following the impact, part of the energy is absorbed by the concrete (permanent deformation energy), the other part causes the rebound of the moving mass which is proportional to the energy remaining available.

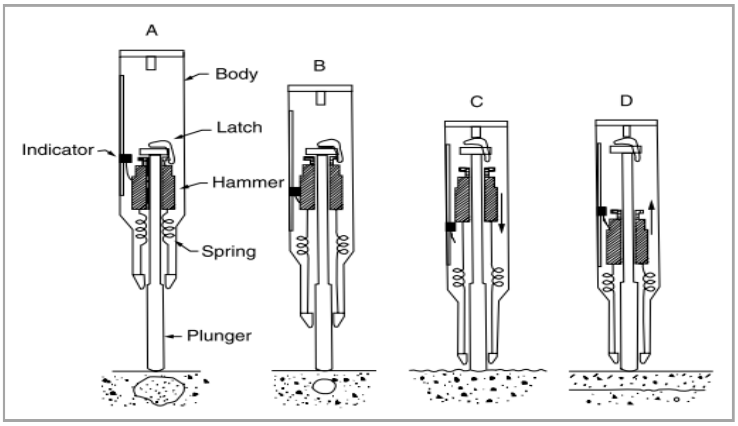

Fig. 4. Illustration of the procedure for measuring the rebound index [10]

Fig. 5. Layout of the Schmidt model N standard hammer for rebound index measurements

The rebound index is the measure recorded on a graduated scale fixed relative to the frame of the hammer apparatus, after the projection of a spring-loaded weight on a metal rod in contact with the concrete surface. This measurement depends on the angle of inclination of the device relative to the horizontal line [2]. If this angle is different from zero, corrections are made to the values obtained. In this study, the device is positioned horizontally so there were no corrections related to the inclination (Fig. 5).

2.2.4 Combination of methods: Son RED method

It is generally difficult to directly deduce the mechanical strength of concrete from non-destructive measurements with acceptable precision [13]. Indeed, the result is often affected by errors related to the precision of the measurement and the variability of the material [12]. These techniques (ultrasound and rebound) are generally influenced by several factors, including the type of cement, the Water / Cement ratio, the age of the concrete, and the grain size and the state of the surface of the test specimen (wet or dry), etc [7]. For example, in the case of Pundit, the speed of the ultrasound varies greatly with the humidity of the concrete [2]. The lack of relevance of the results obtained with simple correlations (impulse velocity or rebound index only) due to the shortcomings of these techniques previously mentioned has led to combined approaches. This approach aims to correct the influence of certain parameters mentioned above and to have more reliable results [4]. This is why, in accordance with the SonRED method [13], correlations combining both destructive press testing, rebound index and pulse velocity were performed. In this analysis, the compressive strength measured with the press is the dependent variable. The hammer rebound index and the ultrasound propagation speed are the independent variables. To do this, single and multiple linear regression analyzes are used with the software« IBM SPSS Statistics 20 ».

3. RESULTS AND DISCUSSION

3.1 Descriptive Analysis of the Results

Table 2 below represents the summary of the descriptive analysis made on all the results obtained during the various testings. These results are those of the test specimens taken from the various building sites (see paragraph 2.1) and those of the test specimens formulated in the laboratory.

For all the specimen samples (site and laboratory) studied, it can be seen that the average compressive strength values of the concrete at 7 days reach 70% to 80% of the expected value at 28 days. These values are acceptable with respect to the requirements and technical prescriptions adopted for quality control during execution.

Furthermore, it is noted that laboratory specimens have an average compressive strength that not only reaches the expected value on the 7th or 28th day, but is also higher than the average compressive strength of construction site specimens. This finding on site samples is not surprising, it is even predictable given the defects [14]:

- that are intentional during formulation, i.e. non-compliance with the quantities of the various components of the concrete;
- due to the sampling of the specimens (bad stitching or vibration);
- related to the curing of the test specimens (immersion time, the irregularity of the renewal of water causing the appearance of aggressive chemical agents);
- related to the imprecision of the test equipment.

Table 2. Statistics of properties of study concretes

Properties		Site specimens		Laboratory specimens	
		7th day	28th day	7th day	28th day
F_c^*[MPA]	Average	19.13	25.68	23.62	30.60
	Standard deviation	6.20	7.04	2.52	3.07
V^{**} [m/s]	Average	4140	4435	4648	4810
	Standard deviation	234	234	44	78
I_b^{***} [cm]	Average	27.7	32.1	31.1	31.7
	Standard deviation	3.3	2.4	0.99	1.1

**compressive strength; **Pulse velocity; ***Rebound index*

3.2 Evolution of the Concrete Parameters of the Study Specimens

The analysis carried out on the evolution of the parameters (for all specimens), that are the impulse speeds and the rebound indices of the specimens (Figs. 6 and 7), has shown that:

- The average pulse velocity (Fig. 6) increased from 4140 m / s (7th day) to 4435 m / s (28th day), representing an increase of 7%. But these values remain within the range [3500 m / s; 4500 m / s] allowing to certify of the good quality of the concrete [2].
- The average rebound indices (Fig. 7) have increased by 16%.

The evolution from the 7th to the 28th day of the average values of the two parameters mentioned above is in accordance with the evolution of the determined average values of compressive strength (Fig. 8).

3.3 Correlative Analysis of Test Results

Statistical analysis seems to be the essential way to interpret the observed data [2]. The use of destructive test results from the compression of specimens that are from construction sites and laboratory is necessary to calibrate those of non-destructive tests. For this purpose, we used regression model based on linear law [12]:

- simple linear regression model

$$y = b_0 + b_1 x \quad (2)$$

y : Dependent or explained variable (estimated compressive strength)
x : Independent or explanatory variable (rebound index or pulse velocity)
b_0, b_1 : Theoretical regression coefficients

- multiple linear regression model

$$y = b_0 + b_1 x_1 + b_2 x_2 \quad (3)$$

y : random dependent or explained variable (estimated compressive strength)
x_1 , x_2 : independent or explanatory variables (rebound indices and pulse velocity)
b_0 , b_1 , b_2 :are the empirical regression coefficients

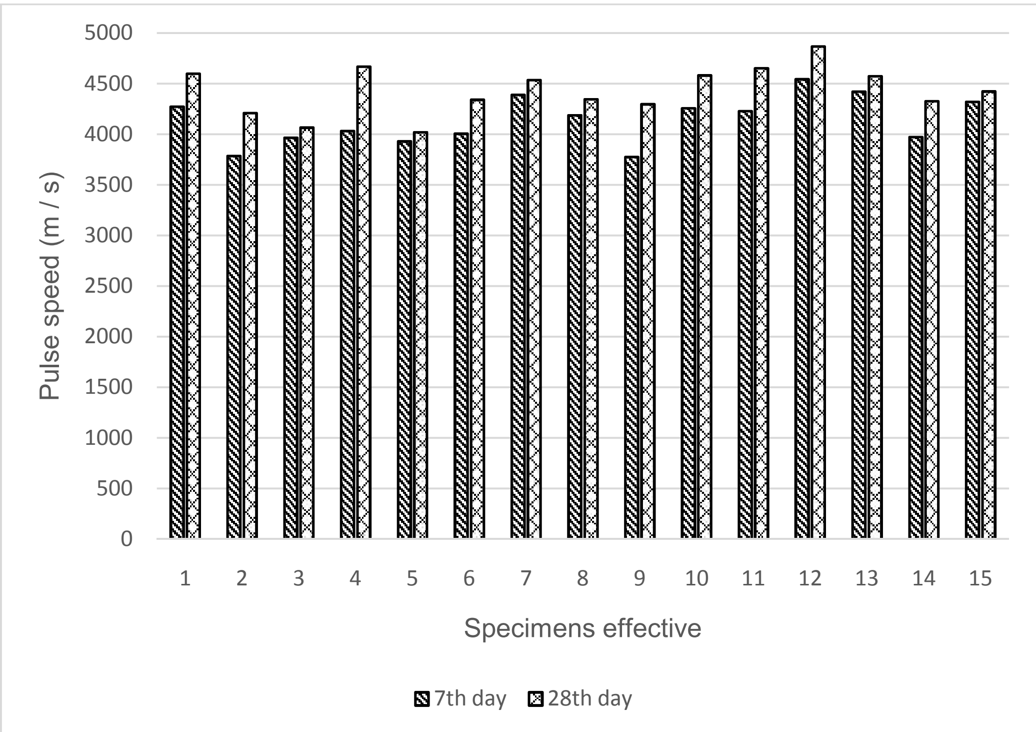

Fig. 6. Evolution of the impulse speeds of the specimens

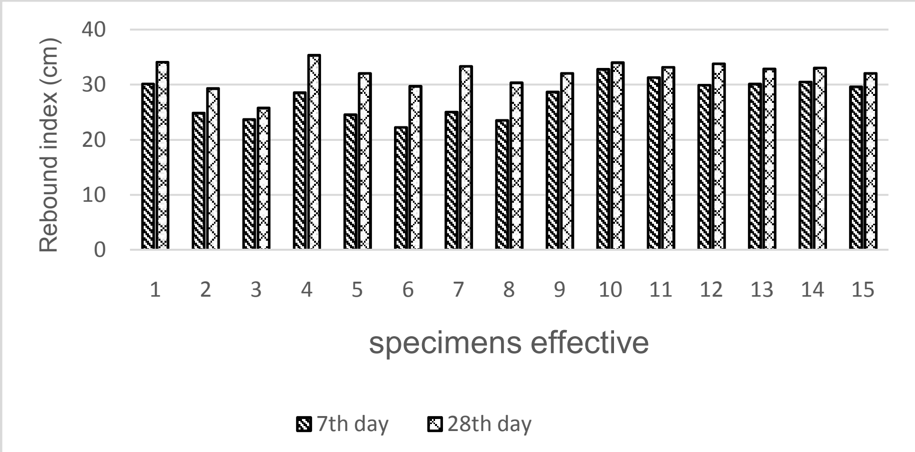

Fig. 7. Evolution of the rebound indices of the test tube sclerometer

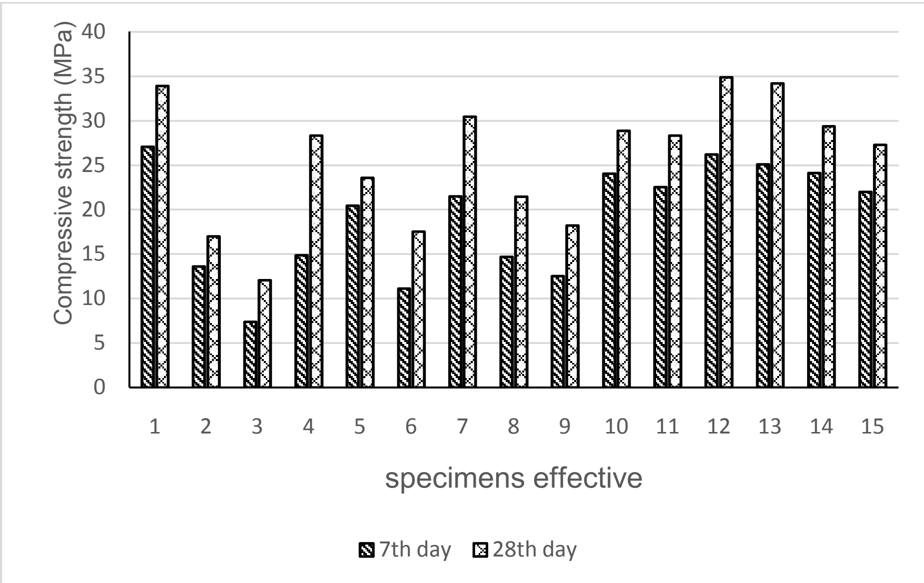

Fig. 8. Evolution of compressive strengths of specimens

3.3.1 Simple linear regression

First of all, we note that the correlations established with the test specimen of construction sites are better (Fig. 9a, R^2 = 0.726 and Fig. 10a R^2 = 0.622) than those obtained with the laboratory test specimen (Fig. 9b R^2 = 0.543 and Fig. 10b R^2 = 0.443) regardless of the rebound index or pulse speed parameter. And then, the comparison of the correlation coefficients shows that the rebound hammer method estimates the compressive strength of the specimens better (R^2 = 0.726) than the UPV ultrasonic method (R^2 = 0.622).

In view of these observations, we would be tempted to conclude that the rebound hammer method is better suited for the non-destructive testing of concrete. In addition, as described in paragraph 2.2.4, the use of these methods is flawed due to the influence of several factors. Therefore, for more reliability in estimating compressive strength using non-destructive technique, the combination of these techniques is essential.

3.3.2 Multiple linear regression

The correlation coefficients obtained with the results of the parameters measured at 7 days (Fig. 11) and 28 days (Fig. 12) show that there is no significant difference between the site test specimens and those in the laboratory.

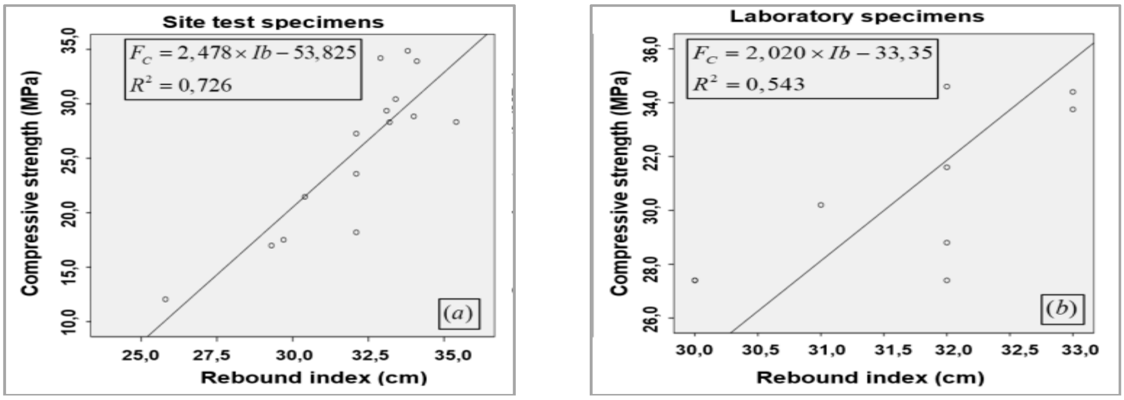

Fig. 9. Correlation between rebound index and compressive strength of study specimens
a: for specimen from site
b: for specimen from laboratory

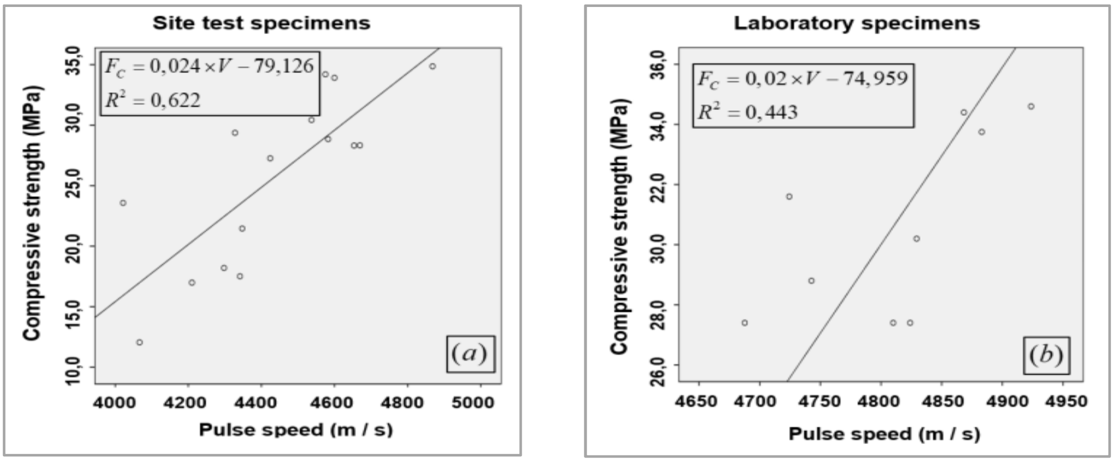

Fig. 10. Correlation between ultrasonic speed and compressive strength of study specimens
a: for specimen from site
b: for specimen from laboratory

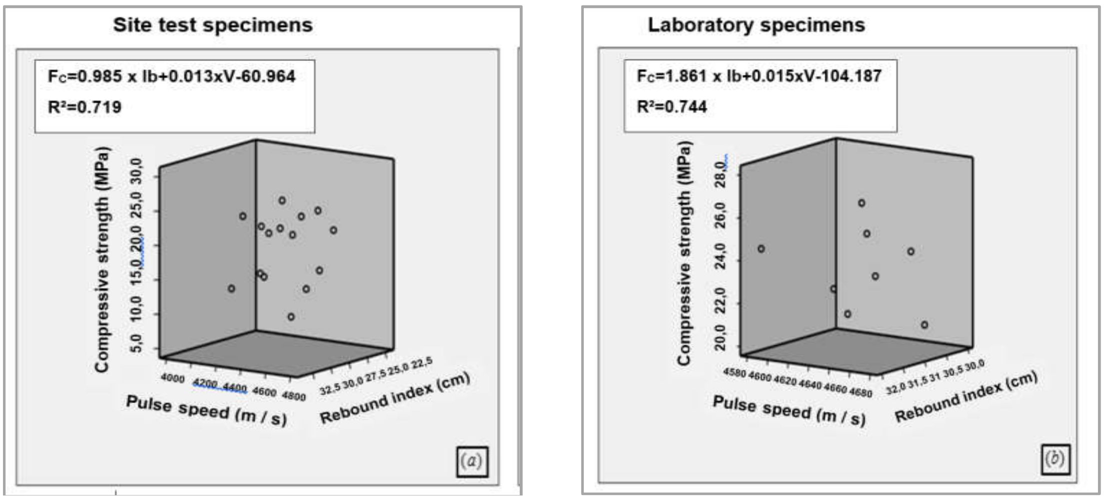

Fig. 11. Correlation between pulse speed, rebound index and compressive strength of the test pieces (7th day)
a: for specimen from site
b: for specimen from laboratory

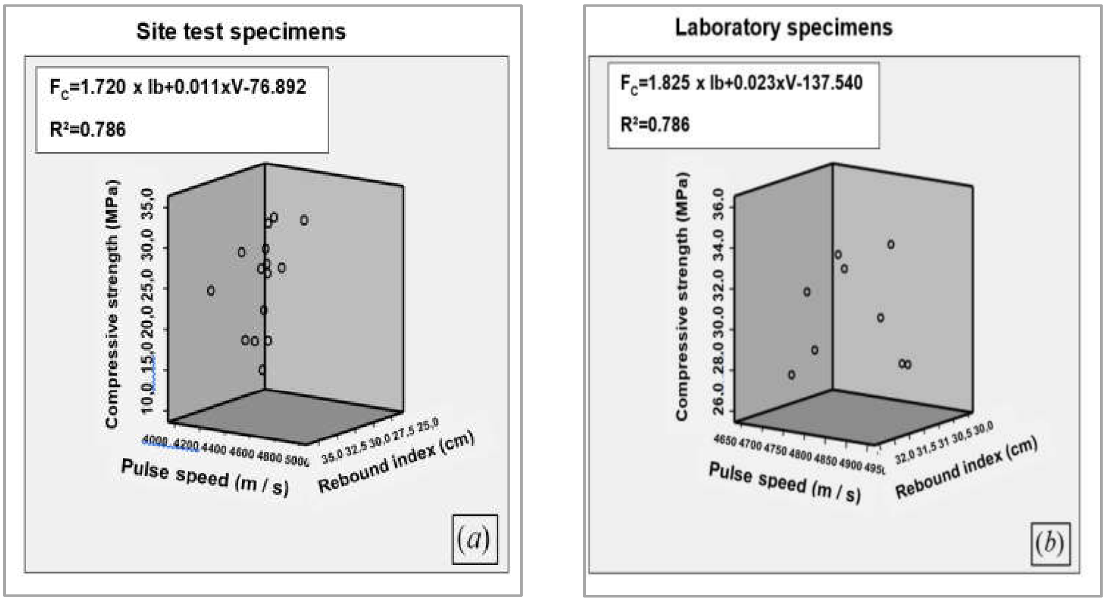

Fig. 12. Correlation between pulse speed, rebound index and compressive strength of the test pieces (28th day)
a: for specimen from site
b: for specimen from laboratory

Likewise, the coefficients of the multiple correlations (rebound index and pulse speed) are better regardless of the duration of curing of the specimens. Indeed, at 7 days and 28 days of treatment, with the combined method, the correlation coefficients obtained are higher than 0.7 while the simple (or linear) regression coefficients are lower. Studies of Hanachi [2], Benyahia and Kenai [4] gave the same tendency, 0.5452 for the combined method and 0.3983 and 0.5213 respectively with the sclerometer indices and the pulse speeds.

Based on this observation, we can conclude that multiple regression combining the two techniques is better because it reduces the errors due to one or the other of the techniques. It is therefore more reliable to use the combined method for estimating compressive strength as highlighted by the studies carried out by Hanachi [2], Ghrici and Kenai [15].

The estimation of the compressive strength, from the multiple correlation equations, allowed to propose the following equations for a 95% confidence interval given by the SPSS software:

- Site concrete (Fig. 12a):

$$F_{C.potential} = F_{C.estimated} \pm 4.49 \text{ MPa} \tag{4}$$

- Laboratory concrete (Fig. 12b):

$$F_{C.potential} = F_{C.estimated} \pm 1.24 \text{ MPa} \tag{5}$$

With

$F_{C.potential}$: compressive strength with estimated error [MPa]
$F_{C.estimated}$: estimated compressive strength [MPa]

4. CONCLUSION

The results from the tests for the measurement of the impulse velocity of all the specimens studied show that the concrete is of good quality (velocity greater than 3500 m/s), which is not necessarily verified in the case of the compression test (destructive test). This is due to the influence of factors related to the concrete specimens mentioned in paragraph 3.1. Likewise, the results obtained show that the expected average compressive strength on the 7th and 28th day of the laboratory specimens is higher than that of the test specimens from the construction sites at the same dates. Also, the evolution from the 7th to the 28th day of the average values of the rebound indices and of the impulse speeds is in agreement with the evolution of the determined average values of compressive strength.

Simple and multiple linear regression analyzes have established several trendlines. The multiple linear regression combining the parameters rebound index, impulse speed and compressive strength gave fairly high and more reliable coefficients, namely $R^2 = 0.79$ for site specimens and $R^2 = 0.88$ for laboratory formulated specimen after 28 days of cure. We note that the correlation of the results of the tests of concrete formulated in the laboratory is better with the combination of the two techniques.

In order to facilitate rapid, adequate and more reliable compressive strength estimates that better approximate the quality of in-situ concrete, tests should be carried out both on structural elements on site and on specimens taken on site.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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