THE USE OF MULTIPLE COMBINED NON DESTRUCTIVE TESTING IN THE CONCRETE STRENGHT ASSESSENT: APPLICATIONS ON LABORATORY SPECIMENS

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Abstract - In this paper a series of non-destructive tests has been performed with the purpose to investigate on the mechanical properties of the concrete employed in the civil buildings.
A series of specimens were prepared in order to correlate the “in situ” concrete strengths obtained by multiple combinated non-destructive methods with the cubical and cylindrical strength obtained by destructive methods. The multiple combined methods (SonReb Methods + Windsor Probe Tests) were used to quality control and strength estimation of the concrete.
In particular, a series of specimens by aggregates having various Mohs'Hardness (inert of fluvial origin) and by aggregate with only a class of Mohs'Hardness (crushed aggregate) has been prepared. During the concrete casting a series of cubical specimens has been prepared. The comparison among non-destructive tests, cubical strength and cores strength are carried out.

Keywords: Non-destructive investigations, concrete, Windsor Probe System, SonReb Methods, Combined Methods.

1 Introduction

The non destructive methods applied in the field of civil engineering having a vast diffusion in this last years. The penetration resistance method (Windsor probe system), the surface hardness method, the ultrasonic method and the combined methods (SONREB method) are the principal non-destructive methods used for quality control and strength estimation of in situ concrete [1, 2, 3]. These methods, being influenced in different and/or opposite mode from some fundamental parameters, allow to get outputs with least dispersions.
In this paper the outputs of these methods are calibrated with the strength of cylindrical specimens (cores) extract from investigated specimens which the non-destructive tests were applied.
Windsor probe test, Schmidt rebound hammer, Ultrasonic Pulse Velocity method [10, 11, 12, 14], SonReb method, Windsor method [8, 9, 13] and a three parameter combined method, appointed as SonRebWin Method, were utilised to investigate on the mechanical property of concrete.
The last, derive from the combination of the results obtained by the well-known SonReb method whit the results of Windsor probe test. The use of these methods is generally justifiable only if a reliable correlation for a particular type of concrete is developed prior to the evaluation of the subject quality concrete.
In the present paper some availability correlation cures [1, 11] will be appropriately adapted to the concrete studied.

2 The Specimens

A total of 6 concrete specimens 600x600x200-mm was designed and fabricated at the Laboratory of the Faculty of Engineering of Mediterranean University of Reggio Calabria.
In particular, 4 specimens (Figure 1), in the following appointed as IF, were prepared by aggregates having various Mohs'Hardness, i.e inert of fluvial origin.
For this specimens values from 3 to 7 of aggregate hardness were measured and the estimated Mohs'hardness equivalent was of 3.15.
Moreover, 2 specimens, following appointed as IS (Figure 2), prepared by aggregate with only a class of Mohs'Hardness, i.e. crushed limestone aggregate were considered. For this specimens a value of 4.5 of Mohs'hardness equivalent were estimated.

Figure 1. Specimens IF prepared by aggregates of fluvial origin - Mohs'hardness variable from3 to 7 and equivalent Mohs'hardness equal to 3.15

All specimens were prepared to obtain a characteristic cube strength of 30 MPa.

3 The SonReb Method

The combination of Schmidt Rebound Hammer with Ultrasonic Pulse Velocity results increase the accuracy of the estimation of the in situ compressive strength of concrete.
In the draft recommendation (RILEM Draft Recommendation) for in situ concrete strength determination by combined non-destructive methods [4], are contained the criteria for beneficial combinations:

- (i) each method provides information about different properties that affect the strength of concrete;
- (ii) special sample preparation should not be required;
- (iii) tests should be quickly carry out;
- (iv) test methods should provide strength estimations to a similar level of accuracy;
- (v) tests should not affect the structural performance of the unit under test.

Figure 2. Specimens IS prepare by crushed limestone aggregate Mohs'hardness equal to 4.5

The following examples of double combinations between simple non-destructive methods are known [4]:

- a) longitudinal pulse velocity + rebound index (SonReb method);

b) longitudinal pulse velocity + indentation diameter;
c) longitudinal pulse velocity + pull-out force;
d) longitudinal pulse velocity + attenuation of ultrasonic pulses;
e) longitudinal pulse velocity + gamma-ray attenuation;
f) longitudinal pulse velocity + damping of vibrations;
g) longitudinal pulse velocity + transverse pulse velocity;
h) longitudinal pulse velocity + maturity concept;
i) rebound index + indentation diameter;
j) rebound index + pull-out force;
k) pull-out force + maturity concept.

In particular, the SonReb method, (based on ultrasonic pulse velocity and rebound hammer techniques), is largely diffused with the objective to determine the potential compressive strength of in situ concrete when its quality is considered to be suspect, due the efforts of RILEM 43 CND [4]. The advantages in the use of SonReb technique is that the variation of some properties of concrete produces opposite effects on the result of each component test. For example, an increase in moisture content increases the ultrasonic pulse velocity but decreases the value of the rebound hammer number.
Then, the use of SonReb method reduce the effects of
(i) aggregate size,
(i) cement type and content,
(ii) water-to-cement ratio,
(iii) moisture content.

In the scientific literature various expressions to determine in situ compressive strength of concrete by means of SonReb method are available:

$$R_{c1} = 7{,}695\ 10^{-10}\, I_m^{1{,}4} V^{2{,}6} \qquad (1)$$

$$R_{c2} = 0{,}0286\ I_m^{1{,}246} V^{1{,}85} \qquad (2)$$

$$R_{c3} = 1{,}2\ 10^{-9}\, I_m^{1{,}058} V^{2{,}446} \qquad (3)$$

$$R'_{Son\,Re\,b} = 2.756\ 10^{-10}\, I_m^{1.311} V^{2{,}487} \qquad (4)$$

In (1) Rc (compressive strength of equivalent cube) is expressed in daN/cm2 and the velocity ultrasonic pulse in m/s [5]; in (2) Rc is expressed in MPa and the ultrasonic velocity in Km/s [6]; in (3) Rc is expressed in MPa and the ultrasonic velocity in m/s [7].
Last relation (4) was the correlation curve applied in the case study. In (4) Rc is expressed in MPa and the ultrasonic velocity in m/s; this relation is related to a standard concrete with the property described in RILEM 43-CND [4].
Where different type of concrete is employed the following relation is applicable:

$$R_{Son\,Re\,b} = R'_{Son\,Re\,b} \cdot (C_c \cdot C_d \cdot C_a \cdot C_f \cdot C_p \cdot C_m) \qquad (5)$$

were $C_c,\ C_d,\ C_a,\ C_f,\ C_p\ and\ C_m$ are coefficients of influence that consent the extension of the (4) a the case of a non standard concrete is utilized.
In the case of examined specimens the values of the coefficients of influence are reported in table 1 [1].

Tabella 1: Coefficients of influence

	Coeff. Infl.	Specimens IF	Specimens IS
For the cement type	C_c	1.00	1.00
For cement content	C_d	0.93	1.06
For aggregate type	C_a	1.35	1.00
For the proportions of fines	C_f	0.94	0.97
For the maximum aggregate size	C_p	1.00	1.00
For admistures	C_m	1.08	1.08

Moreover, for the specimens IF were possible to obtain the following correlation curve:

$$R_{Son\,\mathrm{Re}\,b}^{Corr} = 2.75 \cdot 10^{-10} \cdot V^{2.485} \cdot I_r^{1.430} \qquad (6)$$

4 The “SonReb-Win” Metod

The combination of values obtained using more simple non-destructive methods increase the accuracy of the estimation compared with that from any single method. The following examples of triple combinations between simple non-destructive methods are known [4]:

a) longitudinal pulse velocity + rebound index + pull-out force;
b) longitudinal pulse velocity + rebound index + attenuation of ultrasonic pulses;
c) longitudinal pulse velocity + rebound index + transverse pulse velocity;
d) longitudinal pulse velocity + slope at the first wave front + reverberation time.

In this paper another triple combination between simple non-destructive methods was employed:

a) longitudinal pulse velocity + rebound index + penetration force (SonReb-Win);

The correlation curve in this case was expressed by the following formula:

$$R_C = a \cdot I_{rm}^b \cdot V_{L,s}^c \cdot L_e^d \qquad (7)$$

where:

- L_e is the length of the part of probe not penetrated in the concrete (figure 3);
- V is the longitudinal pulse velocity;
- I_r is the rebound index;
- a, b, c and d are constants definable by the application of last square principle.

Only for specimens IF were possible, also in this case, to obtain a the correlation curve; this has the following expression:

$$R_{Son\,\mathrm{Re}\,b-Win}^{Corr} = 5.390 \cdot 10^{-3} \cdot V^{0.0401} \cdot I_r^{0.250} \cdot L_e^{1.997} \qquad (8)$$

5 Applications and results

In this section the more important results of non destructive investigation conduced in situ on a series of concrete specimens are shortly discussed.
For the specimens IF, compressive strength of cores is compared, with the assessment of concrete strength obtained by the application of Windsor method (Mohs’hadness=3.15), SonReb method and SonReb-Win method in the figure 5.
In particular, the values of compressive strength of cores are compared with those obtained by SonReb and SonReb-Win combined methods and with the Windsor method applied singularly.
It is easy to see that the SonReb-Win method gives resistance values close to actual ones. Moreover, the assessment of the strength by the penetrometric method (Windosor methot with equivalent Mohs’hardness equal to 3.15) gives values of resistance in concordance with the actual value of strength of cores.

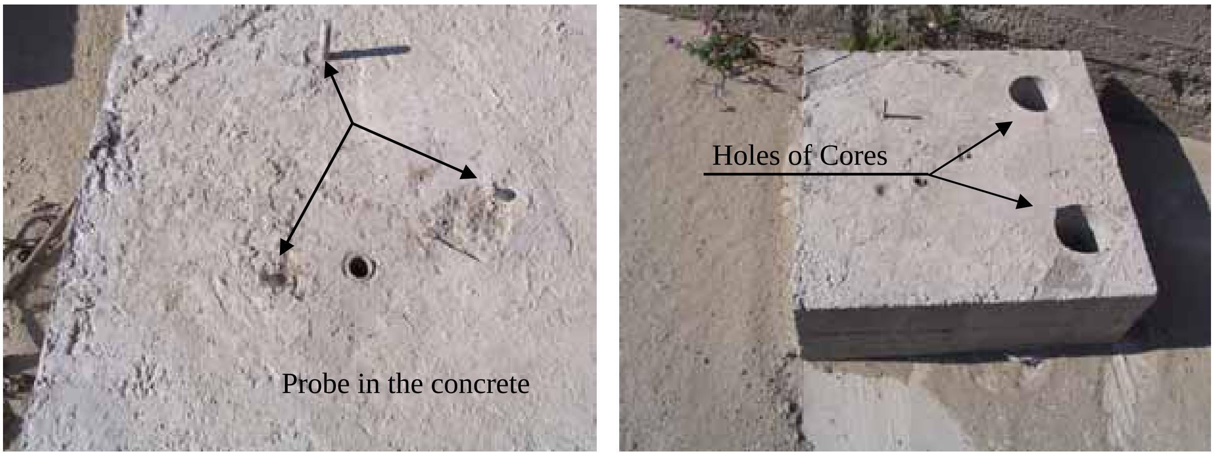

Figure 3. Specimens IF after experimental tests

Figure 4. Specimens IS during the experimental tests

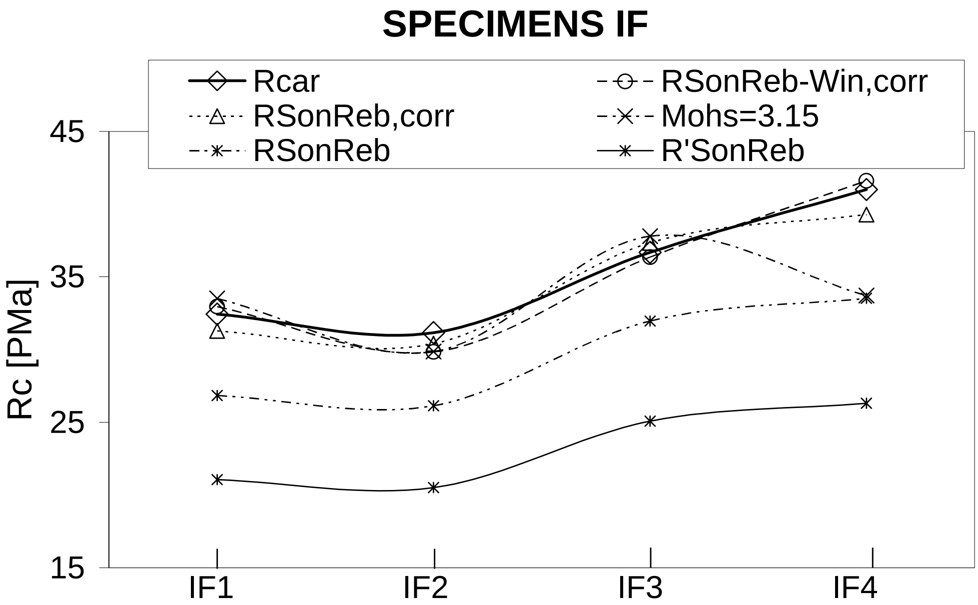

Figure 5. Specimens IF - Experimental Test Results

Figure 6 show the comparison among the cores strength, Windsor strengh (Mohs'hadness equal to 4.5), SonReb strenght and the strength assessment by application of SonReb-Win method.

In this case, where only two specimens were available (and where was not possible develop an adequate correlation curve), the Windsor probe system is the more reliable method that gives resistance values close to actual ones.

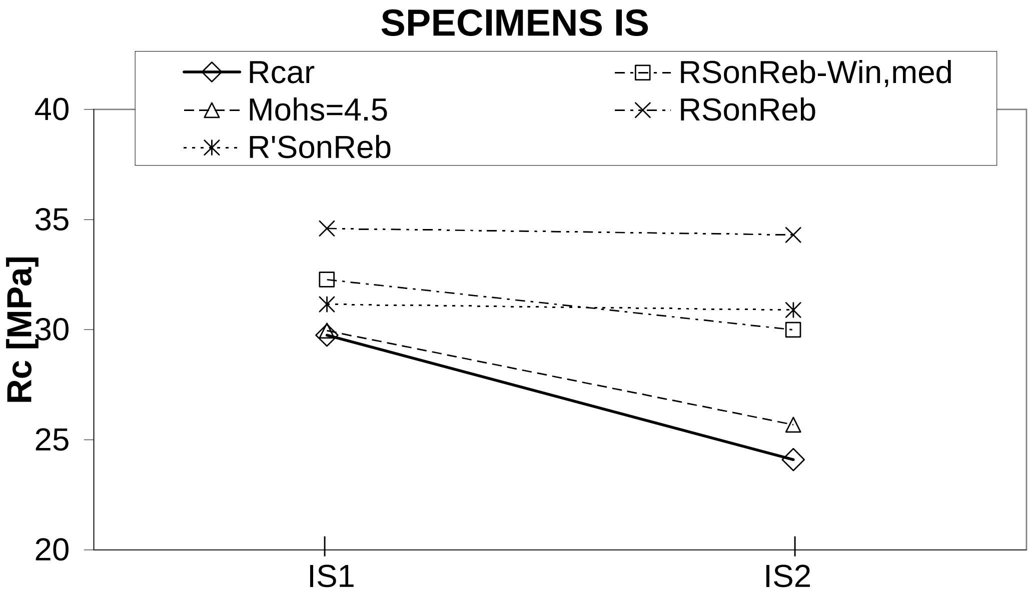

Figure 6. Specimens IS - Experimental Test Results

6 Conclusions

A series of non-destructive tests were carried out with the purpose to investigate on the mechanical properties of the concrete employed in the civil buildings. In this purpose a series of specimens were prepared and afterwards subject to non-destructive tests (Windsor, SonReb and "SonReb-Win").
With reference to Windsor Probe Systems, the study has evidenced that, when a concrete by aggregate of fluvial origin is employed, the hardness of the aggregate assume a important role in the correct evaluation of strength. In this case, the use of Windsor methods is generally justifiable only if a reliable correlation for a particular type of concrete is developed. The Windsor Probe Systems assessment of concrete strength is adequate in the case of aggregate with only a class of Mohs'Hardness. The SonReb-Win method gives resistance values close to actual ones. It is very suitable for the assessment of concrete strength when an appropriate correlation curve is drawn up.
Moreover, the advantages in the use of SonReb as well as of SonReb-Win techniques is that the variation of some properties of concrete produces opposite effects on the result of each component test.

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