The impact of cement type on the correlation between non-destructive testing and the compressive strength of concrete

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Abstract

Buildings' concrete structures are weakened by destructive tests like "coring", which compress cylindrical specimens in the lab to measure the compressive strength of in situ hardened concrete. These tests also produce trash that is hazardous to the environment. Alternative methods to destructive concrete testing include rebound hammering and ultrasonic non-destructive testing of hardened concrete. The first goal of this research is to determine the link between compressive strength, rebound hammer, and ultrasonic pulse velocity tests. The second goal is to investigate the impact of cement type and concrete age on these correlations. In this case, two cement kinds (CEM I 42.5 and CEM II 42.5) and two concrete compositions based on local resources were developed in this context. Simultaneous tests on cubic samples (ultrasonic test, rebound hammer test, compressive strength test) were conducted at ages 7 and 28 days. According to the studies' findings, there is a strong association between compressive strength and the ultrasonic and rebound hammer tests. The compressive strength of concrete can be predicted using these relationships without the requirement for destructive testing. Additionally, the results demonstrate that these correlations are impacted by the type of cement and the age of the concrete, demonstrating that these two parameters have an impact on the outcomes and that it is important to consider them.

Keywords: non-destructive testing, rebound hammer, ultrasonic pulse velocity, compressive strength, cement type

Kulcsszavak: rombolásmentes vizsgálat, Schmidt kalapács, ultrahangos impulzussebesség, nyomószilárdság, cement típus

1. Introduction

The compressive strength of the concrete is a crucial indicator of the quality of this material. This characteristic is often measured using the compressive strength test on concrete samples, that have been prepared in the site. In order to confirm the obtained concrete's compressive strength by using the compression test in the laboratory, the quality of the hardened concrete on the site can be also checked using nondestructive tests, such as the rebound hammer and the ultrasonic pulse velocity test. These types of tests are simpler to carry out and allow for a quick assessment of the concrete's compressive strength to withstand the stresses planned by the engineering design.

In the past few decades, numerous tests on hardened concrete have been developed. These tests are categorized as either completely non-destructive (where there is no damage to the concrete), slightly destructive (where there is slight damage to the concrete), or partially destructive (where there is some damage to the concrete), such as coring.

These two concrete tests have drawbacks that are economic and structural stability because the coring test on the hardened concrete is typically conducted on structural elements by taking sample cores. Moreover, the destructive control methods are divided into two classes, which are: the coring test performed on the actual structure and the compressive strength performed in the laboratory on samples test constructed on site.

However, the coring operations on the concrete are expensive and the concrete structures tested can undergo degradations, which will weaken the concrete structures and minimize their service life. In the same context, the compressive tests made in the laboratory on samples, are not generally representative because they are not made in the same conditions of the site. Moreover, these samples generate significant waste, which has a harmful effect on the environment. To address this concern, the non-destructive methods are coming to remedy to these drawbacks by offering a practical and reliable means to control the concrete without damage.

In this paper, non-destructive techniques based on ultrasonic pulse velocity and the rebound hammer are the focus. The major goal of this research is to establish a correlation between the compressive strength of concrete on cylindrical samples, using a combination of the rebound hammer, ultrasonic pulse velocity, and other techniques without using the destructive tests. The obtained relationship will enable the civil engineer to forecast the compressive strength of structural components without using the destructive tests.

A mathematical model was created in this field to predict the compressive strength of hardened concrete on the site. This model provides a relationship between the compressive strength of the cores taken from the building concrete and the compressive strength determined by the two non-destructive tests, the ultrasound pulse velocity and the Rebound hammer [1]. Other models based on combined non-destructive test (rebound hammer and ultrasonic velocity) were developed by Revilla-Cuesta V et al. [2], in order to predict the compressive strength of high flowability SCC in real structures. There is a strong correlation between all the models in a linear mathematical relationship between compressive strength and Rebound Number readings using the Minitab 15 program; the correlation ranges from 91% to 98%, indicating a perfect relationship between the concrete compressive strength and the readings of Rebound Hammer Number [3]. Additionally, the destructive compressive test and the rebound hammer test were correlated using MATLAB software, and the three obtained relations (linear, quadratic, and cubic) allowed for the evaluation of the compressive strength of concrete using only the rebound hammer test. These relations were as follows:

Linear relation $f = 1.0501x_1 - 11.8402$ (1)

Quadratic relation $f = -0.0078\, x_1^2 + 1.5979\, x_1 - 21.1986$ (2)

Cubic relation $f = -0.029\, x_1^3 + 0.2975\, x_1^2 - 8.8004x_1 + 94.4267$ (3)

Where x_1 = is the Schmidt hammer rebound strength (MPa), these relationships can be used by engineers to predict the concrete compressive strength [4]. Moreover, the validity of the analytical models that were published in the literature was tested using a destructive and non-destructive test database. This work suggests a fresh, reliable model that can forecast the compressive strength of structures made of Italian reinforced concrete [5]. Similar to this, a study was carried out to evaluate the compressive strength of concrete utilizing ultrasonic pulse velocity and Rebound Hammer testing. The results of this study show that the concrete compressive strength measured via sample smashing, non-destructive tests (ultrasonic pulse velocity and Rebound Hammer), and combination testing are all connected by this relationship. The relationship is:

$f_c(V, R) = -173.04 + 4.07V^2 + 57.96\,V + 1.31\,R$ [6] (4)

A mixed empirical model using non-destructive techniques is also included (Rebound Hammer and Utrasonic pulse velosity). This model allows for a 10% error in the prediction of concrete compressive strength [7].

In order to evaluate the compressive strength of concrete structures in the cities of Izmit and Istanbul (Turkey), a further combined method test (combination between the concrete core strength and Ultrasonic Pulse Velocity) is also utilized. The linear relationships are as follows:

CCS = 0.544 (UPV) -15.343 with a correlation
$R^2 = 0.8452$ (Cores of Istanbul) (5)

CCS = 0.062 (UPV) -46.497 with a correlation
$R^2 = 0.914$ (Cores of Izmit) (6)

CCS: Concrete Core Strength, UPV = Ultrasonic Pulse Velocity. Since each region has its unique aggregates and cements that affect the results of ultrasonic testing, it is evident from relations (5) and (6) that each region has its own relation, indicating the need to construct a relation for each region [8, 9]. On the other hand, the non-destructive tests used to ascertain the mechanical characteristics of the hardened concrete demonstrate that the evaluation of the strength of the concrete is significantly influenced by the hardness of the particles [10]. Calibration of the obtained compressive strength with the non-destructive methods and the compressive strength of the cylindrical samples (cores) extracted from the same structural elements close to the non-destructive test locations are required due to the variation in the mechanical properties of the concrete tested on site and its relationship with the combined test methods [11]. Studies were conducted on the impact of the components of concrete, the mixture, and the variables related to the effectiveness of non-destructive testing methods for concrete (Rebound Number and Ultrasonic Pulse Velocity) to create a method that combines the two approaches for evaluating the compressive strength of concrete. This study demonstrates that the Rebound Hammer Number increases with concrete compressive strength and that cement kinds, aggregate types, and the presence of voids in concrete have a significant impact on ultrasonic pulse velocity outcomes. Combining the two approaches will address these drawbacks and enable accurate evaluation of concrete compressive strength [12]. The variability of NDT measures can be studied with statistical analyses in order to increase the dependability of the results from non-destructive tests [13]. Additionally, a survey of the non-destructive methods' literature reveals that most of the (NDT) techniques are founded on empirical relationships supplied by the devices' producers. These devices' output findings need to be adjusted utilizing a set of laboratory-conducted correlations [14, 15]. The dependability of the data obtained depends on the type of non-destructive tools used, such as the rebound Hammer [16]. A method for calibrating non-destructive tests on the spot is also needed to enhance the assessment of concrete durability indicators. The study of the in-situ data and the acquisition of the sustainability indicators were the two goals for which this calibration was suggested (porosity and degree of saturation). Compressive strength and water content can both be accurately assessed in the same setting [17, 18]. Non-destructive tests were reviewed, their benefits and drawbacks shown, and a classification of these techniques based on these factors and their applications formed [19]. The accuracy of the concrete compressive strength prediction formulas, which are most frequently employed in Italy, is also examined using the findings of the Rebound Hammer and Ultrasonic pulse velocity. The combined techniques (Rebound Hammer and Ultrasonic Velocity) can increase their accuracy and forecast the compressive strength of concrete [20].

The obtained relationships were the following:

$$f_c = 7.695.10^{-11}.(RI)^{1.4}.(V)^{2.6} \quad (7)$$

$$f_c = 1.2.10^{-9}.(RI)^{1.058}.(V)^{2.446} \quad (8)$$

$$f_c = 0.0286.(RI)^{1.246}.(V)^{1.85} \quad (9)$$

Additionally, relationships between destructive and non-destructive tests were proposed, and these relationships make it possible to combine the two non-destructive tests—ultrasonic pulse velocity and non-destructive test—to estimate the concrete's compressive strength (ultrasonic velocity and Rebound Hammer). These connections also depend on the tested concretes' range of compressive strengths [21, 22]. a connection between the compressive strength of cubes or cylinders, the ultrasonic pulse velocity measurement method, and the rebound hammer. There is a 20% inaccuracy indicated [23]. The ultrasonic pulse velocity approach is the most effective method for assessing the compressive strength of existing reinforced concrete structures, according to their study [24, 25]. Furthermore, as concrete ages, the compressive strength measured using destructive and non-destructive tests declines [26]. Another option is to estimate how much the old structures are deteriorating using non-destructive approaches [27, 28]. Moreover, the results from these tests are influenced by numerous factors such as the w/c ratio, concrete carbonation, cure and the cement type [29].

The main goal of this work is to investigate and emphasize these impacts because, according to earlier research in the field listed in this one, they have not been studied in relation to non-destructive test findings. The first step in conducting this investigation is to establish a correlation between the compressive strength measured by crushing (a destructive method) and the Rebound Hammer and ultrasonic pulse velocity indices. The readings of the Rebound Hammer and Ultrasonic Pulse Velocity are also influenced by the type of cement used in the creation of concrete. The second portion of this work involved two concrete formulations using two different types of cements (NA 442- CEM I 42.5 R and CEM II/A-L 42.5 R). The findings of this study indicate that the relationship between compressive strength and non-destructive testing is influenced by the kind of cement and the age of the concrete (the Rebound Hammer and Ultrasonic Pulse Velocity). Additionally, without using destructive tests, the results for the two types of cement enable engineers to anticipate the compressive strength of concrete buildings in situ.

2. Materials

2.1 Cements

The two types of cements used in this study (NA 442- CEM I 42.5 R and CEM II/A-L 42.5 R) were made in BISKRA, which is in the southeast of Algeria, and are known as BISKRIA CEMENT. The characteristics with regard to Algerian Standard NA 442 are presented for NA 442- CEM I 42.5 R in the *Tables 1, 2*, and *3* and for CEM II/A-L 42.5 R in the *Tables 4, 5,* and *6*, respectively.

The cements densities are respectively 3.07 g/cm³ for NA 442- CEM I 42.5 R and 3.13 g/cm³ for CEM II/A-L 42.5 R.

Elements	Content %	Standards
SO_3	2.30	(NA 237) < 3.5%
CL	0.028	(NA 5080) ≤ 0.1%
P.A.F	2.04	(NA 237) ≤ 5%
C_3S clinker	62	In accordance with Bogue
C_2S clinker	13	In accordance with Bogue
C_3A clinker	1.5	In accordance with Bogue
C_4AF clinker	17	In accordance with Bogue

Table 1 Chemical characteristics of used cement NA 442- CEM I 42.5 R
1. táblázat A felhasznált cement NA 442- CEM I 42.5 R kémiai jellemzői

Designation	Measures	Standards
Specific surface Blaine (cm²/g)	3420	(NA231)
Start of taking (min)	180	(NA233) ≥60 min
Hot expansion (min)	0.5	≤10mm(NA232)
Consistence (%)	25.7	T(NA290)

Table 2 Physics characteristics of used cement NA 442- CEM I 42.5 R
2. táblázat A felhasznált cement NA 442- CEM I 42.5 R fizikai jellemzői

Mechanic proprieties			
Compressive strength (MPa)	2 days	≥10	10
	28 days	62.5≥R≥42.5	40

Table 3 Mechanic characteristics of used cement NA 442- CEM I 42.5 R
3. táblázat A felhasznált cement NA 442- CEM I 42.5 R mechanikai jellemzői

Elements	Content %	Standards NA 442
SO_3	2.00	< 3.5%
CL^-	0.08	≤ 0.1%
C_3S clinker	60	In accordance with Bogue
C_2S clinker	6	In accordance with Bogue

Table 4 Chemical characteristics of used cement CEM II/A-L 42.5 R
4. táblázat A felhasznált cement CEM II/A-L 42,5 R kémiai jellemzői

Designation	Measures	Standards
Specific surface Blaine (cm²/g)	4200	(NA442)
Start of taking (min)	180	(NA442) ≥60 min

Table 5 Physics characteristics of cement CEM II/A-L 42.5 R
5. táblázat A CEM II/A-L 42,5 R cement fizikai jellemzői

Mechanic characteristics		
Compressive strength (MPa)	2 days	≥10
	28 days	62.5≥R≥42.5

Table 6 Mechanic characteristics of cement CEM II 42.5/A-L 42.5 R
6. táblázat A CEM II 42.5/A-L 42.5 R cement mechanikai jellemzői

2.2 Aggregates

- Sand

The alluvial sand utilized in the two concrete formulations originates from the Oued M'zi quarry, which is close to the Algerian city of Laghouat. According to the granulometric analysis curve (*Fig. 1*), this sand has tight granulometry and ranges in fineness from around 2.5 to 5 mm. Its sand equivalent indicates that it is clean sand, and by current standards, it may be utilized to produce high-quality concrete.

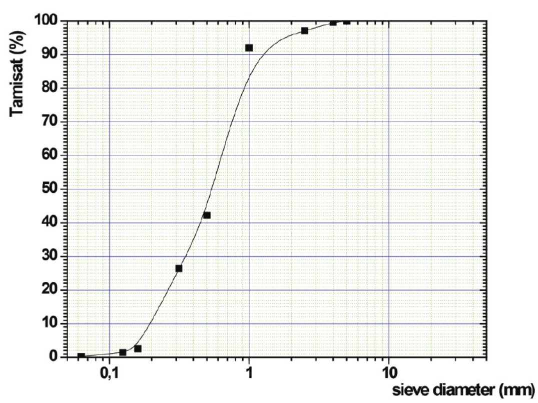


Fig. 1 Curve of granulometric of used sand
1. ábra A használt homok szemcseméret-eloszlása

- Gravels

The gravel utilized was limestone crushed gravel, consisting of two granular classes with sizes ranging from 3 to 8 millimeters to 8 to 15 millimeters, and it came from a quarry in Algeria's Laghouat region. The granulomere curves for the two categories of gravel are shown in *Fig. 2*. The physical characteristics of the employed gravels are summarized in *Table 7*.

Physical characteristic of the used gravels and sand	Standard	Aggregates		
		Sand	Gravels	
		0/5	3/8	8/15
Apparent Density (g/cm³)	NF P 18-554	1.564	1.319	1.255
Absolute density (g/cm³)		2.6	2.65	2.65
Absorption Coefficient (%)		1	1.5	1.5

Table 7 Physical characteristic of the used aggregates
7. táblázat A felhasznált aggregátumok fizikai jellemzői

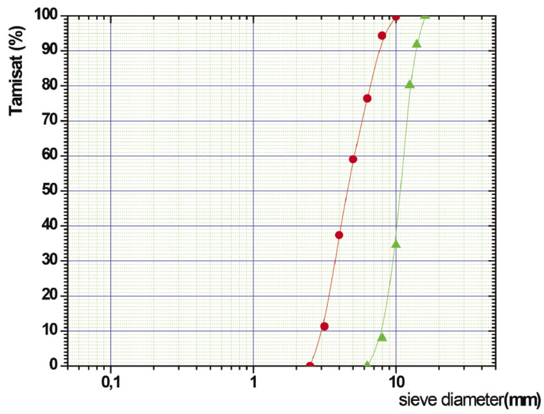


Fig. 2 Granulometric curve of the two classes of gravels size 3-8 mm and 8-15mm
2. ábra A 3-8 mm és a 8-15 mm méretű kavicsok két osztályának szemcseméret-eloszlási görbéje

Fig. 2 show, that the grain size is acceptable for both classes of the used gravel.

- Concrete formulations

The DREUX GORISSE method was used to formulate the concrete, and *Table 8* shows the outcomes of various formulations.

Designation of components		Constituent per weights (kg/m³)	Concrete density (kg/m³)	Slump test (cm)
		Biskria Cement E/C=0.6		
Cement	CEM II/A-L 42.5 R	350	2270	7.5
	NA 442- CEM I 42.5 R	350		
Sand 0-5 mm		586,5		
Gravel	3-8mm	174,8		
	8-15mm	943,5		
Water		215,44		

Table 8 Results of the two concretes formulations
8. táblázat A két betonkészítmény eredményei

All of the mixes were combined in a concrete mixer with a vertical axis and a fixed tank with a capacity of 130 litres after washing and drying the used aggregates.

Gravel, cement, and sand were introduced first before the other components. The water is added after one minute of dry mixing, and mixing is continued for at least two minutes to produce a homogeneous slurry. The workability was assessed immediately following each mixing in accordance with standard NF EN 12350-2 using the Abrams cone; the results of the slump test are displayed in *Table 8*.

- Preparation and storage of samples

For each type of cement, cubic samples measuring $10 \times 10 \times 10$ cm³ were prepared based on the concrete formulations' results (*Table 9*).

Storage mode	Age (days)	Number of confectioned samples		Water / cement
		CEM II/A-L 42.5 R	NA 442- CEM I 42.5 R	
Controlled humidity chamber	7	50	50	0.6
	28	50	50	

Table 9 Samples for the both concretes formulations
9. táblázat A két betonkészítmény mintái

All types of concrete were made in a laboratory setting. All samples were covered right after preparation to minimize the risk of excessive evaporation and plastic shrinkage. The samples were taken out of the moulds 24 hours later and maintained in the humid chamber (RH = 90%) (*Fig. 3*).

Fig. 3 Samples conserved in laboratory environment
3. ábra Laboratóriumi környezetben tárolt minták

3. Methods

3.1 Materials used for destructive and non-destructive testing

The cubic samples were subjected to destructive and non-destructive tests at ages 7 and 28 days. To get ready for non-destructive tests, the faces of each cubic sample must be sanded with an abrasive stone prior to the start of each test.

The metal molds were used to prepare the 10 x 10 x 10 cm³ concrete cubic samples.

The non-destructive tests were conducted using a Schmidt Rebound Hammer and an ultrasonic pulse velocity instrument; the models of the utilizing devices are as follows:

3.1.1 Schmidt Rebound Hammer (Rebound Hammer)

The Rebound Hammer test entails projecting a load with a fixed initial energy onto the concrete surface. After the shock, some of the energy is absorbed by the concrete and some of it makes the mass bounce back. The impact energy is created by a system of springs, whose recoil movement's amplitude depends on the recoil energy and spring system properties.

A non-destructive method of assessing a concrete's strength is to measure its impact hardness. This approach is intriguing because it is straightforward and enables quick verifications of the consistency of the concrete in a construction.

The method for determining hardness involves measuring the amount of recoil that a spring-controlled mobile device experiences after colliding with a concrete surface. The Schmidt hammer test, also known as the Rebound Hammer test (*Fig. 4*), was created by ERNST SCHMIDT in 1948 and is one of the oldest non-destructive tests still in use today.

Fig. 4 Rebound Hammer type N model C 181
4. ábra C 181 típusú N típusú Schmidt kalapács C 181

- Operating mode of the Rebound Hammer

Before beginning the Rebound Hammer tests, the test pieces were placed between the press plates with the molded faces in contact, ensuring that the direction of compression was perpendicular to the direction of the concrete confection. This was done after the test pieces had undergone an ultrasound pulse velocity test to remove any remaining grease from their faces. According to standard NF EN 12504-2, the sample was maintained between the plates by compression under an initial load of around 15% of the final charge after the loading speed was set to 0.5 MPa/s (i.e., 5 KN/s, which corresponds to the 10 cm cube).

The maintained sample test's two opposite faces were subjected to twelve Rebound Hammer tests, which were conducted in the horizontal compression machine position (*Fig. 5*). The test result for each sample test is then expressed as a whole number in accordance with European Standard NF EN 12504-2 and represents the median value of all readings taken on both sides.

Fig. 5 Measurement of the rebound index with the Rebound Hammer
5. ábra A visszapattanási index mérése a Schmidt kalapáccsal

3.1.2 The ultrasonic device

The Ultrasonic Pulse Velocity is type E 46 with transducers of 50 mm of diameter and 54 kHz of frequency (*Fig. 6*).

Fig. 6 The used device of Ultrasonic Pulse Velocity
6. ábra Az ultrahangos impulzussebesség mérésére használt eszköz

- Operating mode of the ultrasonic Pulse velocity device

The operator must verify that the instrument is functioning correctly by calibrating it using the calibration bar before performing the ultrasonic tests. The direct transmission method was used to conduct the ultrasonic tests, ensuring that the direction of transit time measurement was parallel to the direction of preparation. The two transducers were positioned on the opposing sides of the test tube with a thin coating of grease in between them (*Fig. 7*), and the transit time in microseconds was then recorded. According to standard NF EN 12504-4, the ultrasonic test result for each sample is the median value of two measurements made in both directions. As a result, the determined ultrasonic speed is expressed as 0.01 km/s.

Fig. 7 Transit time measurement with ultrasonic device
7. ábra Átfutási idő mérése ultrahangos eszközzel

3.1.3 Compression machine

The study's damaging test was a straightforward compression test employing a hydraulic press with a 3000 kN capability (*Fig. 8, 9*).

Fig. 8 Hydraulic press with the capacity of 3000 kN
8. ábra 3000 kN kapacitású hidraulikus prés

Fig. 9 Crushing of the cubic samples
9. ábra A kocka alakú minták törése

4. Results and discussions

At the civil engineering research lab, these tests were conducted. Utilizing the hydraulic press described in the section prior, cubic samples were subjected to crushing tests, Rebound Hammer tests were conducted using a calibrated Rebound Hammer, and ultrasonic tests were conducted using a device available in the Laghouat University's Civil Engineering Research Laboratory.

4.1 Relationship between compressive strength (MPa) and the Rebound Hammer (I) in horizontal position

4.1.1 Concrete formulation with NA 442- CEM I 42.5 R at 7 and 28 days

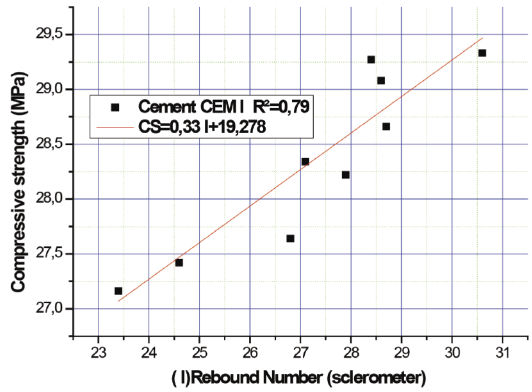
The rebound Hammer index as a function of compressive strength at 7 and 28 days of concrete age is depicted in *Fig. 10*.

The correlations between the compressive strength and the Rebound Number (I) that were discovered from the *Fig. 10* are linear regressions.

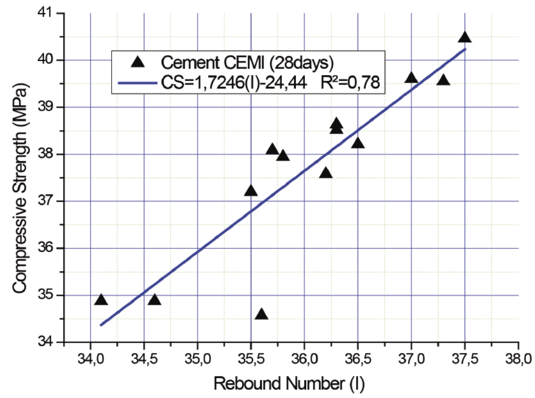
For age 7 days CS = 0.33 I +19.278
with the coefficient of correlation $R^2 = 0.79$ (10)
For age 28 days CS = 1.4248 I - 24.44
with the coefficient of correlation $R^2 = 0.78$ (11)

Where CS is the predicted compressive strength of cubic samples in MPa and I is the rebound hammer number. These two relationships allow concretes made with cement type NA 442- CEM I 42.5 R to be estimated to have compressive strength using the reading of the Rebound Hammer Number at a young age (7 days) and at an age (28 days).

Additionally, these relationships demonstrate that the compressive strength of concrete cubic samples at 7 days of age was between 27 and 29 MPa, while at 28 days of age it was between 34 and 41 MPa. These data can be used to forecast the compressive strength of concretes made using NA 442- CEM I 42.5 R cement at the commonly applicable ages (7 days and 28 days) allowing the engineers to assess the concrete construction in-situ using just a nondestructive test (Rebound Hammer). These findings also demonstrate the impact of concrete age on compressive strength measurements made with a rebound hammer.



a)



b)

Fig. 10 Rebound Hammer Index as function of the compressive strength at 7 (a) and 28 (b) days age of concrete (NA 442- CEM I 42.5 R)
10. ábra A visszapattanási index a nyomószilárdság függvényében a beton 7 (a) és 28 (b) napos korában (NA 442- CEM I 42,5 R)

4.1.2 Concrete formulation with CEM II/A-L 42.5 R at 7 and 28 days

The compressive strength of concrete at 7 and 28 days old is shown in the *Fig. 11*, along with the rebound number of the Rebound Hammer.

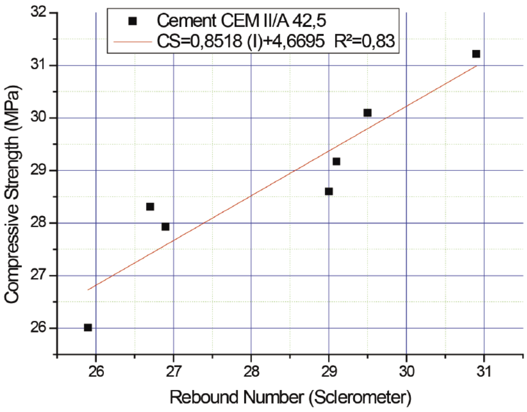
The relationship (12) and (13) between the compressive strength and the Rebound Number(I) that were discovered from the *Fig. 11* are linear regressions.

For 7 days of age CS = 0.8518 I +4.6695
with the coefficient of correlation $R^2 = 0.83$. (12)
For 28 days of age CS = 0586 I + 17.57
with the coefficient of correlation $R^2 = 0.78$. (13)

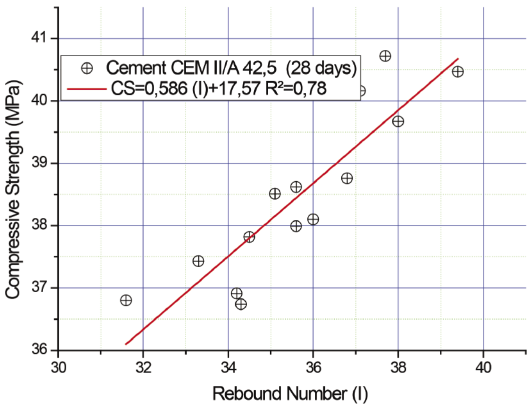
Where CS: the predict compressive strength in (MPa) on cubic samples; I: Rebound Number.

For concretes that are formed using cement of the CEM II/ A-L 42.5 R type, these two relationships (12) and (13) allow for the prediction of the compressive strength as a function of the reading of the Rebound Hammer index at early ages (7 days) and at ages of 28 days.

Additionally, these connections demonstrate that the concrete compressive strength of cubic samples at 7 days of age ranged from 27 MPa to 31 MPa, whereas that at 28 days of age ranged from 36 MPa to 40 MPa.



a)



b)

Fig. 11 *Rebound Hammer Index as function of the compressive strength at 7 (a) and 28 (b) days age of concrete (CEM II/A-L 42.5 R)*

11. ábra *A visszapattanási index a nyomószilárdság függvényében a beton 7 (a) és 28 (b) napos korában (CEM II/A-L 42.5 R)*

These data can be used to forecast the compressive strength of concretes made using CEM II/A-L 42.5 R cement at the typically useful ages (7 days and 28 days) for the engineers to examine the concrete construction in-situ using just a non-destructive test (Rebound Hammer). Additionally, these data demonstrate that the type of cement has an impact on the outcomes of the rebound Hammer test. These correlations led to the conclusion that the age of the concrete and the kind of cement (NA 442- CEM I 42.5 R and CEM II/A-L 42.5 R) had an impact on the compressive strength of the concrete that can be measured using a non-destructive test (Rebound Hammer).

4.2 Relationship between compressive strength and the Ultrasonic Pulse velocity at 7 and 28 days of age

4.2.1 Concrete formulation using cement type NA 442- CEM I 42.5 R at 7 and 28 days

The ultrasonic pulse velocity at 7 and 28 days of concrete age is shown in *Fig. 12* as a function of compressive strength.

The connections between compressive strength and ultrasonic pulse velocity (V) derived from *Fig. 12* are linear regressions.

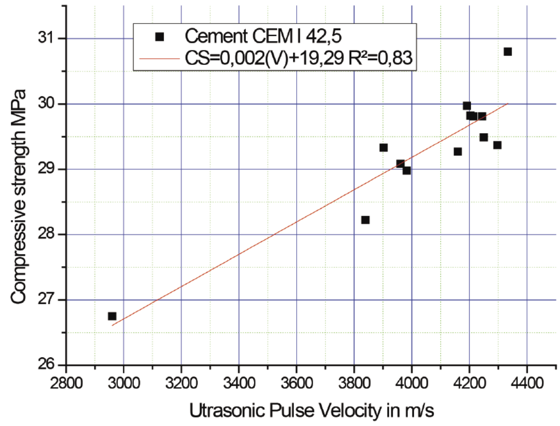
For 7 days of age $CS = 0.002\ V + 19.29$ with the coefficient of correlation

$$R^2 = 0.83 \tag{14}$$

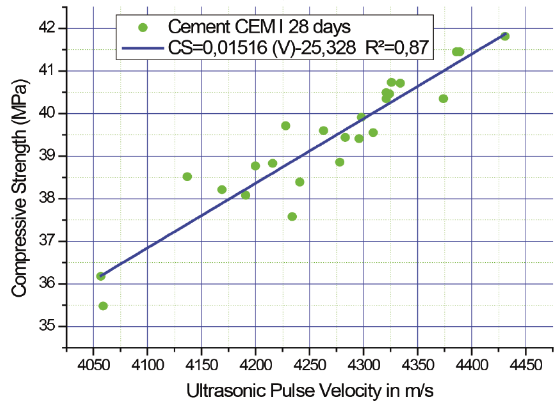
For 28 days of age $CS = 0.01516\ V - 25.328$ with the coefficient of correlation

$$R^2 = 0.87 \tag{15}$$

Where V is the ultrasonic pulse velocity and CS is the predicted compressive strength in MPa for concrete cubic samples. With the aid of these two relationships, compressive strength can be predicted using the Ultrasonic Pulse Velocity reading for both young (7-day-old) concretes and older concretes (28-day-old) made with the NA 442- CEM I 42.5 R cement type. Additionally, these connections demonstrate that the compressive strength of concrete cubic samples at 7 days of age ranged from 26 MPa to 30 MPa, whereas that at 28 days of age it ranged from 36 MPa to 42 MPa.



a)



b)

Fig. 12 *Ultrasonic Pulse velocity as function of the compressive strength at 7 (a) and 28 (b) days of concrete age (NA 442- CEM I 42.5 R)*

12. ábra *Ultrahangos impulzussebesség a nyomószilárdság függvényében a beton 7 (a) és 28 (b) napos korában (NA 442- CEM I 42.5 R)*

These obtained results can be used in the prediction for the compressive strength of concretes formulated using the NA 442- CEM I 42.5 R cement type at the generally useful age (7 days and 28 days) for the check in-situ by the engineers of the concrete structure using only a non-destructive test (Ultrasonic Pulse Velocity).

These correlations lead to the conclusion that the cement type (NA 442- CEM I 42.5 R and CEM II/A-L 42.5 R) and the age of the concrete have an impact on the results of the non-destructive test for concrete compressive strength (Ultrasonic Pulse velocity).

4.2.2 Concrete formulation using cement type CEM II/A-L 42.5 R at 7 and 28 days of age.

Fig. 16 and *17* depict the relationship between the ultrasonic pulse velocity and the compressive strength of concrete at 7 and 28 days of age.

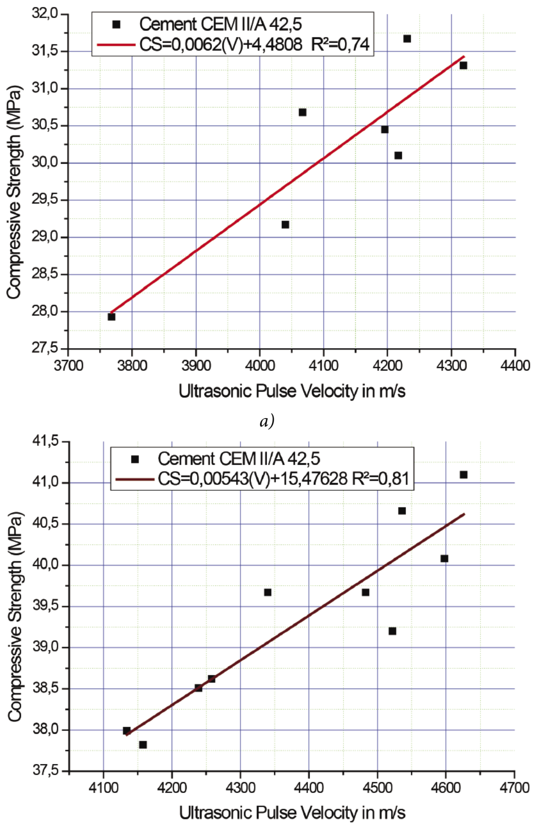


Fig. 13 Ultrasonic Pulse velocity as function of the compressive strength at 7 (a) and 28 (b) days of concrete age (CEM II/A-L 42.5 R)

13. ábra Ultrahangos impulzussebesség a nyomószilárdság függvényében a beton 7 (a) és 28 (b) napos korában (CEM II/A-L 42.5 R)

The connections between compressive strength and ultrasonic pulse velocity (V) derived from *Fig. 13* are linear regressions.

For 7 days of age CS = 0.0062 V + 4.4808
with the coefficient of correlation R^2=0.74 (16)

For 28 days of age CS = 0.00543 V + 15.47628
with the coefficient of correlation R^2=0.81 (17)

Where CS is the anticipated compressive strength of cubic samples in MPa and V is the ultrasonic pulse velocity. The compressive strength can be predicted using the Ultrasonic Pulse Velocity reading for concretes at a young age (7 days) and at an older age of 28 days for concretes made with CEM II/A-L 42.5 R cement type thanks to these two connections.

Furthermore, these connections demonstrate that while the compressive strength of cubic samples at 7 days ranged from 26 MPa to 31 MPa, it varied from 38 MPa to 41 MPa at 28 days. These data can be used to forecast the compressive strength of concretes made using CEM II/A-L 42.5 R cement at the typically usable ages (7 days and 28 days) for the engineers to examine the concrete construction in-situ using only the non-destructive test (Ultrasonic Pulse Velocity).

These correlations lead us to the conclusion that the age of the concrete and the type of cement (CEM I 42.5 and CEM II/A-L 42.5 R) have an impact on the results of the non-destructive test for concrete compressive strength (Ultrasonic Pulse velocity).

5. Conclusions

These relationships were developed for two cement types (CEM I 42.5 and CEM II/A-L 42.5 R), and for two concrete ages, namely 7 and 28 days. In this work, relationships between concrete compressive strength and non-destructive testing (Rebound Hammer and Ultrasonic Pulse Velocity) have been established.

The following conclusions can be summarized from these relationships:

1. Using non-destructive testing tools (Rebound Hammer and Ultrasonic Pulse Velocity), engineers can use the relations to predict the compressive strength of concrete in situ for concrete ages of 7 and 28 days.
2. The age of the concrete affects the results obtained using the non-destructive tests; as a result, engineers must take the age of tested concrete into account when using these relations.
3. The type of cement has an impact on the obtained regression linking the concrete compressive strength and non-destructive tests.
4. Based on these findings, relationships between compressive strength and non-destructive tests for the three most common concrete aging times — 7, 14, and 28 days —need to be established.

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