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Experimental Determination of Concrete Compressive Strength by Non-Destructive Ultrasonic Pulse Velocity Method

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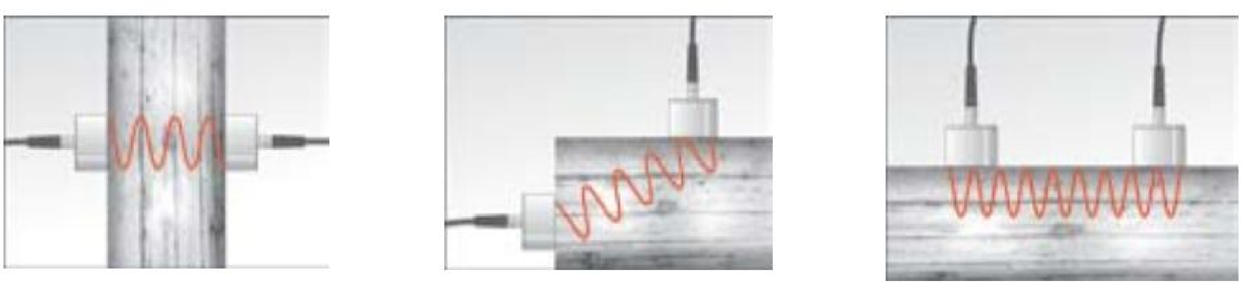
***Abstract**: In this paper are described the experimental researches for determining the concrete compressive strength by the measured velocity of ultrasonic pulse, using the Non-Destructive Ultrasonic Pulse Velocity Method. The researches were performed on 27 cubic specimens and 54 cylindrical specimens produced according to EN 12390-2:2009 and tested on age of concrete between 3 days and 1126 days. The test specimens were prepared of concrete grade C25/30, fine fraction of course aggregate (dmax=12 mm), consistency S3. After determining the probable concrete compressive strengths with portable ultrasonic testing instrument type "Proceq – TICO", using the Non-Destructive Ultrasonic Pulse Velocity Method according to EN 12504-4:2004, the obtained results are compared to experimentally determined concrete compressive strengths according to EN 12390-3:2009 and theoretically calculated strengths according to EN 1992-1-1:2004.*
***Keywords**: Experiment, compressive strength, material density, non-destructive method, ultrasonic pulse velocity method, EN 12504-4:2004*

I. INTRODUCTION

The application of ultrasonic waves for measurements in buildings and facilities construction is a relatively new method. It began tobe used at the end of the last century. In the last years the ultrasonic pulse velocity method is one of the most frequently and widely used methods for non-destructive control of properties of building materials and the quality of performance of concrete and reinforced concrete structures. In this method is measured the time or velocity of distribution of ultrasonic pulses into the mass of tested structural elements. This method is easy to use and the results could be obtained fast in place. The measurements are carried out with specialized portable devices, which consist of:

A. a high frequency generator that produces electrical signals with ultrasonic frequency from 25 kHz to 200 kHz;
B. transmitting transducer that converts electrical signals into ultrasonic mechanical pulses;
C. receiving transducer that converts mechanical pulses into electrical signals;
D. an electric signal amplifier;
E. a digital display where the obtained results are displayed.

Depending on the access to the structural elements, the transmitter and the receiver could be located in one of the following three ways (fig.1) [10].



(a) (b) (c)

Fig. 1 Location of transmitting and receiving transducer at Ultrasonic Pulse Velocity Test –
a) direct transition; b) semi-direct transition; c) indirect or surface transition [10]

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The velocity of propagation of ultrasonic waves V_{UP} in concrete and reinforced concrete elements is [2]:

(1) $$V_{UP} = \frac{L}{T} \; [km/s],$$

where:

$L \; [mm]$ is the distance, passed by ultrasonic waves;

$T \; [\mu s]$ is the time for distribution of ultrasonic waves.

The concrete compressive strength based on the measured ultrasonic pulse velocity is most often determined by [1]:

(2) $$f_{c,UPV} = cV_{UP}^{3,75},$$

where:

V_{UP} is in km/s;

$f_{c,UPV}$ is in MPa;

c is factor in the range of 0,158 to 0,231.

By this method, the concrete strength at each location of a concrete or reinforced concrete element can be determined without any damages. The accuracy of this method is not great, because the velocity of ultrasonic signal depends on the type and age of concrete, on the degree of compaction of concrete, on its humidity, on properties of the coarse aggregates, on temperature and other factors.

Nonetheless, the ultrasonic pulse velocity method is an easy and inexpensive way to determine the strength properties of concrete. For improving the accuracy, it is recommended the results from these measurements to be compared with experimental results of testing standard specimens according to EN 12390-3:2009 in order to be clarified the relationship between velocity and strength.

II. EXPERIMENT – TEST SPECIMENS AND EQUIPMENT

For experimental determination of strength properties of concrete the following test specimens according to EN 12390-2:2009 [7] were produced:

A. 54 cylindrical test specimens with dimensions 150/150 mm;

B. 27 cubic test specimens with dimension 150/150/150 mm (Fig. 2).

Fig. 2 Test specimens for determining concrete compressive strength according to EN 12504-4:2004

Their dimensions are chosen according to the size of the coarse aggregate (EN 12390-1:2012) [6].

They were prepared of concrete grade C25/30, fine fraction of coarse aggregate (dmax=12 mm), consistence S3.

For obtaining reliable test results the specimens were prepared with precise dimensions, flat and smooth sides, straight edges and orners. They were made in formwork moulds of a non-deformable material with possible small deviations from the standard requirements. Formwork moulds for cylindrical specimens were made of steel while for cubic specimens were made of polyurethane.

Sampling of the concrete mixture is according to EN 12350-1 [5]. After mixing the concrete mixture the formwork moulds were filled into two layers, each of which was compacted with a vibrating table. The redundant concrete was removed after compacting, the surface was smoothed and notes with the date of preparation, the number of test specimen and concrete grade were placed.

Test specimens (Fig.2) were left in the formwork moulds for about 48 hours at a temperature $(20 \pm 5)^o C$, they are protected from hit, vibration and drying [7]. They were used for determining the strength characteristics of concrete according to [2], [3], [9] on the age of concrete between 3 days and 1126 days.

The experimental investigations for determining probable concrete compressive strength by the measured ultrasonic pulse velocity, using the Ultrasonic Pulse Velocity Method were performed with portable ultrasonic testing instrument type "Proceq – TICO" with measuring range from 15 µsec to 6550 µsec (Fig. 3).

(a)

(b)

Fig. 3 Determining concrete compressive strength with Ultrasonic Testing Instrument Type Proceq-TICO

III. TEST RESULTS AND DISCUSSION

The measurements are performed on 81 test specimens on age of concrete 3rd, 7th, 14th, 28th, 244th, 280th, 293rd, 342nd and 1026th day. For each specimen 10 measurements were done. Transmitting and receiving transducers were positioned symmetrically against each other (Fig. 3b). Before each measurement, the equipment is calibrated with calibration rod with known velocity of the ultrasonic pulse (Fig. 3a).

The theoretical cylindrical compressive strength of concrete at different age $f_{ck}(t)$ according to EN 1992-1-1 [4] is determined by:

(3) $$f_{ck}(t) = f_{cm}(t) - 8 \ [MPa].$$

Mean value of the cylindrical compressive strength $f_{cm}(t)$ at age t days is calculated by:

(4) $$f_{cm}(t) = \beta_{cc}(t) f_{cm} \ [MPa].$$

The factor $\beta_{cc}(t)$ is determined by the following formula:

(5) $$\beta_{cc}(t) = e^{s\left(1-\sqrt{\frac{28}{t}}\right)},$$

where: s is factor, depending on the type of the cement.

The experimental values of cylindrical compressive strength of concrete, determined according to EN 12390-3:2009, published in [8] are used for the comparison. In Table 1 are given the mean values of measured velocities of propagation of ultrasonic waves at different age of concrete. For each day of measurement 3 cubic and 6 cylindrical specimens were tested.

TABLE 1 Mean Values Of Measured Velocities Of Propagation Of Ultrasonic Waves At Different Age Of Concrete

Age of concrete	Days	3	7	14	28	244	280	293	342	1126
Mean velocity of propagation of ultrasonic waves	m/s	3811.83	4081.33	4148.67	4229.83	4263.00	4288.50	4307.50	4329.17	4368.67

Fig. 4 shows graphical dependencies of mean values of concrete compressive strength for each day of experiments as follows:

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C. with blue line are shown the experimentally determined strengths with ultrasonic pulse velocity method according to EN 12504-4:2004;
D. with red line - experimentally determined strengths according to EN 12390-3:2009;
E. with green line – the strengths calculated according to EN 1992-1-1:2004.

In table 2 are given the mean values of the obtained according the two standards [2], [3] and calculated according to [4] concrete compressive strengths at each day of testing and the error, in percentage, between the experimentally determined and theoretically calculated values.

From the three graphical dependencies, it can be seen that the compressive strength increases with increasing the age of the concrete. The errors (Table 2) of experimentally determined compressive strengths according to [2] related to theoretically calculated by formulas (3), (4) and (5) are greater (from 100,3% to 17,4%) in comparison with those, determined according to [3] (from 47,3% to 13,5%). The big differences are up to age of concrete 28 days.

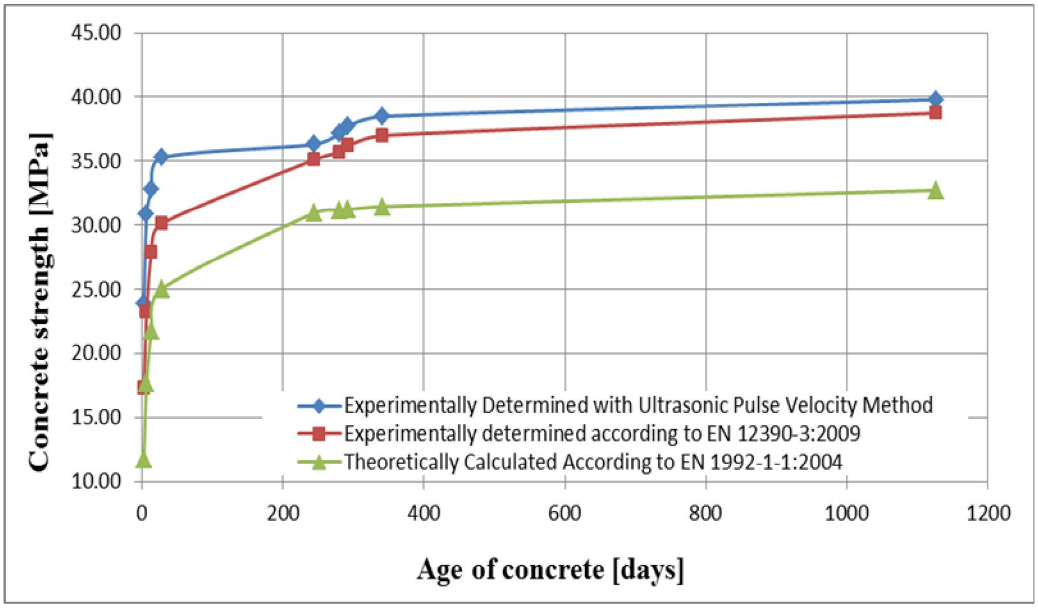

Fig.4 Dependencies of mean values of concrete compressive strength at different age of concrete

TABLE 2
MEAN VALUES OF THE EXPERIMENTALLY OBTAINED AND THEORETICALLY CALCULATED CONCRETE COMPRESSIVE STRENGTHS AND THE RELATIVE ERROR FOR EACH OF THE DAYS

Age of concrete	Compressive strength			Error	
	EN 12504-4	EN 12390-3	EN 1992-1-1	EN 12504-4	EN 12390-3
[Days]	[MPa]	[MPa]	[MPa]	[%]	[%]
3	23.87	17.3	11.74	103.3	47.3
7	30.84	23.2	17.70	74.3	31.1
14	32.80	27.9	21.75	50.8	28.3
28	35.27	30.1	25.00	41.1	20.4
244	36.32	35.1	30.93	17.4	13.5
280	37.14	35.7	31.15	19.2	14.6
293	37.76	36.2	31.22	20.9	15.9
342	38.47	37	31.45	22.3	17.7
1126	39.81	38.73	32.73	21.6	18.3

IV. CONCLUSIONS

In this paper are compared the experimentally determined concrete compressive strengths according to EN 12504-4:2004 and EN 12390-3:2009 with theoretically calculated results at different age of concrete with grade C25/30. This research contributes to a better understanding and the use with greater confidence of the ultrasonic non-destructive method for diagnosing and controlling the properties of building materials and the quality of performance of concrete and reinforced concrete structures, particularly in buildings and facilities in exploitation. The obtained results are reliable, the measurements are quick, the equipment is cheap.

V. ACKNOWLEDGMENT

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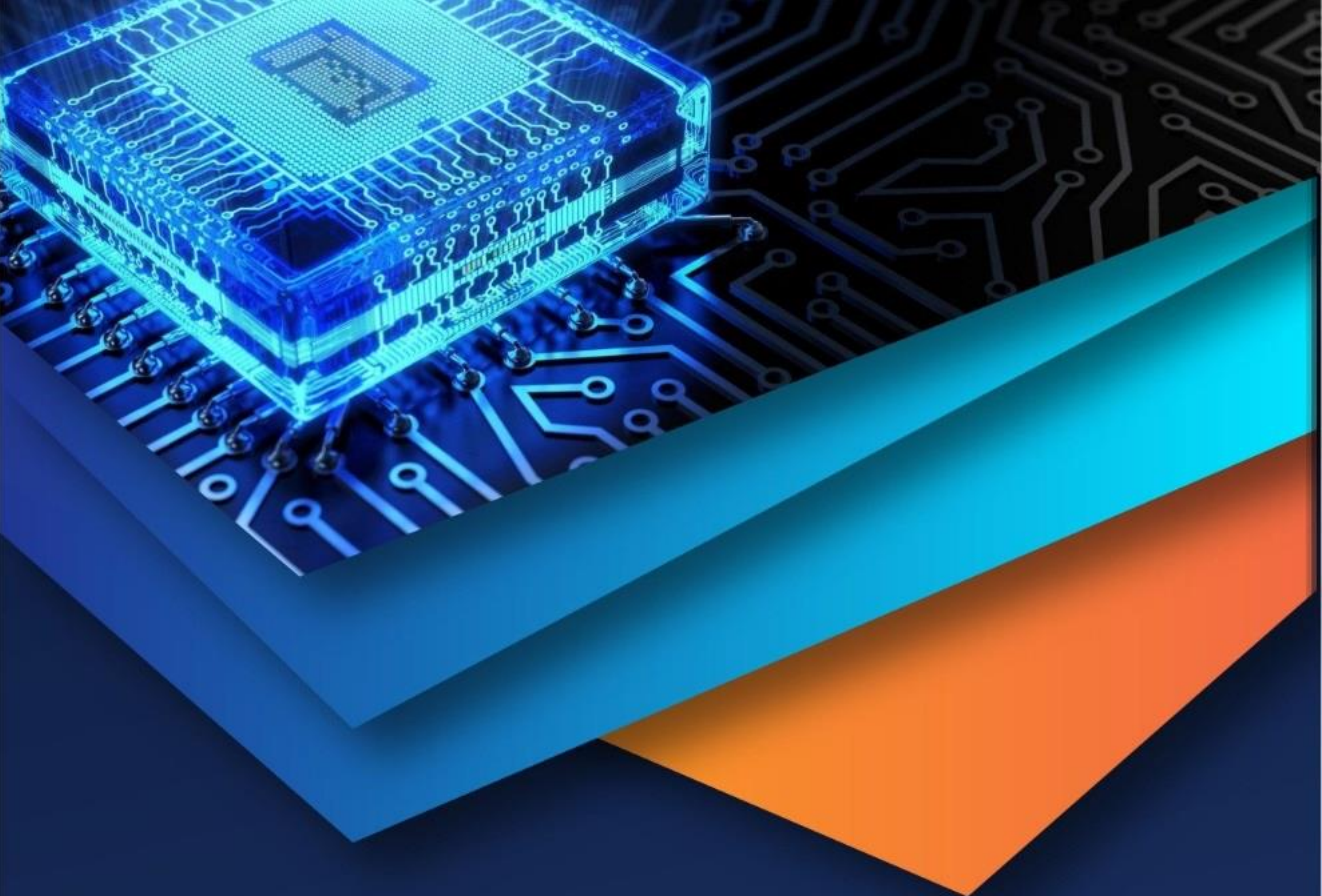

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