The 8th International Conference of the Slovenian Society for Non-Destructive Testing
»Application of Contemporary Non-Destructive Testing in Engineering«
***September 1-3, 2005, Portorož, Slovenia*, pp. 117-122**

USING OF ULTRASONIC PULSE METHOD FOR PREDICTION OF STRENGTH OF BLENDED CEMENTS

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ABSTRACT

One of the ways how to rationalize the experimental work is to put to use the non-destructive testing methods. In case of the strength testing of the various age cement specimens the usage of the ultrasonic pulse method appears to lead to decrease the necessary amount of tested samples. Application of this method requires fixed initial conditions like constant proportion of components, identical testing samples and constant sample's condition during the testing. The methodology of testing and also the calibration correlations for the compressive strength or tensile bending strength and propagation velocity of ultrasonic pulses, are mentioned in this paper.

***Keywords**:* Cement, Non-destructive testing methods, Ultrasonic pulse method, Propagation velocity of ultrasonic pulses, Compressive strength, Tensile strength

1. Introduction

Testing of building materials by ultrasonic pulse method is included in Czech technical standards only in view of concretes [1-4] and natural building stone [5].
In testing of concretes, the ultrasonic pulse method is used to detect dynamic modules of elasticity and homogeneity, to determine the depth of cracks in concrete structures or to discover changes in microstructure of concrete, when tracing its durability (variations of ultrasonic pulse propagation velocity, eventually of dynamic modules reckoned thereof as a supporting parameter for testing of frost resistance or of corrosion resistance within an aggressive medium).
There is a Czech technical standard describing a procedure of natural building stone testing by ultrasonic pulse method which, however, does not find any practical use.
Using of ultrasonic pulse method for defining the material strength is conditioned by existence of calibration correlation between the parameters of non-destructive testing, in this case correlation between the velocity of ultrasonic pulse propagation and the strength, and this all under exactly defined testing conditions.
This article contains testing results measured on Portland cements manufactured according to the ČSN EN 197-1 and testing results regarding the cements masonry complying with the demands of ČSN EN 413-1.

2. Evaluation of Ultrasonic Pulse Method Efficiency for Cement Testing

2.1 Factors influencing measuring results

The results of testing by ultrasonic pulse method are influenced by many a factors, namely by:

- Material moisture
- Structure defects
- Specimen dimension
- Crossover frequency of actuator
- Means of acoustic feedback
- Material components
- Composition defects

The impacts of above mentioned factors on crushing strength differ from case to case, so that we cannot speak about a total correlation thereof with velocity of ultrasonic pulse propagation in relation to the tested material.

2.2 Evaluation of ultrasonic pulse method efficiency

The assessment of ultrasonic pulse method efficiency is based on assumptions as follows:

- Constant shape of testing body (a small beam of 40 × 40 × 160 mm)
- Constant ratio of cement binder compounds (cement : filler = 1:3, cement-water ratio W/C = 0.5)
- Exactly defined filler of cement binder (standard quartz sand of defined aggregate grain-size distribution and composition)
- Unambiguously defined manufacturing technique of testing bodies (statutable technology and processing)
- Exactly defined conditions for storing of testing bodies before testing (storing temperature, humidity).
- The influence of room dimension may be eliminated by using of an actuator with defined frequency
- The influence of acoustic feedback may be eliminated by exact defining of material type.

The above mentioned evaluation gives rise to reality of ultrasonic pulse method utilization for detection of blended cement strength.

3. Testing Methodology and Test Result Evaluation

Principles of measuring and evaluation are as follows:

a) Measuring equipment

- Measuring may follow by using of ultrasonic apparatuses with digital outlet or with screen, or we may use a combined device (with both outlet types) enabling time measuring with accuracy of 0,1 μs. Crossover frequency of actuator equals to 80 -100 kHz
- Environmental temperature 20 ± 8^{0}C, the relative humidity should not exceed 70 %
- A calibration element must be available.

b) Testing samples

- To secure reproducibility of measuring results, before testing, the samples must be stored in standard environment with temperature of $t = 20 \pm 2\ ^{\circ}C$ and relative humidity of $\varphi \geq 95$ %; after the mould remove, the samples should be put into a water bath with temperature of $t = 20 \pm 2\ ^{\circ}C$.
- The samples are taken out of the water bath and the measuring follows immediately after wiping thereof with a damp cloth.

- In the point of measuring, the surface of sample must be smooth; it may not show any protrusions, roughness, defects, holes or pores. If the surface does not comply with these demands, an adjusting is required, e.g. by abrading.
- The surface of sample to be measured must be free of any dirt and foreign particles.

c) Measuring

- The time measuring of ultrasonic pulses follows by means of opposite resonance effect.
- The length of measuring base is determined with accuracy of 0.1 mm.
- To secure a good quality of acoustic feedback in connection with testing of cement materials, it is advisable to use indifferent gel, commonly used in health service. During the process of measuring only one and the same bounding agent is to be used.
- Any dirt must be removed from the surfaces of probes before starting the measuring.
- An optimal measuring requires using of approximately equal thrusts.
- The time of ultrasonic pulses is read with accuracy of 0.1 μs.
- Each testing point is detected two times. A result of measuring with a difference undergoing 5 % (related to the lower value) is acknowledged as to be convenient. In case of differences exceeding 5 %, further measuring shall follow and then the examiners take values varying by less then 5 %. If this condition cannot be fulfilled, the testing place shall be eliminated.

d) Measuring results

- The time of ultrasonic pulse passage and the length of measuring base give the velocity of ultrasonic pulse propagation in accordance with the pertaining relation (1), which has been defined with accuracy of 1 $m.s^{-1}$, eventually 0,001 $km.s^{-1}$.

$$v_L = \frac{L}{t_L} \quad [m.s^{-1}] \tag{1}$$

where:

t_L – measured time of ultrasonic pulse propagation,
L – measuring base.

- Every measured value is a base for calculation of velocity of ultrasonic pulse propagation and consequently for determining the v_L for the given testing body.

e) Calibrating correlation

Calibrating correlations are determined by mathematic statistic methods, based on values measured at the detected points, or by any other convenient manner. in this case, the method of smallest squares has been used. they may be expressed by a regression line or by a straight line. here, we are speaking about an exponential dependence, expressed by the common relation: $y = a.e^{b.x}$.

Utility of calibration correlations expressed by the regression line of residual decisive tolerance must not exceed 0.12 and within its scope it cannot show any extreme values. The calculation formula (2) for reckoning of residual decisive tolerance is:

$$S = \sqrt{\frac{\sum_{i=1}^{n}(D_i - D_m)^2}{n-k}} \tag{2}$$

where:

$$D_i = \left| \frac{f_i - f_{di}}{f_{di}} \right| \tag{2A}$$

$$D_m = \frac{\sum_{i=1}^{n} D_i}{n} \tag{2B}$$

n – number of detected points within the calibrating correlation,
k – number of selected functional parameters within the calibrating correlation,
f_i – strength detected on an i-point of calibrating relation by destructive testing methods,
f_{di} – strength detected on an i-point of calibrating relation and reckoned from a parameter of non- destructive testing method.

4. Measuring Results and Calibration Relations

We have tested blended Portland cements and various cement mixtures complying with the demands of ČSN EN 197-1, as well as masonry cements conforming with ČSN EN 413-1, i.e. cements manufactured with using of various kinds of clinker, bearing various marks of hardness and compactness and containing further additive components (masonry cements containing various kinds of ash, dust or slag).
We were interested in commercially manufactured cements as well as in those prepared within the research activities (selected cement mixtures and masonry cements). The cements tested were 2, 7, 28 and 90 days old. The total amount of testing bodies equals to 255.

4.1 Test results

The results of our testing, inclusively the conditional relation between velocity of ultrasonic pulse propagation and tensile strength under bending resp. compressing strength are shown in the Fig. 1 and 2.

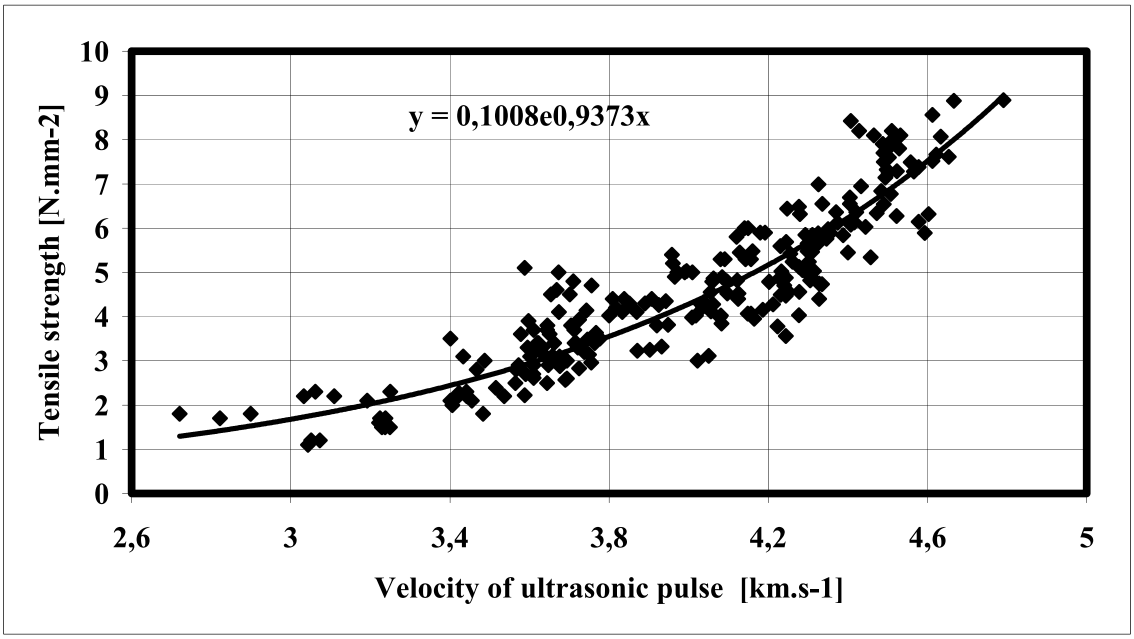

Fig. 1: Cement test results showing conditional relation between velocity of ultrasonic pulse propagation and tensile strength.

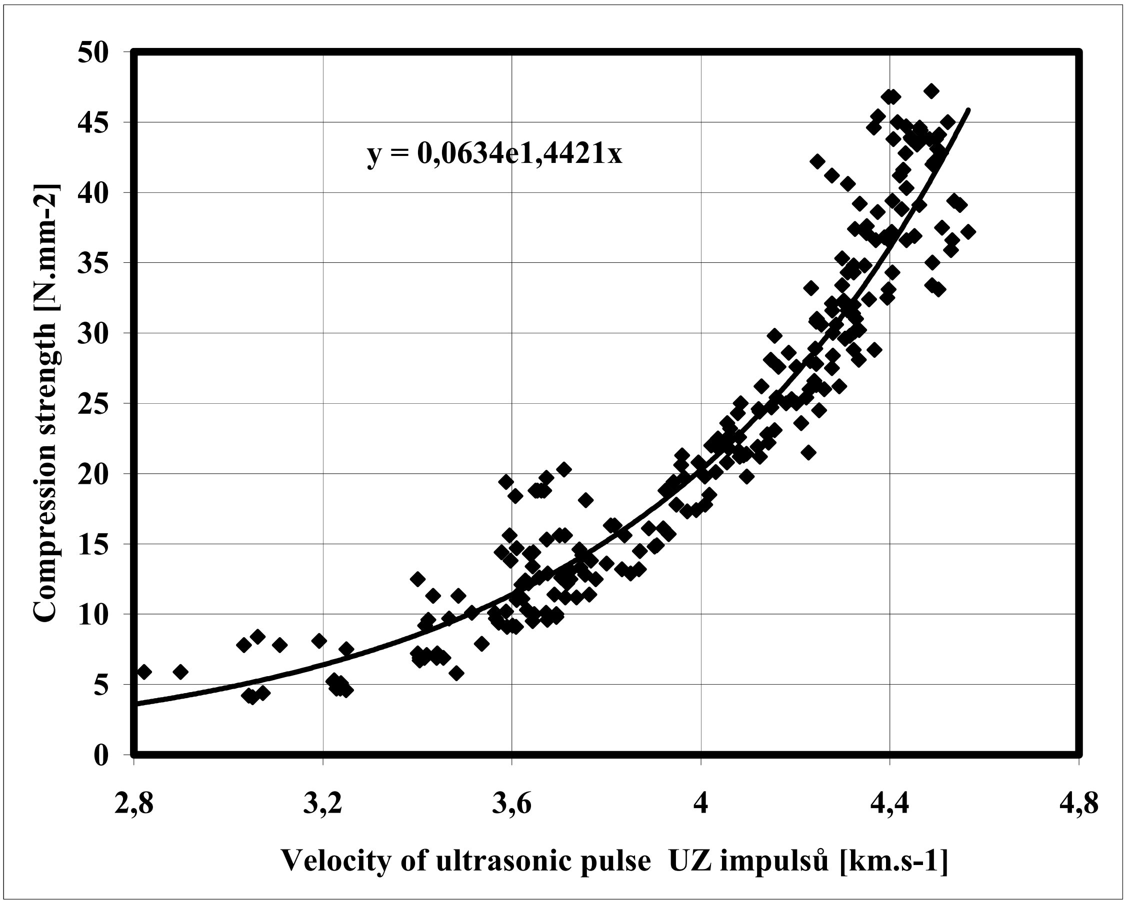

Fig. 2: Cement test results showing conditional relation between velocity of ultrasonic pulse propagation and compression strength.

4.2 *Calibration relations*

Calibration relations determining the cement strength based on velocity of ultrasonic pulse propagation:

- *Compression strength*

$$f_{c,CEM} = 0{,}0634e^{1{,}4421.v_L} \qquad S = 0.087 < 0{,}12 \qquad v_L \in \{2{,}7\ ;\ 4{,}8\}\ [km.s^{-1}] \tag{3}$$

- *Tensile Strength under Bending*

$$f_{t,CEM} = 0{,}1008.e^{0.9373.v_L} \qquad S = 0.106 < 0{,}12 \qquad v_L \in \{2{,}7\ ;\ 4{,}8\}\ [km.s^{-1}] \tag{4}$$

5. Conclusions

There is evidence confirming a possibility of practical utilization of ultrasonic pulse method, when testing the compactness of blended cements based on Portland clinker with gypsum admixture under unambiguously defined measuring conditions.

The calibration relations, mentioned here, prove a high correlation between the variables. The decisive residual tolerance lying between 0.087 and 0.106 undergoes the value of 0.12 limited by ČSN 73 1370, which means that these calibration relations may be practically applied.

The measuring results evidently do not show any important indications of being influenced by the type of clinker or by admixtures (blast-furnace slag granules, steel melting slag, ash, stone dust) contained in the tested cements.
The descriptions of testing method and of measuring process evidently show troublefree usability thereof.
However, the application of ultrasonic pulse method demands a rigorous observance of measuring conditions, mainly a constant humidity of the tested bodies is of a great importance. The tested bodies may not be dessiccated, because a variation of humidity ratio distinctively impacts the values of ultrasonic pulse propagation.
The crossover frequency of actuator is no less important factor influencing the measuring results, as dimensions of testing bodies and currently used probes (between 40 and 100 kHz) do not allow the observance of conditions for one-dimensional and three-dimensional environs in the sense of criteria specified in the Art. 24 of the ČSN 73 1371. In this case, the crossover frequency of actuator must lie between 80 and 100 kHz.
The indifferent gel commonly used in health service is a very effective bounding agent.
Results found provide also anticipation of development rationalization focused on blended cements and brickwork cements. Such optimization facilitates - within the scope of particular component optimum quantity research – manufacturing of test specimens along with feasibility of try out wide spectrum of materials as well as their presence in cements.

Acknowledgments
The work was supported by GAČR 103/04/0169 project and by MSM 0021630511 plan: Progressive Building Materials with Utilization of Secondary Raw Materials and their Impact on Structures Durability.

6. References

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