

Development of method of evaluation of concrete damage in the process of cyclic freeze-thawing

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Abstract.

The research presents a new method for determination of concrete damage under cyclic freeze-thawing by the parameters of the electrical response under impact excitation. It is established that the attenuation coefficient of the energy of the electrical responses under impact excitation can be used as a diagnostic criterion for crack process determination. A higher accuracy of evaluation of crack processes by the parameters of the electrical signal in comparison with the acoustic method is shown.

1. Introduction

Concrete constructions are often operated under significant seasonal variations of temperature. Continuous operation under these conditions leads to the development of crack processes due to the wedging action of water resulting from its freezing in the pores and microcracks.

Acoustic methods are usually used to determine damage in concrete [1-5]. These methods use direct contact with the piezoelectric transducers to generate the ultrasound and to detect the signal. The main problem with these methods is the need for an ideal acoustic contact between the transducer and the test construction.

In recent years many scientists have conducted research to develop non-contact ultrasonic methods [4-6]. Non-contact acoustic methods are based on the recording of surface waves. Therefore these methods depend on the surface roughness and are insensitive to deep cracks.

The method based on the use of characteristics of an electrical signal occurring in concrete under pulsed mechanical excitation can be used to evaluate the extent of damage in concrete [7-10]. The principle of this method consists of the excitation of the sample by a short mechanical impact which leads to the appearance of spherical acoustic waves. The shift of double electrical layers at the boundaries of the components in the heterogeneous material and the emergence of the piezoelectric effect in the piezo-containing materials occur under the influence of the acoustic waves. This gives rise to an external electromagnetic field. This field is detected by the signal receiver placed near the test object. Piezoelectric inclusions are contained in fine and coarse aggregates in concrete. The electrical signal parameters are determined by the processes of acoustic wave scattering on the structural inhomogeneities and defects. Therefore, these parameters can be used to test structural inhomogeneities and defects.

The purpose of this research is development of the criteria for the evaluation of damage in concrete in the freeze-thawing process based on the use of the parameters of the electrical response under impact excitation.



2. Materials and testing procedures

For the research two groups of heavy concrete samples with a size of $100 \times 100 \times 100$ mm were made. For one group of the samples gravel was used as coarse aggregate, for the other group crushed stone was used. After manufacturing, the samples were kept at $+25^\circ\text{C}$ and 60% relative humidity for 28 days. Then the samples were exposed to cyclic freeze-thawing. Freezing was carried out in a climatic chamber at a temperature of -30°C , thawing at a temperature of $(+20 \pm 5)^\circ\text{C}$ and 95% relative humidity.

The research was carried out with the laboratory hardware–software complex that enables production pulsed mechanical excitation of materials and recording of the electrical response. Figure 1 shows the image illustrating the measurement process of the electric signal from concrete samples.

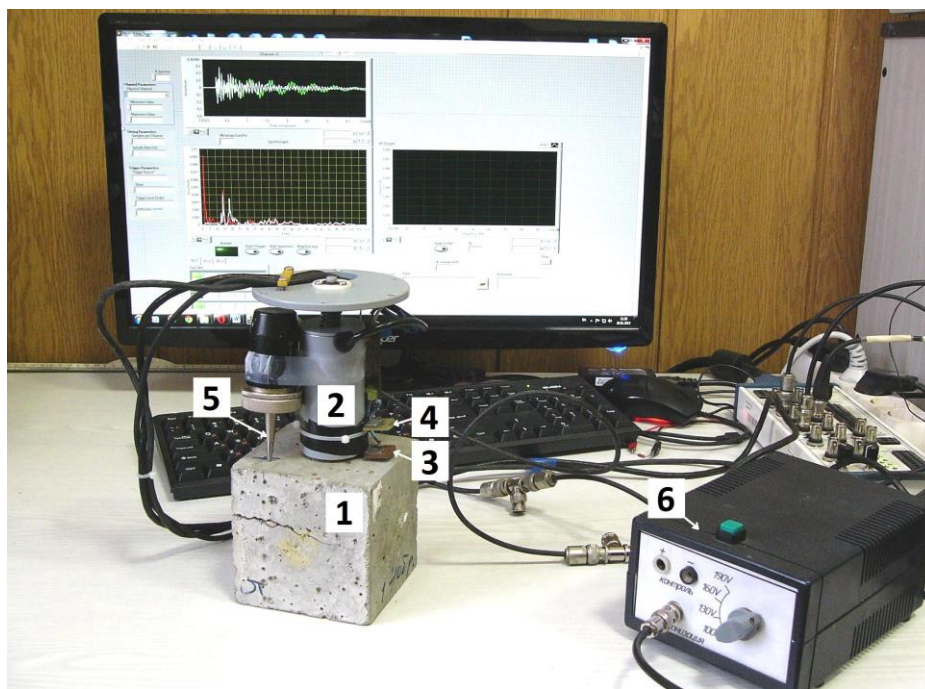


Figure 1. Laboratory hardware–software complex: (1) sample, (2) electromechanical impactor, (3) measuring receiver, (4) compensating receiver, (5) piezosensor, (6) power supply.

The pulsed mechanical excitation of samples is conducted with the electromechanical impact device with a normalized impact force. The differential electrical sensor is used to record the electrical signal. The differential electrical sensor has a measuring and a compensating receiver. The measuring receiver is placed at a distance of 2 mm from the sample surface and perceives both a useful signal and a noise signal. The compensating receiver is placed at a height of 30 mm from the measuring receiver and perceives only a noise signal. The signals from the receivers are inputted to the differential amplifier, where they are subtracted and amplified. This measuring scheme enables reliable detection of the useful electrical signal. The signals from the electrical transducer are recorded using multifunction input-output board “NI PCI 6251” combined with the PC. The multifunction I/O board allows the digitization of time realization of the electrical signal. Then, using a special program in LabVIEW, the signals and spectra are recorded and processed. The measurement technique of the electrical signal under mechanical excitation is described in more detail in paper [11].

The measurement of the acoustic signal by means of a piezosensor, with a tip in the form of a cone (the diameter of the cone is 3 mm), was made in parallel with the measurement of the electrical signal.

3. Experimental research and discussion

Cyclic freeze-thawing leads to the occurrence of cracks in the concrete samples. The scattering of the elastic waves on cracks changes the behavior of the attenuation of the electrical signal. Time-frequency analysis was used to study the behavior of the energy attenuation coefficient of the electrical signal from the concrete samples, because it allows tracking the behavior of change of the spectral energy of elastic waves as a function of time.

The experimental data were processed using a special program in LabView. The program analyzes the changes of the energy of the signal using the sliding window technique.

The main part of the energy of the electrical signals appearing in the concrete samples under elastic impact excitation is in the range of 10 to 25 kHz. Therefore, this frequency range was chosen for the analysis. A detailed technique to determine the attenuation coefficient of the energy of the electrical signal is presented in paper [12].

Figure 2 shows the dependence of the attenuation coefficient of the energy of the electrical signal on the number of freeze-thawing cycles.

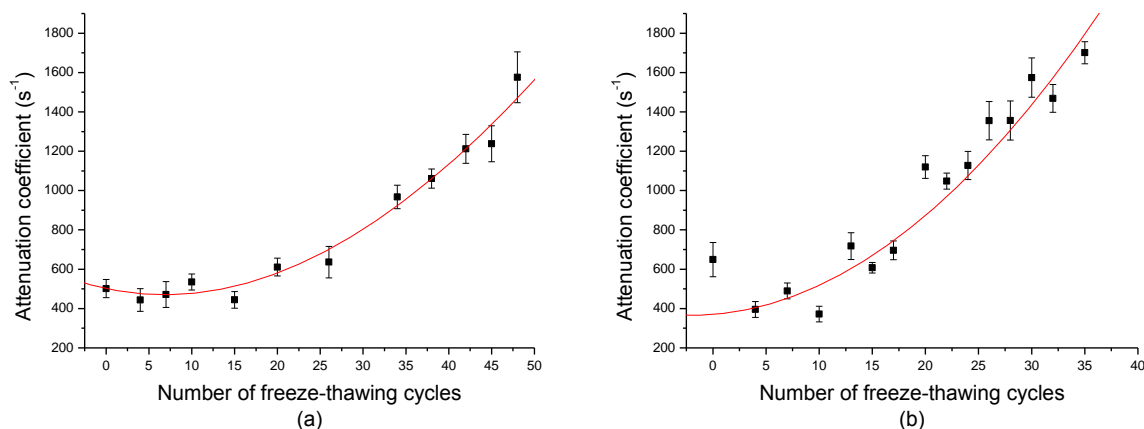


Figure 2. Dependence of the attenuation coefficient of the energy of the electrical signal on the number of cycles: a) for samples with gravel; b) for samples with crushed stone.

As can be seen from Figure 2 the attenuation coefficient of the energy of the electrical signal at the initial stages of cyclic freeze-thawing is virtually unchanged. The attenuation coefficient for samples with gravel (Figure 2.a) increases after the 25th cycle. For samples with crushed stone (Figure 2.b) the attenuation coefficient increases after the 15th cycle. The appearance of visible cracks on the surface of the samples coincides with the increase of the attenuation coefficient. Thus, the attenuation coefficient of the energy of the electrical signals can be used as a diagnostic criterion for evaluation of concrete damages in the process of freeze-thawing.

In a similar way, the acoustic signals were processed from the samples. Figure 3 shows the dependence of the attenuation coefficient of the energy of acoustic signal on the number of freeze-thawing cycles.

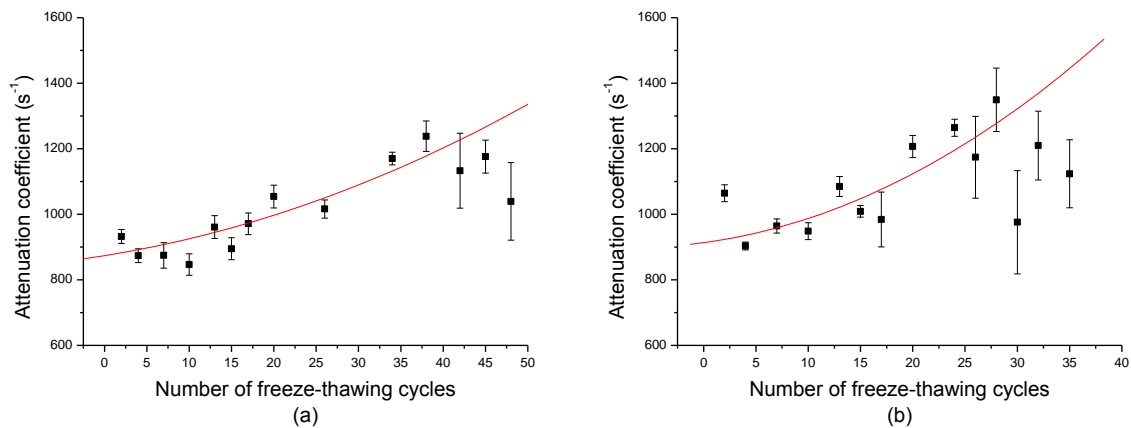


Figure 3. Dependence of the attenuation coefficient of the energy of the acoustic signal on the number of cycles: a) for samples with gravel; b) for samples with crushed stone.

As can be seen from Figure 3, at the initial stage of cracking process for samples with gravel after 25th cycle (Figure 3.a) and for samples with crushed stone after the 15th cycle (Figure 3.b) the attenuation coefficient increases. However, at the stage of the intensive cracking for samples with gravel after the 40th cycle, and for samples with crushed stone after the 27th cycle, a downward bend in the dependence is observed and the attenuation coefficient decreases again and becomes close to that of non-defective samples.

The attenuation coefficient of the energy of the acoustic signal (Figure 3) during the process of freeze-thawing increases by 1.5 times and has a large statistical dispersion. While the attenuation coefficient of the energy of the electrical signal (Figure 2) during the same number of freeze-thawing cycles increases by 3–4 times.

Therefore, the proposed method for evaluation of concrete damage in the process of cyclic freeze-thawing is preferable in comparison to the acoustic method.

4. Conclusion

The purpose of the research was the development of a non-destructive method to test the processes of cracking in concrete by the parameters of the electrical response under elastic impact excitation in the process of cyclic freeze-thawing.

The increase of the attenuation coefficient of the energy of the electrical responses can be used as a criterion for concrete damage evaluation in the process of cyclic freeze-thawing. It is shown that in concrete with different types of coarse aggregates, the difference in the dynamics of crack process is observed. The appearances of visible cracks in the sample with crushed stone occurs after the 15th cycle and in the sample with gravel they occur after the 25th cycle. The attenuation coefficient of the energy of the electrical responses reliably reflects the development of crack processes in concrete samples with different types of coarse aggregates.

A comparison of dependences of the attenuation coefficient of the energy of the electrical and acoustic signals in the process of cyclic freeze-thawing is made. It is shown that the attenuation coefficient of the energy of the acoustic signals at the expansion in the number of freeze-thawing cycles changes slightly and it cannot be used to determine the development of crack processes.

The obtained results show that the parameters of the electrical response under impact excitation more reliably reflect the crack processes compared to the acoustic signal.

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