Use of Simulation Methods of Wave Processes for Non-Destructive Testing of Concrete Products of Different Geometrical Size

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Abstract.

Theoretical and experimental research of electrical responses under pulsed mechanical excitation of different size concrete products was carried out. Comparison of calculated and experimental data shows very close agreement. The obtained results will help to develop new opportunities to improve the method of non-destructive testing of concrete by creating a bank of calculated electrical responses from products of different geometrical arrangement and elastic response and using them as standard samples for defectiveness evaluation of products according to previously established criteria.

1. Introduction

While in operation, constructions of concrete are subjected to mechanical and thermal impacts that often lead to the development of cracks in the material. Hence, there is a need for current defects monitoring in constructions of concrete. To solve this problem various methods of non-destructive testing have been developed. Mostly, acoustic and ultrasonic testing methods are used for these purposes.

Research is being done to determine the starting time of crack formation and its location with the help of acoustic emission [1-3]. These methods enable only observation of the process of crack formation.

Common methods of ultrasonic testing [4, 5] require a perfect acoustic coupling between the transducer and the surface of the concrete.

Currently, research is being done on the development of non-contact ultrasonic methods. The registration of ultrasonic signals through the air and the use of laser vibro-meters is based on the measurement of surface waves [6-9]. However, surface waves are not sensitive to deep cracks and depend on surface undulation of concrete.

To solve the problem of non-destructive testing, the method based on the use of the phenomenon of emergence of alternating electromagnetic fields under pulsed mechanical excitation of non-metallic materials is developed [10-12].

As a result of the previous research, it was established that the coefficient of cross-correlation of spectra of electrical responses from the tests of defect-free samples can be used as a diagnostic criterion for defectiveness determination [13].

In addition it is shown that the use of a reference spectrum enables one to obtain a very high coefficient of correlation with a specially made, defect-free basic reference standard. In our work we used samples of 50×50×100 mm, and the shock impact was imposed in the direction of the major flat surface. Therefore, for the samples of this geometrical arrangement, freely damped harmonic motions were offered to be used as a reference standard. In this paper, theoretical and experimental research is conducted on the development of a similar approach to solving the problem of non-destructive testing of different size products.

2. Methods of experimental and theoretical research

The principle of the method of the research is that under pulsed mechanical load, a transversal wave propagates across the concrete volume. The transversal wave affects electric double layers at the boundary of phase interface and piezo inclusion. Piezoelectric inclusions are contained in sand and gravel which are used for concrete manufacture. The electromagnetic field occurs due to the appearance of charges on the faces of the piezo-quartz under its deformation and owing to the displacement of charge of the electric double layers relative to the electrical receiver. The electrical measuring receiver is located in close proximity to the sample, and is in the coverage area of this field. As the result of the appearance on the surface of the receiving electrode of free charge carriers induced by an electric field, current flows through the input resistance of the measuring circuit.

The experimental research of the electrical response to pulsed mechanical excitation was conducted with the use of a hardware-software complex. The complex includes an electro-mechanical impact device and a differential electrical sensor. The impact device enables it to produce a single impact of 60 μs duration. The electrical sensor consists of a receiver, differential amplifier, input-output board and a computer. The receiver has two receiving metal plates: measuring and compensating. The measuring plate is located at a distance of 2 mm from the sample surface, and the compensating plate is located at a distance of 30 mm from the surface. This construction design of the receiver provides significant reduction of the level of external electromagnetic interferences, and enables it to make measurements of an electrical signal without the use of additional shielding systems. In more details the experimental method is described in [14].

On the basis of the previously performed research, the physico-mathematical model of mechanoelectrical transformations in heterogeneous non-metallic materials is developed [15]. On the basis of the developed model with the use of numerical methods for the simulation of wave processes, the calculation of electrical responses to shock impact is performed.

The numerical implementation was carried out with the use of non-central differencing scheme of second-order accuracy relative to the steps in space and time. The correctness of the numerical results was evaluated both by intrinsic convergence of the results under the change of the parameters of a finite-difference grid and step of integration in time and by calculations of model problems.

The numerical algorithm is based on the Runge-Kutta method for solution of ordinary differential equations.

For the calculation, the following values for the concrete properties were used: density is 2.3×10^3 kg/m^3, modulus of elasticity is 2.1×10^{10} N/m^2; Poisson's ratio is 0.2; longitudinal wave velocity is 4×10^3 m/s. The calculation was performed for the case where the impact is made on the center of the sample and the receiving electrical sensor is located at a distance of 20 mm from the point of impact at a height of 2 mm above it.

To improve the accuracy and convergence the size of the elements in the finite element model was 2.5×2.5 mm. The calculation contains 512 points at sampling frequency with the interval of 1 μs. The finite element model consisted of 1024 elements.

The calculated time signal was transformed into the frequency domain using fast Fourier transform.

3. The results of theoretical and experimental research

The concrete products having a size of 100×100×100 mm, 100×100×200 mm and 100×100×300 mm were manufactured for the research.

Figure 1a shows the calculated electrical responses, and Figure 1b shows the experimental responses of concrete of different geometrical size.

As the images show the spectra of theoretical and experimental results coincide.

The conducted research shows that theoretically calculated electrical responses can be used as standard samples in the procedure of non-destructive testing.

This approach enables to avoid manufacturing of special defect-free samples and to exclude the impact of the original structural inhomogeneity in complex heterogeneous materials.

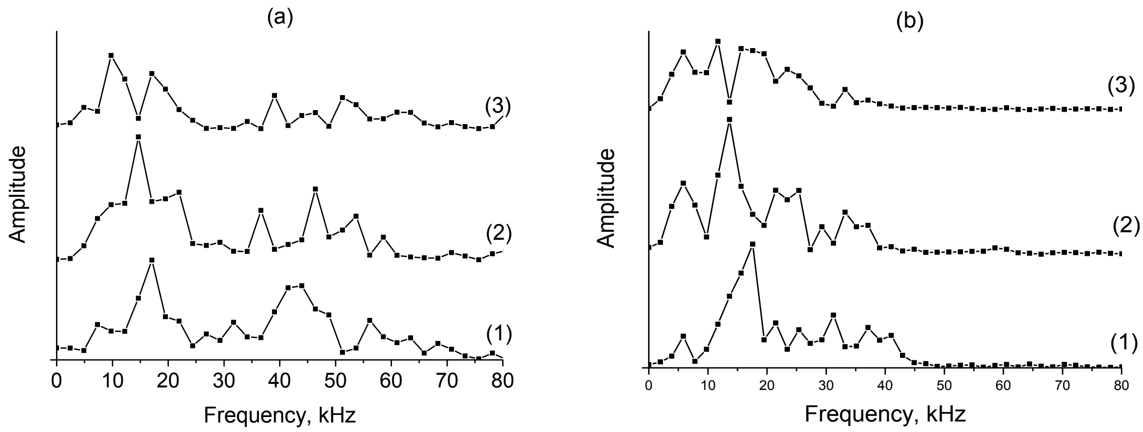

Figure 1. Spectra of the experimental and calculated electrical responses for concrete Products of different geometrical size: (1) 100×100×100 mm, (2) 100×100×200 mm and (3) 100×100×300 mm.

4. Conclusion

The purpose of this work is to carry out theoretical and experimental research of the influence of geometrical dimensions of concrete products on the electrical response and development of applications of numerical methods for non-destructive testing.

The electrical responses to the shock impact of the concrete samples of various sizes were calculated based on the modeling of wave processes with the use of continuum mechanics. The amplitude spectra of the signals were calculated using fast Fourier transform; the comparison with experimental results was made. It is shown that the spectrum of calculated electrical signals is in good agreement with the experimental results. The creation of a bank of theoretically calculated electrical responses from products of different geometrical arrangement and elastic properties will enable using them as standard samples for defectiveness evaluation of products of any geometrical dimensions.

On the basis of the obtained results, new additional possibilities for non-destructive testing of defectiveness can be developed.

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