

# Impact of defectiveness on the parameters of the acoustoelectric transformations in heterogeneous non-metallic materials

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## Abstract.

The article studies acoustoelectric transformations of concrete with a crack. The research presents three-dimensional modeling and 3D visualization of wave processes in a concrete sample with a surface crack. The parameters of the electrical response are found to reflect the processes of interaction between the acoustic wave front and the defect and boundaries of the sample.

## 1. Introduction

The problem of detecting cracks in engineering structures made from heterogeneous non-metallic materials (such as concrete) is of great importance. Surface cracks are the most common defects found in such structures. NDT methods to detect and characterize defects are of current interest for practical applications for civil engineers [1]. NDT methods such as ultrasonic and acoustic are widely used [2], as well as surface wave methods [3]. Extensive research on the development of non-contact NDT methods of concrete has been conducted recently [4-6]. The existing methods are characterized by poor accuracy and low sensitivity to internal defects and inhomogeneities.

The method to increase the accuracy of defectiveness determination taking into account the phenomenon of acoustoelectric transformations in heterogeneous dielectric materials under elastic pulse excitation is being developed [7-10].

The aim of the paper is the search of informative parameters of non-destructive testing to determine the defectiveness of heterogeneous materials by the parameters of the electrical response to mechanical pulse excitation.

## 2. The research results and their interpretation

The experimental research of electrical responses from a concrete sample with a natural crack was conducted. The sample size was 100×100×100 mm.

The natural crack was made in the following way. The sample was cut 5 mm deep to the center. Then a metal wedge was inserted into the cut. The system sample-wedge was loaded with a hand press. Figure 1 shows a photograph illustrating the process of crack growing in the sample of 100×100×100 mm. The sample was made from the mixture of cement, sand and gravel in the ratio 1:2:4 with the maximum fraction size of 20 mm.

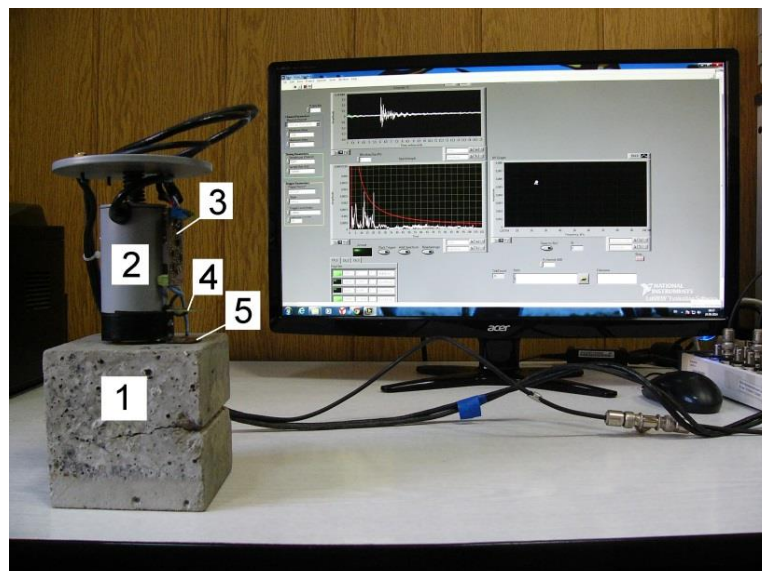




**Figure 1.** Photograph of the loading system.

The experimental research was done using laboratory software and hardware allowing the production of pulsed mechanical excitation of the samples and recording of electrical responses.

Figure 2 shows a photograph illustrating the process of measuring the electrical response from the concrete sample with a crack located perpendicularly to the direction of the shock and in parallel to the plane of the electrical receiver.



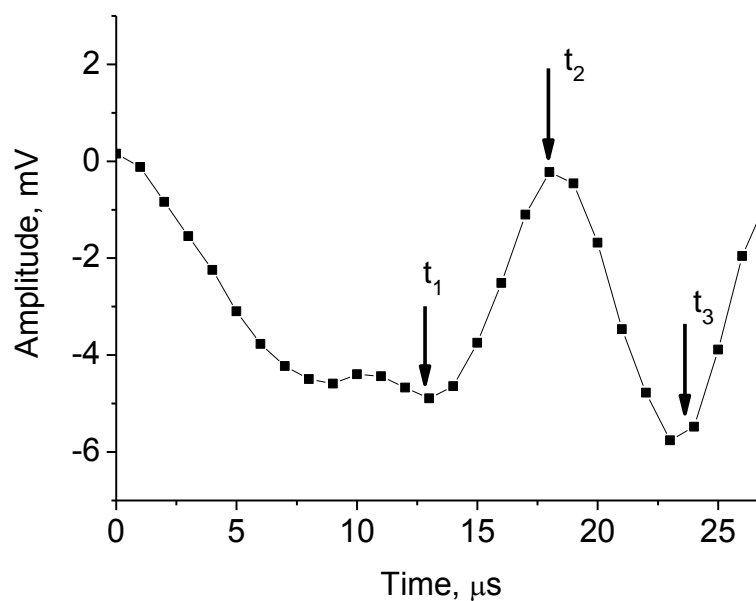
**Figure 2.** Photograph of the measurement system.

Pulsed mechanical excitation of the sample (1) is performed with the help of electromechanical impact devices with standardized impact force (2). To record the electrical response, a differential electrical sensor is used. Electrical measuring receiver (5) is located at the distance of 2 mm from the surface. Thus, the conditions for the noncontact reception are created. Compensation receiver (4) is

located at the height of 30 mm from the measuring receiver. After that these signals are sent to the input of the differential amplifier (3), subtracted and amplified. This measurement design enables to improve significantly the signal-to-noise ratio. The signals from the electrical sensor are recorded with Multi-I/O-card “NI PCI-6251”, combined with the computer, allowing the digitization of time realization of an electrical signal.

More detailed methodology of measuring the electrical response to shock excitation is reported in [11].

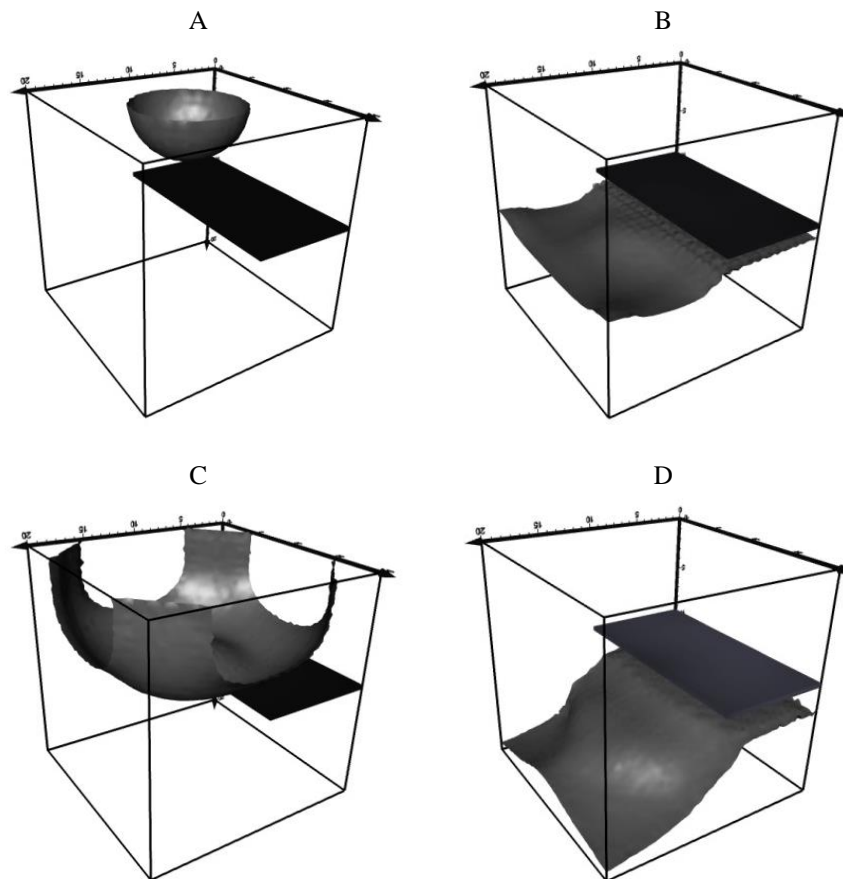
Figure 3 shows the electrical response from the concrete sample with a crack. The crack passes through the center of the side surface of the sample in parallel to the upper surface. The crack depth is 50 mm, length is 100 mm.



**Figure 3.** The initial section of the electrical response from the concrete sample with a crack.

Figure 3 shows significant deformation of the electrical response at 13  $\mu\text{s}$  – ( $t_1$ ), 18  $\mu\text{s}$  – ( $t_2$ ), and 24  $\mu\text{s}$  ( $t_3$ ).

3D modeling of wave processes was used to form the fields of longitudinal displacement in the sample. For calculation, the following concrete values were used: density was  $2.3 \times 10^3 \text{ kg/m}^3$ ; elasticity modulus was  $3.3 \times 10^{10} \text{ H/m}^2$ ; Poisson’s ratio was 0.2; longitudinal wave velocity was  $4 \times 10^3 \text{ m/s}$ . The calculation was carried out for the case when the shock was made towards the sample center. Figure 4 shows 3D visualization of the longitudinal displacements fields carried out with Voxler 3 program.



**Figure 4.** Longitudinal displacement fields in the concrete sample over the time intervals equal to: A is  $5 \mu\text{s}$ ; B is  $13 \mu\text{s}$ ; C is  $18 \mu\text{s}$ ; D is  $24 \mu\text{s}$  after loading.

At the initial stage (see Figure 4A) we can see wave propagation without distortion by defects and boundaries of the sample. The crack is shown in dark in Figure 4. Within this time interval it can be seen that the shape is spherical which corresponds to the wave theory.

In Figure 4A the wave reaches the side boundaries of the sample. After  $13 \mu\text{s}$ , when the wave reaches the side boundaries of the sample, the acoustic wavefront is distorted due to the reflection of the wave from the boundary. This instant time is characterized by the distortion of electrical response which corresponds to  $t_1$  in Figure 3. The increase of the electrical response magnitude in the time interval from  $13$  to  $18 \mu\text{s}$  occurs due to the contribution of the reflected waves. In papers [7, 8], it is shown that in heavy concrete, the main contribution to the electrical response is made by piezoelectric sources of acoustoelectric transformations. The sources are distributed throughout the sample volume. The electrical signal occurs due to the appearance of charges on the faces of the piezoelectric quartz contained in fine and coarse aggregate (river sand and gravel) under its deformation by the acoustic wave, and due to the shift of these charges relatively to the electrical receiver. Consequently, the increase in the magnitude of the electrical response in the time interval from  $13$  to  $18 \mu\text{s}$  is connected with the contribution of the acoustoelectric transformations reflected from the side surfaces of the waves.

At 8  $\mu\text{s}$ , the wave overcomes the level of the crack. In other words, it goes over it, undergoing the maximum distortion in comparison with the previous stage (Figure 4C). The change in the shape of the wavefront affects the level of the electrical response (point  $t_2$ , Figure 3).

At 24  $\mu\text{s}$  (Figure 4D), the wave front is reflected from the opposite face. In Figure 3, this point is marked as  $t_3$ . The reflection from the opposite face causes signal increase.

The change in the wave process causes the change of the electrical response. The analysis of the results of mathematical modeling and obtained electrical responses further the development of non-destructive testing with dynamoelectric transformations phenomenon.

### 3. Conclusion

The purpose of the research is theoretical and experimental studies of the impact of the defectiveness on the parameters of acoustoelectric transformations in concrete. We received the fields of longitudinal shift in the concrete sample with a surface crack on the basis of the results of three-dimensional modeling of wave processes, formed in the sample under shock excitation. 3D visualization was used to trace the interconnection between the characteristics of the electrical response and spatial location of the defect in the sample and its orientation relatively to excitation and reception points. At the instants when the acoustic waves are reflected from the boundaries of the sample and the wave front bends the defect, the electrical response is distorted.

On the basis of the obtained results, new options of non-destructive testing of concrete defectiveness can be developed.

The work is done under the State task "Science".

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