

# Method for determining surface destruction area of concrete elements

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**Abstract.** The article presents data on concrete destruction features, and the evaluation characteristics of this process, taking into account the research experience in this area. For more complete concrete assessment and qualification, it is proposed to study operational and strength parameters as well as critical fracture surface area. The currently available methods for recording material fracture parameters are evaluated. The acoustic emission method is recommended as the most widely implemented of the proposed methods (acoustic emission, electroluminescence, radio radiation). The proposed method is based on theoretical provisions establishing relationship between the area of the newly formed fracture surface in all materials and the acoustic emission amplitude. Taking into account the adhesion coefficient values expressed in terms of the acting voltage and the crack parameters we obtain the energy of material destruction is proportional to the energy of releasing acoustic emission. The article describes test procedure and nature, as well as the standard equipment characteristics and its preparation for measuring acoustic emission. The method proposed by the authors is characterized by relative simplicity, high reliability, and is practically the only one that allows determining the area of concrete destruction under different types of external influence at different destruction stages.

## 1. Introduction

The results of scientific research in the field of concrete durability showed that service life of concrete structures is determined by the destruction processes kinetics. Concrete element destruction at any kind of external influence is accompanied by the cracks growth and opening, both at micro and macro levels. Finally, when the element reaches a certain critical value of the destruction surface area, it loses the ability to resist external influences and it is not able to function, further operation being impossible. It corresponds to the three selected stages of the destruction process. At the first stage, elastic deformations are perceived by the crystal skeleton of the concrete structure, they are very insignificant without the load, the material returns to its original state. At the second stage, as the concentration of defects and stresses increases, microdefects open and grow into larger becoming one macro-crack. And finally, at the third stage, there is an avalanche-like destruction, that is, the material completely loses its strength. The experiments in this area could lead to the qualification of concrete not only by strength or performance parameters, but also by the values of the critical areas of the fracture surface. Probably this criterion would characterize the properties of the concrete structure and its operation reliability more fully than the currently existing characteristics.



## 2. Materials and methods

The solution of the above problem is complicated by the fact that all newly formed cracks in the concrete element are located inside its volume and their parameters cannot be measured by widely tested methods in geometry. Due to the peculiarities of manufacturing technology of concrete structures and elements, based on the complexity of the structure and the peculiarities of its formation occurring inside the concrete specimen, under the influence of a large number of factors that are difficult to control, special attention should be paid to the durability parameters control of construction materials, such as strength, frost resistance, water permeability, etc. The most commonly used methods for determining the concrete durability require heavy equipment, samples of special shapes and sizes and do not guarantee sufficient measurement reliability, being destructive ones. It often takes a significant amount of time to determine the concrete durability characteristics. In this situation, it is possible to use non-destructive methods that allow indirect characteristics with the necessary accuracy for practical purposes to measure the desired parameter of destruction. Currently available methods of parameters recording of materials destruction can be used to solve the problem. In this case, non-destructive methods are usually operational and do not require a lot of time to determine the quantitative characteristics. As it is shown by the studies performed in the field of hardware registration of fracture parameters of materials, when cracks are formed, the fracture energy is accompanied by sound (acoustic emission), light (electroluminescence) and radio emission [1, 2, 3, 10, 11, 12, 13, 14, 15]. Moreover, all the three types of radiation are tightly connected with the processes of destruction and provide sufficiently reliable information about the state of the structure of the material subjected to destruction. Of all these methods, the most widely used for the registration of destruction processes was the method of registration of acoustic emission. In addition, this method is provided with reliable commercially available equipment. Based on the fact mentioned above, the method of recording acoustic emission was chosen for the practical implementation of the proposed method of determining the surface destruction area of concrete elements.

## 3. Results

The proposed method is based on the following theoretical positions. As it was established in [4], the following dependence exists between the area of the newly formed fracture surface in all the materials and the amplitude of acoustic emission:

$$\Delta F = \frac{CE}{K_1^2} \sum A^2 \quad (1)$$

Here:  $\Delta F$  - the crack area increase in the process of its jump-figurative development,  $m^2$ ;

$A$  – is acoustic emission amplitude accompanying formation process of this crack area, B;

$E$ -modulus of elasticity of the material, Pa;

$C$  - is the intensity coefficient of the first kind of stress,  $H / m^{3/2}$ ;

$K_1$ - is proportionality coefficient,  $Hm/B^2$ .

As it has been shown by numerous studies, concrete destruction being a brittle material, begins when the values of the intensity coefficient of the first kind of magnitude equal to the coefficient of adhesion. Setting in formula (1) the values of the adhesion coefficient expressed in terms of the acting strain and crack parameters, we obtain the equation:

$$\sum A^2 = \frac{2\pi\sigma^2 L \Delta F}{CE} \quad (2)$$

where:  $\sigma$  - is the acting strain on the crack, Pa;

$L$  - is crack length, m.

In the right part of equation (2) there is nothing but the energy of destruction of the material, and in the left – the energy of acoustic emission accompanying the material destruction process. Therefore, the destruction energy of the material is proportional to the energy of acoustic emission emitted at the same time.

The authors in [16] determined the values of the fracture surface area using the mathematical apparatus of the energy concept of fracture mechanics, which was not only of scientific, but also of applied character, making it possible to classify concretes by their initial structure and external influence intensity on the material under study. The results are shown in table 1.

**Table 1.** The values of the fracture surface area

| The fracture surface area, $\Delta F$ , m <sup>2</sup> . |                 |
|--|-----------------|
| Air-dry  | Water-saturated |
| 1275,4   | 1238,8          |
| 3054,5   | 1068,2          |
| 2154,9   | 2838,2          |
| 4533,2   | 2212,5          |
| 629,1  | 901,6           |
| 1838,1   | 593,6           |
| 1264,1   | 965,5           |
| 1900,9   | 715,7           |
| 1887,2   | 1261,5          |
| 1095,3   | 886,2           |
| 2387,6   | 1761,8          |
| 1180,5   | 919,64          |
| 1624,0   | 2636,6          |
| 1491,4   | 1243,4          |
| 2258,9   | 3349,0          |
| 1716,8   | 1689,9          |

The essence of the proposed method for determining the area of surface destruction of the concrete element is as follows. A concrete sample is selected. In the process of a control crack forming it is possible to measure the destruction area and the energy of acoustic emission accompanying the process of destruction. The sample is tested and the acoustic emission energy is determined. The specific energy of the acoustic emission is then calculated as a unit of area. At the second stage the investigated concrete element is destroyed by any kind of external influence to some certain level. The acoustic emission energy is also measured. The total energy dividing of acoustic emission by its specific value allows obtaining the desired surface destruction area of the concrete element.

In practice, as a control sample, one can use a specimen of a special shape in the form of a plate with an initiated crack, as suggested by the authors in [5, 6, 7] subjected to tensile forces, or standard cubic samples can be used to determine the compressive strength of concrete and cracking. In both cases, it is quite simple to determine the control area of the surface destruction by linear measurements with great accuracy.

To measure the magnitude of acoustic emission it is possible to use the standard instrumentation for registration of acoustic emission with the following measuring range.

1. The frequency range of 200 Hz...120 kHz.
2. The duration of the recorded pulses  $10^{-5}$  ...  $10^{-2}$ s.
3. The total number of registered pulses is more than  $10^7$ .
4. The amplitude at the input of the preamplifier up to 1 mV.

5. The energy of the registered pulses is  $10^{-8}$ J.
6. The total energy accumulated by the device up to 1 J.
7. The amplification factor of the device is  $5 \times 10^5 \dots 1 \times 10^6$ .
8. The level of intrinsic noise to the output is less than 5 ... 10  $\mu$ V.

Before use, the device is calibrated according to the energy equivalent by the method known in this type of equipment.

#### 4. Conclusion

The development of rapid methods to determine the concrete durability parameters includes several stages: mathematical description of the concrete fracture processes under various types of external influences and identifying of the totality of physico-mechanical material characteristics depending on the value of the controlled parameter.

The method proposed by the authors is characterized by relative simplicity, high reliability, and is practically the only one that allows determining the destruction area of concrete under different types of external influence and at different stages of destruction.

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