Estimation of concrete durability using kinetic characteristics of its destruction

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Abstract. The article deals with the research results of concrete destruction processes by different types of external impact. The materials were obtained by the Samara research school of architecture and construction academy. The paper analyzes the process of concrete destruction and determines its main flow stages, depending on the amount of released energy of crack formation. Initial parameters of concrete structure are proposed, including: surface energy, modulus of elasticity and Poisson's coefficient. The authors paid special attention to kinetic characteristics including tendency of concrete crack formation and crack formation intensity. The combination of kinetic characteristics is given as a criterion for concrete durability assessment. Quantitative dependence of kinetic characteristics on moisture and porosity is confirmed.

1. Introduction
The durability of structural materials, including building materials, is largely determined by the rate of their destruction under operating conditions and depends on both the type of external impact and its intensity [1-4]. At the same time, unlike other materials, structural concrete durability not only ensures the reliable operation of buildings and structures, but also significantly increases the efficiency of capital investments. Therefore, as experience shows, the cost of operating buildings and structures, as a rule, exceeds the initial capital investment over the life of the building structures. Therefore, the more accurately the terms of failure-free operation of a concrete or reinforced concrete structure are determined, the more efficient capital investments are and the longer the overhaul periods of a building or structure are used, and the lower the costs of their operation.

2. Materials and methods
At present, there are practically no quantitative methods for predicting the durability of structural concrete, as in other buildings and structures in general. To do this, there is a set of quality indicators in the form of buildings reliability and the requirements of regulatory documents, where a number of concrete parameters are regulated at the level of “no worse.” At the same time, given the peculiarities of construction, as well as the low level of technological discipline and quality control in Russian
construction, it is difficult to hope that any erected building or structure will “last” to the planned overhaul without additional work to maintain its operability.

Concrete and reinforced concrete structures, which are currently used almost everywhere and for various purposes in large volumes, differ from structures made of other materials in that their structure, strength and operational properties are formed directly in the structure manufacture. Unlike steel or plastic structures, they cannot be assembled from rolled products or parts manufactured in the factory, under strictly regulated technological parameters. The variation of technological parameters is often much higher than the requirements of the technology on the construction site and concrete and reinforced concrete structures and products factories. It is important not only to improve the production culture, but also to control the quality of the resulting construction products, which allows you to guarantee at least some durability of structures.

The studies show, including those performed by the authors of this article [4-8], that concrete durability is a consequence of cracking processes manifested in its structure under external influence (force, low temperature, humidity, etc.). It is the kinetics and, ultimately, their consequences in the form of material destruction processes that determine concrete or reinforced concrete structure service life.

This paper proposes quantitative criteria for assessing the durability of concrete as a structural material, in which the kinetic characteristics of concrete failure processes under a certain type of impact are proposed: the concrete tendency to crack and the crack formation intensity.

3. Results
The study of concrete destruction processes performed by the authors showed that, like other structural brittle materials that crack down, concrete has three stages of destruction, regardless of the type and intensity of external influences. They are qualified by three levels of energy state, in accordance with the main provisions of the energy destruction theory.

At the first level, with a low intensity of external influence, the energy of concrete destruction is small, which is explained by the small number and small parameters of the cracks formed in the material. At the next level, as the intensity of the external influence increases, the destruction energy increases and reaches the value and devices can measure it. In this case, the number of cracks and their parameters increase, they begin to unite, and initiate the development paths of the main cracks are outlined. This stage in the destruction physics is called the stage of “preparation for destruction”. At the last stage, called “destruction”, an increase in the intensity of external influences leads to the formation of main cracks and the separation of the material into separate parts that are not able to withstand external influences. At this stage, the energy of destruction reaches a maximum value characterizing the energy abilities of the destroyed material.

The authors of this work were able to mathematically describe the sequence of concrete destruction at all the three stages of its destruction under cyclic low-temperature, force impact by compression, tension and bending, as well as under hydrostatic pressure [9-20]. In this case, the mathematical apparatus of the energy theory of fracture mechanics was used, based on the work of A. Griffiths [11] and the kinetic concept of S.N. Zhurkov [12]. Studies have shown that the destruction rate of concrete depends on two types of characteristics: the initial parameters of the structure of the material and kinetic characteristics that quantitatively relate the rate of application of external influences to the material with the destruction rate. The initial parameters of concrete structure were assigned: surface energy, elastic modulus and Poisson's ratio, kinetic - the concrete tendency to crack formation and of crack formation intensity.

4. Discussion
The analysis of kinetic characteristics showed that they are informative enough, accessible for physical understanding and can be determined experimentally. In particular, the concrete tendency to crack formation has dimensions that include the mediated time parameter: m/cycle of low-temperature cyclic effect or m/Pa under force or hydrostatic pressure. The crack growth intensity is dimensionless,
characterizing the relative level of material destruction at a certain level of its loading by external action. The method accepted by the authors to determine the values of the aggregate of kinetic characteristics \([4,14,15]\) through experimental studies and laboratory testing of the material by standard methods and the calculation of the latter allowed to obtain their quantitative values, shown in Table 1.

| №  | Air Dry | Water Saturated |
|----|---------|-----------------|
| 1  | 16,06   | 16,33           |
| 2  | 4,46    | 10,01           |
| 3  | 8,91    | 3,79            |
| 4  | 2,51    | 5,14            |
| 5  | 25,68   | 13,34           |
| 6  | 5,74    | 14,89           |
| 7  | 11,62   | 7,36            |
| 8  | 5,6     | 10,93           |
| 9  | 7,09    | 7,15            |
| 10 | 19,36   | 10,03           |
| 11 | 6,71    | 7,17            |
| 12 | 10,7    | 18,87           |
| 13 | 9,54    | 4,24            |
| 14 | 9,41    | 10,86           |
| 15 | 7,42    | 3,69            |
| 16 | 11,03   | 10,06           |

It was noted, however, that these characteristics are sufficiently sensitive to the intensity of the application of external influences and to some extent can serve as a criterion for the durability of concrete. In particular, a quantitative relationship between the material loading intensity and the values of the aggregate kinetic characteristics was established. Influence of humidity and porosity on values of kinetic characteristics was also noted. The dependence of the set of kinetic characteristics on the porosity is shown graphically in Figure 1 and Figure 2.

Currently, research is being carried out to develop a relatively simple and fairly reliable methodology for determining the kinetic characteristics of the processes of concrete destruction which would qualify concrete durability, depending on the intensity of the external impact of a particular type. Special attention is paid to the non-destructive method, which allows determining the real level of material destruction in the structure. The acoustic method of ultrasonic attenuation at different levels of material loading is considered to be promising one.

5. Conclusion
The researches carried out by the authors allow to develop and further apply in practice a quantitative method of predicting the durability of structural concrete based on measuring the values of kinetic characteristics of the processes of its destruction, such as concrete tendency to crack formation and the intensity of crack formation.
**Figure 1.** Dependence of aggregate kinetic characteristics on capillary porosity for air-dry samples.

**Figure 2.** Dependence of set of kinetic characteristics on capillary porosity for water-saturated samples.
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