The two-factor destructions model of the composite

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Abstract. The article examines the destruction of a composite using a diamond disk. The composite structure is adopted as a two-factor symmetric model, in which the composite grains are represented as balls in the matrix body. A feature of the design is the symmetry of the crack along the two main planes. A model of interaction of a diamond disk with a composite is developed. The destruction of composite models was carried out by cutting the individual bands. Cutting revealed the cyclical nature of the energy characteristics of the fracture models. The cyclic nature is described by a sinusoidal wave of structure destruction. The simulation results provide a formula for the composite structure, which is described using the energy characteristics of cutting. The structure and parameters of the fracture model obtained during cutting allowed us to fully describe the composite structure model. The results of modeling show that it is possible to fully describe the model of a concrete composite using only the energy parameters obtained during cutting of the material.

1. Introduction

Construction in the context of the development of the modern world involves a large number of options for the development of technical thought and its adaptation to specific project tasks [1]. The requirements of modern construction are the strength of building structures, as well as low cost. These conditions provide new technologies that are constantly being improved. Even today, experts, when discussing the future of construction, talk about the possibility of reducing costs due to the use of new technologies [2]. The tasks of creating new materials that meet the requirements of the time, the development of technologies that go beyond solving typical practical problems of the construction industry and, accordingly, the occurrence of related problems make up the picture of modernity [3, 4, 5]. Timely calculation of the reliability of structures allows avoiding negative consequences and man-made accidents at work, which remains one of the most important tasks in modern construction [6, 7].

The processes of concrete deformation and its destruction are studied by construction mechanics. Concrete is a multi-component material, which presents a certain complexity in the study of crack formation. Under operating conditions, a concrete / reinforced concrete structure is affected by the properties of its constituent materials, so one of the most important tasks is to select criteria that can comprehensively characterize the main parameters of concrete [8]. On this subject, the works of Kiradov A., Guzeeva E. A., Mamaeva T. L., Abdulueva K. U., Zaitseva Yu. V., Tsaava G. F., etc. have been studied. Obtaining the strength characteristics of concrete used structures is still an urgent task. One of the methods of studying the structure and properties of concrete is drilling or sawing concrete in a
structure. To adapt these methods in real conditions, it is necessary to compare the real structure of concrete with the model of its structure and identify the resulting relationships.

The article proposes to consider the ideal structure of concrete. The features of this structure are the symmetry of the fracture along the two main planes. The destruction of concrete is carried out by sawing individual strips of concrete - this destruction is the basis of the method for obtaining the strength characteristics of concrete.

Previously, it was found that considering the two-factor structure of concrete is sufficient to assess its strength [9]. For our case, we consider a two-factor model that determines the main parameters of concrete. In this paper, we consider the model of sawing an ideal sample of a symmetrical structure. On the basis of the actual piling in the program on a computer and theoretical analysis (maximum aggregate size in the mortar part of concrete is 5 mm) depth of cut adopted a value of 5/2 = 2.5 mm (accepted size (5 mm) defined standards for aggregate for mortar part of concrete, consistent with the parameters of cutting is the minimum size of the macrostructure so Dark size above this is already the structure beta. The adoption of a minimum size allows you to identify the minimum heterogeneity of the macrostructure of concrete). For further work, we took the width of the cut equal to 2.0 mm, the length of the cut according to the size of the face of the standard sample-100 mm. to identify inhomogeneities in various directions, we isolated similar volumes from a conditional cube filled with balls (the accepted model of two-factor ideal concrete). The furrows of the cuts were directed perpendicular to the faces of the cube [10], but the directions of these furrows pass at different angles relative to the axes of symmetry if we consider their projections on the plane of the face (Fig. 1).

The research objectives can be presented as follows:
- development of a model of interaction of a diamond disk with concrete [11-13];
- obtaining a dependence for determining the specific energy of destruction during multiple sawing of the structure;
- evaluation of the tested symmetrical ideal samples according to the following parameters: the ratio of the matrix strength to the filler; the volume concentration of the filler; the different diameter of the filler in the sample.

The importance of the research carried out using mathematical modeling methods allows you to project the results on structures that work in real conditions, which will allow you to design and build strong and durable buildings and structures made of concrete and reinforced concrete.

2. Methods
For the study, a special program was developed that allows you to accurately determine the amount of matrix and placeholder in each selected volume [14-17]. Using Microsoft ® Excel 2002 was built a distribution graph in relative coordinates W

\[ W = C_a \cdot \alpha + C_v \cdot \beta , \]

(1)

where \( C_a \) - is the reduced energy of destruction of each small volume of filler, \( C_v \) - is the reduced energy of destruction of each small volume of the matrix.
Figure 1. Model sawing concrete for φ = 0.45 and Ø = 10 mm.

In accordance with this, in the formula for calculating the specific energy of destruction (1), the value of $C_a = 1$, $C_v = R_M / R_T$ - the ratio of the matrix strength to the filler strength.

3. Results and Discussion

For each furrow containing 40 separate values, the change in strength characteristics looks like a wave-like curve with successive highs and lows. In each sample, distributions were analyzed for seven separate furrows, and as a result, they had the full probability distribution zone shown in figure 2. The furrow with the lowest value was found by calculating the area of the projection of the filler on the surface of the cube model. This furrow ran at an angle of 45° and is located symmetrically diagonally passing between the lines connecting the foci of the fillers.

Figure 2. Graph of probability distributions for a concrete specimen

The selected distributions are generally discrete random variables due to the fact that the angles of their inclination (sawing) are specific numbers: 0°, 9°, 18°, 36° and 45°. In fact, the angle of the furrow can be from 0 to 360°. As a result, the displayed range is played 8 times, and the previous one is played each time. Let us show the most possible separations and intervals that contain more than 80% of the values. To do this, let's go to the continuous random division and estimate the mathematical expectation of any consecutive section. Let us assume that each section will be indistinguishable when it is shifted by a small amount, i.e. the section will occupy a certain sector. The Wi energy values for the 0 and 45° rotation angles will be defined as the edge values. In this case, the penetration of cuts in these sectors will be twice as rare as in the rest, defined by the angles of 9°, 18° and 36°. The results of probability calculations based on the above principle are shown in table 1. The area of the sectors is
calculated according to the geometric projections of the placeholder on the face of the model. For furrows passing at the angles of 0 and 45°, a sector corresponding to the area where the amount of filler is stable was selected. In other cases, the face was determined by the middle between the foci of adjacent furrows.

The form of the most possible energy distribution will be recorded:

\[ W_i = W_{i0} \cdot P_{(0)} + W_{i9} \cdot P_{(9)} + \ldots + W_{i45} \cdot P_{(45)} \],

where \( W_{i0} \div W_{i45} \) – are the values of the reduced fracture energy for the selected furrow; \( P_{(0)} \div P_{(45)} \) – corresponding probabilities of the values of the reduced destruction energies.

**Table 1.** Calculation of the probability of getting the \( W_i \) values of different sawing bands into the sawn volume

| Position   | Angle sector × number of sectors | Probability of hitting (occupied share) |
|------------|---------------------------------|----------------------------------------|
|            | 0.25   | 0.35 | 0.45 | 0.55 | 0.25 | 0.35 | 0.450 | 0.550 |
| angle 0°   | 8\times2 | 4\times2 | 4\times2 | 1\times2 | 0.088 | 0.044 | 0.044 | 0.011 |
| angle 9°   | 9.5\times4 | 11.5\times4 | 11.5\times4 | 13\times4 | 0.209 | 0.253 | 0.253 | 0.286 |
| angle 18°  | 9\times4 | 9\times4 | 9\times4 | 9\times4 | 0.198 | 0.198 | 0.198 | 0.198 |
| angle 27°  | 9\times4 | 9\times4 | 9\times4 | 9\times4 | 0.198 | 0.198 | 0.198 | 0.198 |
| angle 36°  | 10.5\times4 | 9.5\times4 | 10.5\times4 | 10.5\times4 | 0.231 | 0.209 | 0.231 | 0.231 |
| angle 45°  | 6\times2 | 8\times2 | 6\times2 | 6\times2 | 0.066 | 0.088 | 0.066 | 0.066 |
| minimum W  | 1\times2 | 1\times2 | 1\times2 | 1\times2 | 0.011 | 0.011 | 0.011 | 0.011 |
| except for 0 and 45° | 38\times4 | 39\times4 | 40\times4 | 41.5\times4 | 0.835 | 0.857 | 0.879 | 0.911 |

If the values of the most possible energy distributions are transferred to the graph, they will fall quite close to the smooth periodic curve (Figure 2 and 3), which can be defined by a sinusoidal function (see figure 3):

\[ W = a \cdot \sin (\omega \cdot x_i + \psi_o) + c , \]

where \( x_i \) – is the relative number of grooves, \( a \) – amplitude of the sine wave, \( \omega \) – frequency sine wave, \( \psi_o \) - the initial phase, \( c \) - is the displacement coefficient of the sine in the y-axis.

As already noted, the destruction energy of the aggregate in concrete \( R_Z \) can be 2.5-8 times higher than the strength of the matrix \( R_M \). In this case, we can assume that the energy spread when sawing different furrows can change with a change in the ratio \( R_M / R_Z \), taking into account that when the destruction energies of the filler and the matrix are equal, there will be no energy spread [20-23].

To construct theoretical scatter lines, the ratio of \( R_M / R_Z \) was changed from 0.15; 0.29 to 0.4, the filler diameter from Ø5 mm, 10, 15 to 20 mm), and the volume concentration of the filler (from 0.25; 0.35; 0.45 to 0.55). To find the most appropriate coefficients of the model (3), we used a software package (Table Curve V. 2.0 (Copyright © 1989 AISN Software)). Calculations of approximations of the most adequate theoretical models are shown in table 2.

**Figure 3.** Schedule of approximation of the most probable distribution
Table 2. Results of determining the theoretical distribution of energy characteristics of samples

| Characteristics of the concrete | Parameters of the sinusoid |
|-------------------------------|---------------------------|
| Rₘ/RY                        | ϕ, mm | a | Ω | c | R² |
| 0.15                          | 5     | 0.25 | 0.04 | 75.4 | 0.35 | 0.91 |
|                               |       | 0.35 | 0.35 | 81.7 | 0.41 | 0.84 |
|                               |       | 0.45 | 0.03 | 94.2 | 0.48 | 0.77 |
|                               |       | 0.55 | 0.04 | 100.5 | 0.56 | 0.68 |
|                               |       | 0.25 | 0.05 | 37.7 | 0.37 | 0.94 |
|                               |       | 0.35 | 0.04 | 44.0 | 0.42 | 0.81 |
|                               |       | 0.45 | 0.032 | 75.4 | 0.35 | 0.91 |
|                               |       | 0.55 | 0.047 | 56.5 | 0.6 | 0.71 |
|                               |       | 0.25 | 0.059 | 18.8 | 0.36 | 0.95 |
|                               | 10    | 0.35 | 0.051 | 25.1 | 0.42 | 0.82 |
|                               |       | 0.45 | 0.034 | 31.4 | 0.53 | 0.79 |
|                               |       | 0.55 | 0.063 | 37.7 | 0.62 | 0.65 |
|                               |       | 0.25 | 0.03 | 75.4 | 0.459 | 0.93 |
|                               |       | 0.35 | 0.02 | 81.7 | 0.51 | 0.83 |
|                               |       | 0.45 | 0.018 | 94.2 | 0.57 | 0.78 |
|                               |       | 0.55 | 0.035 | 100.5 | 0.64 | 0.66 |
|                               |       | 0.25 | 0.04 | 37.7 | 0.48 | 0.92 |
|                               | 0.29  | 0.35 | 0.03 | 44.0 | 0.51 | 0.82 |
|                               |       | 0.45 | 0.023 | 50.3 | 0.59 | 0.86 |
|                               |       | 0.55 | 0.042 | 56.5 | 0.67 | 0.77 |
|                               |       | 0.25 | 0.05 | 18.8 | 0.6 | 0.94 |
|                               | 20    | 0.35 | 0.04 | 25.1 | 0.51 | 0.82 |
|                               |       | 0.45 | 0.03 | 31.4 | 0.61 | 0.85 |
|                               |       | 0.55 | 0.06 | 37.7 | 0.68 | 0.65 |
|                               |       | 0.25 | 0.022 | 75.4 | 0.54 | 0.91 |
|                               |       | 0.35 | 0.016 | 81.7 | 0.59 | 0.8 |
|                               |       | 0.45 | 0.015 | 94.2 | 0.63 | 0.79 |
|                               |       | 0.55 | 0.023 | 100.5 | 0.69 | 0.69 |
|                               |       | 0.25 | 0.03 | 37.7 | 0.56 | 0.9 |
|                               | 0.4   | 0.35 | 0.024 | 44.0 | 0.58 | 0.88 |
|                               |       | 0.45 | 0.02 | 50.3 | 0.65 | 0.82 |
|                               |       | 0.55 | 0.03 | 56.5 | 0.72 | 0.73 |
|                               |       | 0.25 | 0.035 | 18.8 | 0.55 | 0.93 |
|                               | 20    | 0.35 | 0.03 | 25.1 | 0.58 | 0.82 |
|                               |       | 0.45 | 0.027 | 31.4 | 0.67 | 0.77 |
|                               |       | 0.55 | 0.04 | 37.7 | 0.72 | 0.67 |

The resulting approximation level $R^2 = 0.65÷0.95$ reveals that there is a spread of the most possible values of the energy distribution from the accepted sine wave, which describes the possible ideal distribution. Probably the resulting spread is determined mainly by the lack of a relationship between the accepted depth of the saw furrow and the actual dimensions of the model components. The discrete approach to determining the values of possible energy distribution values also affected. Reducing the volume to be destroyed, and therefore reducing the structural elements, gives a better approximation to the theoretical $W$ curve. Deviations in the model description are obtained due to the sampling of the filler diameters, energy values $W_i$ and $\phi$. However, the largest errors of each of the values do not exceed $1÷3\%$.

Taking into account the presence of the method error and good correlation in the studied variants ($R^2 \geq 0.8$), we consider these errors acceptable [24,25].

Data from table 2 were processed on a computer using mathematical methods of multivariate analysis. Using the program for Excel, the nature of dependencies was determined using the graph analysis method, and using the Reg Analysis of Statis Windows statistics (STAT STATSOFT Inc., USA) set regression coefficients. The characteristics of an ideal concrete model are most closely related to the parameters of the sinusoid by the following functions.

Bulk concentration of large aggregate:
\[ \varphi = c + a^{0.8}(1 + 0.03 \times \omega) - 0.32, \]  

(4)

where \(c\), \(a\), and \(\omega\) are the parameters of the sine wave;

Ratio of matrix strength to filler strength:

\[ \frac{R_m}{R_Z} = \frac{c - \varphi}{1 - \varphi}, \]  

(5)

The grain size of coarse aggregate:

\[ \phi = \frac{(62 \times \pi / \omega - 2 \times \varphi)}{(0.73 - \varphi)}, \]  

(6)

According to the dependence (4), the value of the spread at a constant cutting mode characterizes the ratio of the components of the concrete. On the graph of this function (Fig.3) we can distinguish the step of the sine wave \(H_{\text{sin}}\) by the following dependence:

\[ H_{\text{sin}} = 2 \times \pi \times n \times h / \omega, \text{ mm}, \]  

(7)

where \(n\)- is the total number of saws, \(h\)- average depth of sawing, mm.

According to the symmetric model, the \(H_{\text{sin}}\) step is nothing more than the size of the \(h_Z\) energy cell.

4. Conclusions

After analyzing the possible modes of sawing samples, the authors developed a model of interaction of a diamond disk with concrete. To implement the proposed method, the following limiting parameters are defined: the same type of cutting tool, limiting the width of the diamond disk within 2-3 mm, limiting the depth of the slot to 2.5 mm.

Two variants of the approach are studied from the point of view of the probability theory of solving the problem of possible energy expenditure for sawing concrete of the model structure. In the first variant, it was assumed that all concrete particles (in the case of sawing, these are chip particles) are evenly distributed in the model of the concrete cube before sawing begins. In this case, when studying the volume of concrete, which is greater than the size of a single particle by a hundred or more times, the difference in the number of filler particles in the model from the amount that determines its volume concentration, will not be more than +15% (this is in the case of a relative content of a large filler \(\varphi\) greater than 0.3) for a reliability level of 0.95. In the second variant, the concentration of individual particles in the filler grains distributed in the matrix of the solution part was considered. For this variant, it was found that the best possible image of this variant of the aggregate distribution describes the model of an ideal symmetrical distribution of large grains in the concrete body. In this case, large aggregate grains were represented by balls with a weighted average diameter. The balls were evenly and symmetrically placed in the body of the matrix. The specific energy intensity of each component of the model was used for the mechanical characteristics of the spherical fill and matrix. The result is a formula for estimating the specific energy of destruction of the entire model for multiple sawing.

Analysis of the results of sawing different concrete compositions using different fillers and mortar components, using different sizes of filler, allowed us to identify the close-to-symmetrical structure of concrete in different directions. The study of changes in the average specific energy of destruction obtained during the formation of separate successive slots in the concrete body allows us to estimate the location of the aggregate, the average size of its grains and the specific energy of destruction of the matrix (strength) at a known average specific energy of destruction of the aggregate (strength).

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