Microcrack appearance and coefficient of tension intensity ceramsite concrete on multicomponent binding

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Abstract. The results of experimental research of microcrack appearance and coefficient of tension intensity of experimental patterns from ceramsite concrete on multicomponent binding and quartz sand are given. Optimal compositions of construction and heat insulation ceramsite concrete on multicomponent binding are presented. Methodology of experimental researches, parameters of experimental patterns with description of technology of their making, results of basic patterns tests and their analysis, and also volume, aims and results of auxiliary standards tests are described. In the process of tests the longitudinal and transversal deformations of patterns, value of crack appearance loading, size of the destroying loading were measured. The done experimental researches of limits of microcrack appearance and coefficient of tension intensity of patterns from ceramsite concrete on multicomponent binding allowed to educe the characteristic features of their tensely-deformed state, to define the high and lower bound of crack appearance, deformability and size of the destroying loading of experimental patterns.

1. Introduction

Over the past decade, a study of the basic physical and mechanical properties of lightweight concrete on various aggregates and binders has been carried out [1-4], however, the parameters of the fracture mechanics of these concretes have remained unexplored.

The destruction of concrete has its own characteristics associated with the parameters of the fracture mechanics of individual components of the concrete structure (aggregate, matrix, contact zone between the aggregate and the matrix).

It is known that the phenomenon of destruction of concrete and reinforced concrete is a complex multistage process of the appearance, growth and development of cracks. Hence, it becomes necessary to study concrete and reinforced concrete from the standpoint of fracture mechanics, which in the broad sense of this concept includes that part of the science of the strength of materials and structures associated with the study of the bearing capacity of a body, taking into account the initial distribution of cracks, as well as with the study of various patterns of their development.

The use of fracture mechanics requires the determination of an additional concrete characteristic, which is characterized by crack propagation on the support. There are several such characteristics in fracture mechanics, which take into account the influence of irreversible deformations at the end of the crack in different ways. These parameters include the complexity of their experimental determination and structural analysis. To simplify the application of fracture mechanics to concrete, based on previous studies, a “stress intensity factor” and a corresponding crack propagation criterion are commonly used.

However, the stress intensity factor has not yet been sufficiently studied for concretes with multicomponent binders and research values are necessary.

2. Analysis of recent research and problem statement

The emergence of main cracks, as is known, involves the processes of microfracturing, which are observed in the areas of the so-called pre-fracture. The description of the processes of deformation and cracking of concrete at this stage became possible due to the use of methods of fracture mechanics and
the theory of cracks. It can be noted that thanks to the research of Y. V. Zaitsev, P. I. Vasiliev, V. G. Orekhov, A. P. Pak, E. N. Peresypkin, L. P. Trapeznikov and other scientists, carried out back in the 70s of the 80s of the 20th century, the priority of domestic science in the field of concrete fracture mechanics is generally recognized today.

When determining the parameter of the stress intensity factor, standards and recommendations were developed [5-16], which recommend the use of many variations of concrete specimens with artificial cuts, produced in different ways. An artificial cut cannot be tied in its final natural fracture area. This drawback of an artificial cut occurs when loading concrete samples: as can be seen from the experiments carried out at the end of the cut, its continuation always develops in the form of a stable natural crack. The increase in the section is quite significant and the calculation of the stress intensity factor along the length of the section without taking into account the increment due to the increase in the crack leads to an underestimated value of the stress intensity factor.

In [17], the authors argue that in an inhomogeneous body, cracks can propagate not only in one or another fold material, but also in the zone of their contact. If the strength of the contact zone is high enough (higher than the strength of each of the materials), then on the contact surface the crack will not go along this surface, but will propagate deep into one or both materials according to the laws of crack development in homogeneous bodies. If the strength of the contact zone is insufficient, then the crack will be directed along the contact surface. In addition, in an inhomogeneous material, depending on the ratio of the properties of its components and the characteristics of the contact zone of these components, cracks can develop in different areas of the material.

To determine the stress intensity factor in laboratory conditions, you can use the method of S. N. Leonovich, O.V. Popov, K.A. Piradov [18], the essence of the method consists in determining the maximum loads that destroy control samples during compression and calculating the critical values of stress intensity. The challenge for the authors was to find a way to determine the stress intensity factor in already existing structures.

Identifying the previous unresolved parts of the common problem:
1. The use of methods for determining the stress intensity factor in heavy concrete based on cement binder is very numerous, but still insufficiently standardized for lightweight concrete based on multicomponent binders.
2. Based on the analysis of the results of studies of cracks from the point of view of fracture mechanics, the expediency of using the data in heavy concrete on a cement binder is obvious, for which special requirements are imposed. There are not enough publications on the use of lightweight concrete in scientific periodicals.

3. Goals and objectives of the study
The aim of the work was to conduct experimental studies of the influence of the factors of the composition of expanded clay concrete on a multicomponent binder on microcracking and the stress intensity factor. To achieve this goal, the following tasks were solved:
- to determine the lower and upper boundaries of the micro-thickness setting in the structural and heat-insulating expanded clay concrete on a multicomponent binder;
- to reveal the appearance of crack reproduction along the notch to determine the stress intensity factor in structural and heat-insulating expanded clay concrete on a multicomponent binder.

4. Materials and methods for studying expanded clay concrete on a multicomponent binder.
The research methods were the use of previous experience in certain micro-gaps and stress intensity factors, which included the determination of the upper and lower boundaries of cracking in accordance with the current standards [16].

The Odessa State Academy of Civil Engineering and Architecture has developed a technology for low-cement concretes. The technology is based on the use of a four-component binder, which, in addition to portland cement and ground quicklime, also contains an active mineral additive (fly ash) and gypsum [4].
The materials used in the studies had the following characteristics:
- expanded clay gravel 5 ... 10 mm, not fractionated by the Kulindorovsk industrial concern "Into-Stroy", grades by bulk density M 600, conditional strength in the cylinder equal to 2.8 ... 3.0 MPa;
- quartz sand of the Kremenchuzhzky quarry;
- cement M 400 of the Krivorizhzka plant - DSTU B V.2.7-112-2002;
- fly ash of the Chelyabinsk CHPP - GOST 25818-91;
- quicklime lime of the Kulindorovsky plant, the content of active calcium oxide CaO 75%;
- building gypsum - DSTU B V.2.7-104-2000;
- superplasticizer S-3 - TU-2481-001-51831493-00.

Based on the dependences obtained in earlier studies [1-3], as well as on the basis of the requirements [19] for lightweight concretes, the optimal compositions of expanded clay concrete on multicomponent binder and quartz sand were assigned, which are shown in Table 1.

**Table 1.** Optimal compositions of expanded clay concrete on a multicomponent binder.

| Design strength, MPa | Aggregate-structural factor, r | Cement, kg/m³ | Lime, kg/m³ | Fly ash, kg/m³ | Ceramsite, kg/m³ | Sand, kg/m³ | Gypsum, kg/m³ | S-3, % | Water, l |
|----------------------|--------------------------------|---------------|--------------|----------------|------------------|-------------|---------------|--------|----------|
| 10                   | 0.5                            | 100           | 110          | 100            | 495              | 500         | 25            | 0.3    | 205      |
| 12.5                 | 0.3                            | 110           | 150          | 105            | 460              | 210         | 25            | 0.3    | 225      |
| 15                   | 0.3                            | 150           | 125          | 145            | 475              | 215         | 25            | 0.3    | 235      |
| 20                   | 0.3                            | 200           | 105          | 190            | 455              | 205         | 25            | 0.3    | 220      |
| 25                   | 0.3                            | 220           | 150          | 200            | 460              | 200         | 25            | 0.3    | 230      |

Investigations to determine the boundaries of microthickness in expanded clay concrete on a multicomponent binder were reduced to constructing a diagram of the state of concrete, expressed by the curve of changing the transit time of ultrasonic vibrations in concrete. Determination of the lower $R^0_T$ and upper $R^v_T$ boundaries of the area of microthickness of structural concretes was carried out by the ultrasonic method in accordance with the methodology [20] using the UK-10PMS device in parallel with the determination of their strength and deformation characteristics. The measurement of the transit time of ultrasonic pulses $\tau_\sigma$ through the prototype with increasing load was carried out in the direction perpendicular and diagonal with respect to the direction of axial compression. In the first case, the ultrasonic probes were installed on opposite faces of the sample strictly opposite each other, and the instrument readings were taken at three positions of the probes: above, in the middle, and at the bottom of the sample. In the second case, the probes were also mounted on opposite faces of the sample, one on top and the other at the bottom of the sample. Thus, a large area of uniaxial stress state of the concrete prism was covered.

One of the most important elements of improving the quality of prefabricated load-bearing wall structures is the optimization of the composition of concrete, aimed at increasing its crack resistance. To experimentally determine the critical stress intensity factor, two types of samples were used: notched beam samples (Figure 1) and notched cubes (Figure 2) in accordance with DSTU B 2.7-227: 2009 [16].
The study of the stress intensity factor in expanded clay concrete on a multicomponent binder was carried out on samples of cubes 10 × 10 × 10 cm with notches and beams 10 × 10 × 40 cm with notches, which were tested according to the three-point bending scheme, respectively, according to DSTU B.2.7-227: 2009 [16]. The samples were tested on a PG-50 hydraulic press, loading them with a low load until the appearance of the crack reproduction along the notch.

5. The results of the study of expanded clay concrete on a multicomponent binder

5.1. Microcracking

Figure 3 shows the results of studies of the dependence of the transit time of ultrasonic pulses on the stress levels of axial compression. This figure shows the processes of compaction of the material (this is evidenced by a decrease in the pulse transit time). The limit $R^0_T$ correspond to the shortest time of ultrasound passage through the sample. Further, decompaction occurs, the development of micro-ruining (above the limit $R^0_T$) and their next intensive development. The intersection of the curve with the ordinate axis $R^v_T$ corresponds to the upper boundary of the microfracture setting and reflects significant changes in the stress and strain state of the material under load. The limit $R^v_T$ stands out when microfracture begins to prevail over compaction processes.
Figure 3. The dependence of the increments of the passage time of the ultrasonic pulse on the levels of axial compression stresses: $1 - f = 6\, \text{MPa}; 2 - f = 8\, \text{MPa}; 3 - f = 10\, \text{MPa}$.

The relative measurement of the time of passage of ultrasonic pulses through the concrete was determined by the formula:

$$
\Delta \tau = \left( \frac{\tau_{\sigma} - \tau_0}{\tau_0} \right),
$$

(1)

where $\tau_0$ - is the transit time of ultrasonic pulses through concrete under tension $\sigma$;

$\tau_0$ - the same, before the start of the load application.

The stress levels corresponding to the lower and upper boundaries of microcracking of concrete on a multicomponent binder are higher than those for heavy concrete. With an increase in the strength (class) of the concretes under study, an increase in the indicated parametric levels is observed, similar to ordinary expanded clay concrete.

Thus, an increase in the limits of microcracking of expanded clay concrete on a multicomponent binder in comparison with conventional expanded clay concrete can be explained, firstly, by the structural features of this concrete due to the presence of a porous aggregate and filler, and secondly, by the increased adhesion strength of the multicomponent binder with the aggregate.

5.2. Stress intensity factor

Fracture of all samples took place along the crack formed from the notch. The nature of the destruction was the same as for ordinary lightweight concrete - the surface of the destruction passed through both the mortar and the aggregate grains, that is, the destruction of the “matrix-filler” type took place, when the crack cuts the matrix and the filler [18]. The failure of the cube specimen was the same as for the bar specimen.

The processing of the experimental results was carried out according to the formulas:

- for a beam sample:

$$
k_{\lambda C} = \frac{3EIL}{2bh^2_{in}} \lambda^{rac{1}{2}} \left[ 1.93 - 3.07 \left( \frac{\ell}{h} \right) + 14.53 \left( \frac{\ell}{h} \right)^2 - 25.11 \left( \frac{\ell}{h} \right)^3 + 25.8 \left( \frac{\ell}{h} \right)^4 \right].
$$

(2)

- for a cube sample:
where: \( L \) - span of the beam; \( \ell \) - the length of the cut (in the conducted experiments it was 0.01-0.03 m); \( b \) - the width of the sample; \( h \) - cross-sectional height of the specimen (excluding the notch length, \( h_n = (h - \ell) \) for a bar specimen).

The main data (averaged over 6 samples of each composition) on the geometric dimensions of the samples, the value of the breaking (critical) load and the obtained values \( k_{IC} \), together with the value of the tensile strength \( f_{cd} \) obtained by breaking the rest of the sample, are shown in Table 2.

### Table 2. Test results of beams and cubes with a notch

| Design strength, MPa | \( F_{cr} \), MN | \( L \), m | \( h \), m | \( b \), m | \( k_{IC} \), MN/m\(^{3/2} \) | \( f_{cd} \), MPa |
|----------------------|----------------|-----------|----------|---------|----------------|----------------|
| Beam specimens       |                |           |          |         |                |                |
| 10                   | 0.0016         | 0.275     | 0.83     |
| 12.5                 | 0.0015         | 0.268     | 0.9      |
| 15                   | 0.0013         | 0.257     | 0.87     |
| Cube specimens       |                |           |          |         |                |                |
| 10                   | 0.0012         | 0.134     | -        |
| 12.5                 | 0.0028         | 0.181     | -        |
| 15                   | 0.0025         | 0.168     | -        |

As can be seen in Figure 4, for a beam specimen, the change in the aggregate-structural factor in the concrete mixture affects the crack resistance insignificantly. For cube specimens, a change in the aggregate-structural factor in a concrete mixture affects crack resistance more noticeably than in the case of testing beams. The very dependence of crack resistance on the content of the aggregate-structural factor has a complex "wavy" character. At the same time, it can be stated that an increase in the aggregate-structural factor (including fine aggregate) leads to a decrease in crack resistance, and its decrease - to an increase in crack resistance.

Analysis of the results also shows that there is a close correlation between the tensile strength \( f_{cd} \) and the critical stress intensity factor \( k_{IC} \). The results obtained - the relationship between these two quantities - is shown in Figure 5. As can be seen, all experimental points are satisfactorily approximated by the dependence:

\[
k_{IC} = \alpha f_{cd},
\]

where \( \alpha = 0.265 m^{1/2} \) is the value characterizes the angle of inclination of the approximating straight line.
6. Conclusions

1. The increased limits of micro-thickness setting allow us to recommend the developed expanded clay concrete based on a multicomponent binder for structures designed for the combined effect of force factors and unfavorable environmental influences.

2. The area of stress state, located within the limits of micro-blasting, is of fundamental importance for assessing many important processes of deformation and strength of concrete. It was revealed that the most effective in terms of strength and crack resistance are concrete warehouses with the highest content of filler and aggregate, which should be recommended for the manufacture of structures.

3. The warehouses of expanded clay concrete on a multicomponent binder given in the article can be recommended for the manufacture of structures, taking into account the observance of the technology of their manufacture.

4. The results of studies of micro-thinning are presented, which are the initial link in determining the main properties of expanded clay concrete on a multicomponent binder and require further study of the effect of micro-thinning and stress intensity factor on the operation of structures made of this concrete.

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