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MOSKALKOVA YU. H.
PhD, ass. prof., Belarusian-Russian University, Mogilev, Republic of Belarus,
e-mail: julia43@tut.by,
tel. +375 (29) 742-91-83,
ORCID: 0000-0002-4107-2452

BEHAVIOR OF CLAYDITE AT THE STAGE OF MICROCRACK FORMATION

ABSTRACT. In view of the increase of structural lightweight concrete importance the studies of the lightweight concretes under static loading (single and low-cycle) are conducted within the framework of the state program of scientific research "Building Materials and Technologies" on the basis of the Belarusian-Russian University. The purpose of the research is to develop the national application of the Republic of Belarus to Eurocode 2. In the paper the results of the experimental research of claydite concrete with the use of expanded-clay gravel as fine aggregate are presented and the dependencies for determining the relative loads corresponding to the upper and lower limits of microcracks formation are proposed.

KEY WORDS: concrete, claydite concrete, microcracks

МОСКАЛЬКОВА Ю.Г.
Канд. технічних наук, доц., Білорусько-Російський університет, м. Могильов, Республіка Білорусь,
e-mail: julia43@tut.by,
тел. +375 (29) 742-91-83,
ORCID: 0000-0002-4107-2452.

ОСОБЛИВОСТІ РОБОТИ КЕРАМЗИТОБЕТОНУ НА СТАДІЇ УТВОРЕННЯ МІКРОТРІЩИН

АНОТАЦІЯ. У Білорусько-Російському університеті в межах державної програми «Будівельні матеріали та технології» проводяться дослідження роботи керамзитобетону різних класів при статичному навантаженні. Метою досліджень є розроблення національного додатка до Єврокодів 2. У цій статті представлено результати експериментальних досліджень роботи керамзитобетону, запропоновано залежності для визначення відносних навантажень, що відповідають верхній та нижній межі утворення мікротріщин.

КЛЮЧОВІ СЛОВА: бетон, керамзитобетон, мікротріщини.

МОСКАЛЬКОВА Ю.Г.,
канд. техн. наук, доц., Белорусско-Российский университет, г. Могилёв, Республика Беларусь,
e-mail: julia43@tut.by,
тел. +375 (29) 742-91-83,
ORCID: 0000-0002-4107-2452

ОСОБЕННОСТИ РАБОТЫ КЕРАМЗИТОБЕТОНА НА СТАДИИ ОБРАЗОВАНИЯ МИКРОТРЕЩИН

АННОТАЦИЯ. В Белорусско-Российском университете в рамках государственной программы проводятся исследования работы керамзитобетона различных классов при статическом нагружении. Целью проводимых исследований является разработка национального приложения Республики Беларусь к Еврокоду 2. В данной статье представлены результаты экспериментальных исследований работы керамзитобетона, предложены зависимости для определения относительных нагрузок, соответствующих верхней и нижней границам микротрещинообразования.

КЛЮЧЕВЫЕ СЛОВА: бетон, керамзитобетон, микротрещины

RANGE OF APPLICATION AND ADVANTAGES OF CLAYDITE CONCRETE

At the present time ensuring the energy performance of buildings is one of the key directions in the construction. In our climatic zone the main item of expenses is domestic space heating. In this regard, the use of structural lightweight concrete becomes increasingly in demand.

To date, in CIS countries, claydite concrete is used in the construction of 10-15 % of residential buildings, while in Western Europe its share reaches 40 %. This type of concrete is particularly popular in Germany, the Czech Republic, the Netherlands and the Scandinavian countries. The claydite concrete blocks are often called "bioblocks" because of their high environmental performance. For its thermal conductivity, claydite concrete is almost equal to aerated concrete, but the strength and deformation characteristics of claydite concrete are much higher, which allows using it for manufacturing not only enclosing, but also bearing structures. Moreover, claydite concrete is one of the least expensive building materials.

For instance, claydite concrete as a material for covering has practically no equal products in its price category, since heavy concretes have high thermal conductivity, and almost all lightweight concretes have low strength. The main disadvantage of claydite concrete is moisture permeability, that is, waterproofing is mandatory.

Research of the claydite composition forming, its strength and deformation behavior [1–5], claydite production technology [6, 7], materials [8] and structures [9–12] on claydite basis is scientific interest. The works [13, 14] are devoted to peculiarities of stress-strain state of claydite buildings.

EXPERIMENTAL INVESTIGATIONS

Significant characteristics of strength and deformability of concrete (in particular, claydite concrete) include the upper and lower limits of microcracks formation. Before reaching the lower limit of microcracks formation, the number of contact microcracks in the body of concrete is insignificant, and they can be neglected. When the limit is exceeded, the number of microcracks, their length and opening width substantially increase and the combined microcracks appear. They cause the sliding of coarse aggregate grains relative to the cement matrix without disturbing the system stable state, which results in the manifestation of concrete inelastic properties.

The further load increase leads to the microcracks merging into macrocracks, and so the upper limit of microcracks formation is reached. The macrocracks divide the structure of concrete into blocks that begin to shift relative to each other. At this stage of loading there are the irreversible destructive processes resulting in concrete disintegration under the further application of load even without its increase. Thus, a risk of fatigue failure during prolonged loading arises.

The purpose of the performed experimental studies was to determine the specifics of the claydite concrete work at the microcracks formation stage in comparison with the traditionally used heavy concrete.

These features were found out by means of testing the standard samples in the form of prisms with dimensions of 150 × 150 × 600 mm and the cylinders of 150 mm in diameter and 300 mm high. The prototypes were made of heavy concrete (coarse aggregate of crushed stone) and claydite concrete (coarse aggregate of expanded-clay gravel produced by JSC "Expanded-Clay Gravel Plant Novolukoml). The fraction of coarse aggregate for all series of prototypes was 5-20 mm. The fine aggregate was quartz sand with a size modulus of 1.8, cementing aggregate was Portland cement grade M 500 of JSC "Belarusian Cement Plant". The water-cement ratio was 0.55 ± 0.05.

The manufacture of test samples from claydite concrete and their testing were carried out by the post-graduate student I. Meliantsova at the Belarusian-Russian University Department of Building Structures, Buildings and Constructions.

Based on the tests results, the relative loads corresponding to the upper and lower limits of microcracks formation (ηvcrc and η0crc, respectively) were determined for claydite concrete and heavy concrete.

The upper limit ηvcrc was determined as a peak point of the graph "Loading level η - volume strain εV", and the lower limit η0crc was determined by taking the second derivative of the dependence "Loading level η - Poisson's ratio ν" (from the correlation curves of the dependences «$\frac{d\nu}{d\eta}-\eta$» and «$\frac{d^2\nu}{d\eta^2}-\eta$») [15–18].

PROPOSALS FOR CALCULATING THE RELATIVE LOADS CORRESPONDING TO THE UPPER AND LOWER LIMITS OF MICROCRACKS FORMATION

Based on experimental data, it is established that there is a linear relationship between the values of relative loads for the upper and lower limits of microcracks formation. The ratio of the values of load level corresponding to the lower limit of the microcracks formation to the value of the load level corresponding to the upper limit remains constant regardless of concrete grade [18]:

$$\frac{\eta_{crc}^{0}}{\eta_{crc}^{V}} = \text{const}. \qquad (1)$$

The value of ratio $\frac{\eta_{crc}^{0}}{\eta_{crc}^{V}}$ can be taken

– for heavy concrete as $\frac{\eta_{crc}^{0}}{\eta_{crc}^{V}} \approx 0,67$ [18];

and

– for claydite concrete as $\frac{\eta_{crc}^{0}}{\eta_{crc}^{V}} \approx 0,60$ (according to the obtained experimental data).

The empirical coefficient k_{crc} taken according to the value of $\frac{\eta_{crc}^{0}}{\eta_{crc}^{V}}$ can be used for the calculations of concrete and reinforced concrete structures as follows:

$$k_{crc} = k_{c1} \cdot \frac{\eta_{crc}^{0}}{\eta_{crc}^{V}} \qquad (2)$$

Table 1. The comparison of the experimental and theoretical values of the relative loads corresponding to the upper $\eta^{v}{}_{crc}$ and lower $\eta^{0}{}_{crc}$ limits of microcracks formation

Strength f_{cm}, MPa	Experimental values		Ratio $\frac{\eta^0_{crc}}{\eta^V_{crc}}$		Coefficient k_{c1}	Coefficient k_{crc}	Calculated values		Deviations of calculated values from experimental ones, %	
	η^0_{crc}	η^v_{crc}	experimental	accepted			η^0_{crc}	η^v_{crc}	$\Delta\eta^0_{crc}$	$\Delta\eta^v_{crc}$
Claydite concrete										
9,1	0,41	0,71	0,58	0,6	1,2	0,72	0,37	0,62	8,6	12,0
10,7	0,44	0,73	0,60				0,41	0,66	6,1	9,2
11,2	0,44	0,73	0,60				0,42	0,67	3,6	7,7
15,9	0,50	0,75	0,67				0,51	0,76	-1,5	-1,0
17,7	0,45	0,75	0,60				0,53	0,78	-18,4	-4,4
Heavy concrete										
18,7	0,51	0,75	0,68	0,67	1,0	0,67	0,50	0,75	2,5	0,3
19,4	0,58	0,85	0,68				0,51	0,76	12,8	11,1
22,3	0,54	0,81	0,67				0,54	0,79	0,7	2,9
28,1	0,53	0,83	0,64				0,59	0,84	-10,9	-0,9
28,2	0,57	0,84	0,68				0,59	0,84	-3,2	0,2
29,0	0,58	0,86	0,67				0,59	0,84	-2,5	1,8
Average deviation (in absolute value) is $\overline{\Delta\eta_{crc}} = \frac{1}{n}\sum_{i=1}^{n}\left|\Delta\eta_{crc,i}\right|$									6,4	4,7

The coefficient k_{c1} is introduced into formula (2) with its value being specified for claydite concrete as $k_{c1} \approx 1.2$ (for heavy concrete and some other types of concrete $k_{c1}=1.0$ is used [18]). This coefficient is introduced because of the specificity of claydite concrete work under static loading: the initial elasto-plastic modulus of claydite concrete is lower and the final one is higher than for heavy concrete.

Thus, according to formula (1) we obtain:

– for heavy concrete

$$k_{crc} = 1.0 \cdot 0.67 = 0.67;$$

and

– for claydite concrete

$$k_{crc} = 1.2 \cdot 0.60 = 0.72.$$

To determine the relative values of loads corresponding to the upper and lower limits of microcracks formation, the dependences (formulae (3) and (4)) are proposed, in which, in addition to the concrete strength, the type of concrete is taken into account (in contrast to the dependences proposed by O. Berg [19]).

$$\eta^0_{crc} = 0{,}33k_{crc} \cdot \ln\frac{f_{cm}}{f_{cm,0}} - 0{,}15; \quad (3)$$

$$\eta^v_{crc} = 0{,}33k_{crc} \cdot \ln\frac{f_{cm}}{f_{cm,0}} + 0{,}1, \quad (4)$$

where f_{cm} is an average strength of concrete, MPa; and $f_{cm,0}$ is a single value of a concrete average strength, $f_{cm,0}=1$MPa.

The natural logarithm use in formulas (3) and (4) instead of the decimal one [19] allows to calculate η_{vcrc} and η_{0crc} in a wider range of strengths, and the introduction of the empirical coefficient kcrc makes the proposed dependences universal and applicable for concretes of various types (in addition to heavy concrete and claydite concrete, steel fiber concrete on the basis of a factory made "Vulkan Harex" fiber and concrete with the use of cupola slag as fine aggregate were also studied [18]).

In Table 1 the experimental and calculated relative values of loads corresponding to the upper and lower limits of microcracks formation are compared for samples of claydite concrete and heavy concrete.

As can be seen from Table 1, the dependencies proposed for the determination of the upper and lower limits of microcracks formation ensure the satisfactory convergence with experimental data. The assigned values of the empirical coefficients are adequate.

CONCLUSIONS

The value of the coefficient kcrc can be used to evaluate the efficiency of the usage of the various types of concrete for the construction of structures operating under the conditions of varying loads (for instance, natural or low-cycle loads). The higher the value of the coefficient kcrc is, the more stable will be the work of concrete under the action of a variable static load, since the upper limit of microcracks formation will be higher (for the same strength characteristics).

Thus, the coefficient value $k_{crc} \approx 0{,}72$ indicates a higher low-cycle adaptability of claydite-concrete in comparison with traditional heavy concrete. This assumption requires empirical verification, since such studies have not been carried out so far, but an argument in favor of this assumption is the fact that the values of η0crc and ηvcrc for claydite concrete exceed the corresponding characteristics of the axial compression strength for heavy concrete of the same grade.

The advantages of lightweight concrete in comparison with other traditional types of concretes are not only a low value of specific weight, low thermal conductivity and sound permeability. High values of relative loads corresponding to the upper and lower limits of microcracks formation make it reasonable to use structural lightweight concretes for the manufacture of structures subject to low-cycle static loads.

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