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RESEARCH AND ANALYSIS OF THE INFLUENCE OF RECIPE AND TECHNOLOGICAL FACTORS ON THE STRENGTH OF EXPANDED CLAY CONCRETE ON QUARTZ SAND

ДОСЛІДЖЕННЯ Й АНАЛІЗ ВПЛИВУ РЕЦЕПТУРНО-ТЕХНОЛОГІЧНИХ ФАКТОРІВ НА МІЦНІСТЬ КЕРАМЗИТОБЕТОНУ НА КВАРЦОВОМУ ПІСКУ

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Метою роботи є дослідження міцності та деформаційних властивостей керамзитобетону на цементно-зольному в'яжучому та доведення технічної можливості та економічної доцільності його використання в конструктивних елементах цивільних будівель. Для вивчення властивостей керамзитобетону були використані методи математичного планування експерименту, зокрема, реалізовано п'ятифакторний план B_5. У матриці кожен з технологічних факторів змінювався на трьох рівнях (-1; 0; +1), що дозволило отримати квадратичні математичні моделі вихідних параметрів - об'ємної маси бетону, кубікової та призмової міцності керамзитобетону у віці 1 (п.п), 28, 115, 180 і 360 діб, при постійному осіданні конуса керамзитобетонної суміші – ОК = 2... 6 см). Обробка результатів експерименту для виявлення закономірностей впливу досліджуваних факторів – витрата: цементу (x_1); вапна (x_2); золи-винесення (x_3); керамзитового гравію (x_4); кварцового піску (x_5) на водопотребу керамзитобетонних сумішей – В, об'єм міжзернових пустот V_n, щільність керамобетонної суміші ρ_o і щільність керамзитобетонних ρ дозволили отримати при 95% надійності квадратичні рівняння регресій з урахуванням лише значущих коефіцієнтів регресії. За результатами експериментальних досліджень отримано з 95% надійністю квадратичні рівняння регресії кубикової та призмовоої міцності у віці 1 (п.п.), 28, 180 та 360* діб, керамзитобетону на ЦВЗ в'яжучому та кварцовому піску з урахуванням лише значущих коефіцієнтів регресії. Розглянуто та проаналізовано вплив рецептурних та технологічних факторів на міцність керамзитобетону на кварцовому піску. Отримані залежності кубикової та призмової міцності керамзитобетону на кварцового піску з застосуванням багатокомпонентного* *в'яжучого можна використовувати для подальшою перспективою економії цементу і заповнювачів.*

The aim of the work is to study the strength and deformation properties of expanded clay concrete on cement-ash binder and to prove the technical possibility and economic feasibility of its study in structural elements of civil buildings. The five-factor plan B5 was implemented. In the matrix, each of the technological factors changed at three levels (-1; 0; +1), which made it possible to obtain quadratic mathematical models of output parameters - the bulk mass of concrete, cubic and prismatic strength of the expanded clay concrete at the age of 1 (a.s), 28, 115, 180 and 360 days, when the expanded clay concrete mixture is mobile (the constant draught of the cone is DC= 2...6 cm). Processing of experimental results to identify regularities of influence of studied factors - consumption: cement (x_1); lime (x_2); fly ash (x_3); expanded clay gravel (x_4); quartz sand (x_5) on water consumption of ceramic and concrete mixtures – B, volume of inter-grain voids V_n, the density of the ceramic concrete mixture – ρ_o and the density of the expanded clay concrete ρ allowed to obtain with 95% reliability quadratic regression equations, taking into account only significant regression coefficients. Based on the results of experimental studies with 95% reliability quadratic regression equations of cubic and prismatic strength in the age of 1 (a.s), 28, 180 and 360* days are obtained, expanded clay concrete on CLF-binder and quartz sand with only significant regression factors. The paper examines and analyzes the influence of recipe and technological factors on the strength of expanded clay concrete on quartz sand. The invention makes it possible to use the dependence of a cubic and prism strength expanded clay concrete on quartz sand using a large component binder with a further prospect of saving cement and fillers.*

Key words: deformability, expanded clay concrete on quartz sand and cement-ash binder, fly ash, regression equation, prism strength, cubic strength, aggregate-structural factor.

Ключові слова: деформативність, керамзитобетон на кварцовому піску та цементно-зольному в'яжучому, зола-винесення, рівняння регресії, призмова міцність, кубикова міцність, агрегатно-структурний фактор.

Introduction. Particular attention in the difficult war and future postwar times is paid to the problem of cheapening public and civilian objects, increasing their level of industrialization, which can only be achieved by improving constructive solutions, the use of effective building materials. The use of light concretes, including expanded clay concretes on cement-ash binder with chemical additives is an urgent task, since it involves saving raw materials, cement, recycling production waste and improving the condition of the environment.

Analysis of previous studies. Recently, many studies have been made on the strength and deformability of light concretes and structures based on them, which are given in the works of A. I. Kostyuk [1], I. A. Stolevich [2, 3], Chandra S. [4], Dilly M. [5], Melby K. [6], Neville A. [7], Norden J. [8], Suraneni P. [9], Zarif M. [10], etc. A significant contribution to the development of concretes using slag and ash was made by Ocheretny V.P., Kovalsky V.P. [11], L.J. Dvorkin [12], etc., mainly the use of ash and slag was considered for heavy concretes.

Purpose. In this regard, we set a method of strength and deformation properties of expanded clay concrete on CLF-binder and prove the technical possibility and economic feasibility of its use in structural elements of civil buildings.

Results and discussion. The application of light concretes on porous aggregates in various construction fields is of great interest in many countries. Issues of improving the structure and properties of light concretes, as well as their features and advantages on mixed aggregate and composite binders were reflected in many domestic and foreign studies. The most common rules for the construction of light concrete as a composite material are the reasonable choice of binder according to the requirements of the product, design and construction, as well as the rational selection of individual components taking into account the minimum cost. It is possible to increase the amount of concrete produced by the use of a multicomponent binder, which, in addition to a reduced amount of Portland cement, includes quicklime, fly ash and chemical additives [13].

Among the numerous wastes and by-products (waste from mining and processing plants, metallurgical slags and phosphorus production, thermal power plant ash, etc.) the use of thermal power plant ash with relatively high hydraulic activity is of the greatest interest. At present, Ukraine and foreign practice have gained considerable experience in the use of pulverized fly ash in the production of concretes and structures made of it. The introduction of ash, lime and chemical additives into cement systems alters the composition of the liquid phase, induces saturation relative to the hydrate phases, and changes in these parameters affect the formation kinetics and composition of hydrate formations, the size of the crystals, the strength of their fusion contact, which together determines the strength of the solidified cement stone [14,15].

The widespread use of ash in concrete began after it was discovered that fine particles of high quality ash have puzzolan properties. By 1980, ash was recognized worldwide as an important material as an additive to concrete replacing cement.

The effectiveness of the additives depends significantly on the mineralogical and material composition of the Portland cement used, lime and ash properties. This is due to the fact that the action of the additive occurs in an environment that has changed as a result of the hydration of the cement-ash binder, the composition of which largely determines these changes [14].

In order to obtain adequate results with the minimum possible number of experiments to study the properties of expanded clay concrete on a multicomponent binder, methods of mathematical experiment planning were used [14]. In particular, a five-factor B5 plan was implemented. In such a matrix, each of the technological factors changed at three levels (-1; 0; +1), which made it possible to obtain quadratic mathematical models of output parameters - the bulk mass of concrete, cubic and prismatic strength of the clay concrete at the age of 1 (a.s), 28, 115, 180 and 360 days, when the expanded clay concrete mixture is mobile (the constant draught of the cone is DC = 2...6 cm).

To achieve this objective, it was necessary to:

- to obtain the convenient for the practical study of the dependence of the main properties of clay concrete mixture on the cement-ash binder with the index of mobility DC =2... 6cm and concrete from the main formulation and technological factors;
- to obtain statically convenient dependencies, allowing to predict water consumption of the mixture, volume mass, volume of inter-grain voids, cubic and prism strength.

Research factors on materials used in studies:

X_1 - 180±60 kg/m^3, Portland cement OJSC «SOUTH cement» brand 400;

X_2 -125±25 kg/m^3, ground ungashed lime, Kodyma, activity on CaO - 58%;

X_3 - 150±50 kg/m^3, fly ash Ladygenskaya thermal power plant;

X4- 400±140 kg/m^3, ceramic gravel (Kulindorovsky Zavod from the clay deposit of the Orel region of the Odessa region) fraction 5...10 and 10... 20mm in volume ratio $V_{5...10}/V_{10...20}$ = 1,5;

X5- 290±30 kg/m^3, sand river dense "Telman quarry", "Kremenchuk river port", module of size 1,36.

Plasticizer C-3 was introduced as 0.6% of cement mass and gypsum - 25 kg/m^3.

Processing of experimental results to identify regularities of influence of studied factors - consumption: cement (x_1); lime (x_2); fly ash (x_3); expanded clay gravel (x_4); quartz sand (x_5) on water consumption of clay concrete mixture - B, volume of inter-grain voids $V_п$, density of clay concrete mixture - ρ_0 and density of expanded clay concrete ρ allowed to obtain with 95% reliability quadratic regression equations, which, taking into account only the significant regression coefficients, are:

$$B=269,4+4,9X_1+6,9X_2+2,4X_5+3,12X_1X_3+2,25X_2X_3-$$
$$-11,06X_3^2-4X_3X_4+4.44X_4^2-2X_4X_5+5.94X_5^2. \quad (1)$$
$$\rho_0=1334+66,9X_1+24,7X_2+37,7X_3+132,2X_4+34,2X_5+$$
$$+12,51X_2^2-10,44X_3X_4. \quad (2)$$
$$V_n=1,602-0,25X_1-0,20X_4-0,30X_1^2+0,25X_1X_2+$$
$$+0,27X_1X_3+0,58X_2^2+0,14X_2X_4+0,16X_3^2+0,27X_3X_5+0,29X_4X_5. \quad (3)$$

The water content of clay concrete mixture depends almost equally on the content of the astringent components and on the content of large, fine aggregates [16]. Analysis of the water consumption regression equation and its graphical interpretation given in figure 1. It shows that the aggregate-structural factor r has a mixed influence on water consumption. For a certain consumption of multi-component binder, there is an optimal content of expanded clay gravel and quartz sand (r_{opt}), corresponding to the minimum possible water consumption of the mixture, provided that the predefined convenience.

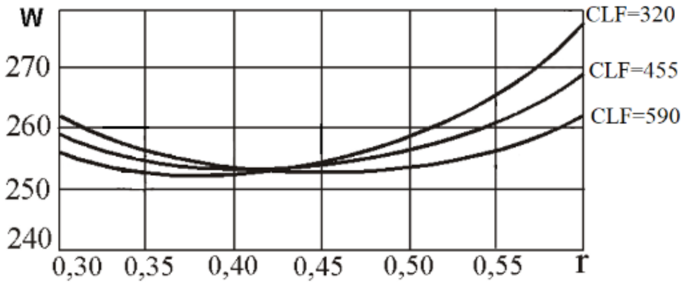

Fig. 1. Dependence of water consumption expanded clay concrete on the values of the aggregate-structural factor and the consumption of CLF-binder DC 2-6cm

On figure 2 the zone of optimum values of the aggregate-structural factor r_{opt}, limited by the lines corresponding to the indicators of DC =2... 6cm (upper) and H= 30c (lower). The figure shows that the optimal value of the aggregate-structural factor decreases in proportion to the increase in the consumption of the CLF-binder.

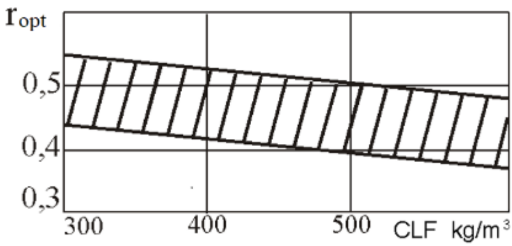

Fig. 2. Zone of optimal values of aggregate-structural factor

Based on the results of experimental studies with 95% reliability quadratic regression equations of cubic and prismatic strength in the age of 1 (a.s), 28, 180* and 360* days are obtained expanded clay concrete on CLF-binder and quartz sand, which, taking into account only significant regression coefficients, have the form:

$$f_{c\,(a.s)} = 17{,}1+3{,}1X_1+1{,}5X_2+1{,}7X_3+2{,}7X_4+2{,}1X_1^2+1{,}2X_1X_2+ +1{,}3X_1X_3-1{,}2X_3X_4-1{,}5X_4^2-1{,}5X_5^2. \quad (4)$$

$$f_{c\ (28)} = 19{,}95+3{,}7X_1+1{,}7X_2+1{,}9X_3+3{,}0X_4+2{,}7X_1^2+1{,}2X_1X_3-1{,}2X_3X_4-1{,}4X_4^2-2{,}1X_5^2. \quad (5)$$

$$f_{cd\ (a.s)} = 15{,}58+3X_1+1{,}4X_2+1{,}5X_3+2{,}5X_4-0{,}5X_5+2{,}6X_1^2+1{,}2X_1X_2+1{,}2X_1X_3-1{,}1X_3X_4-1{,}4X_4^2X4-1{,}4X_5^2. \quad (6)$$

$$f_{cd\ (28)} = 18{,}5+3{,}3X_1+1{,}5X_2+1{,}7X_3+2{,}8X_4+2{,}5X_1^2+1{,}1X_1X_3-1{,}079X_3X_4-1{,}178X_4^2-1{,}833X_5^2. \quad (7)$$

To simplify the quadratic regression equations (4-7), a linear relation was used. The rationale for "x" was based on the need to take into account the one that had a significant impact on strength but was not included as a water consumption factor. The final argument is to assign x = [(W/ CLF)+r], which can be taken as a generalized factor of composition. On the basis of mathematical and static analysis, it has been established that random quantities x = [(W/ CLF)+r] are subject to the law normal distribution. The null hypothesis of the zero general correlation coefficient H_0: $\rho_{xy} = 0$ is rejected in favour of the alternative H_1: $\rho_{xy} \neq 0$ at the dependency level $\alpha = 0{,}05$, which suggests a linear relationship between f_{cd} and x=[(W/ CLF)+r] of each of the age taken for expanded clay concrete. This allowed the linear regression equations of type to be obtained for each of the ages taken:

$$f_{cd\ (a.s)} = 45{,}1- 29{,}1[(W/ CLF)+r]. \quad (8)$$

$$f_{cd\ (28)} = 49{,}2 - 30{,}3[(W/ CLF)+r]. \quad (9)$$

Graphical interpretation, as an example, of the dependence of strength $f_{cd\ (28)}$ on the generalized factor of composition x=[(W/ CLF)+r] within 95% confidence intervals is given in figure 3 (a, b). .

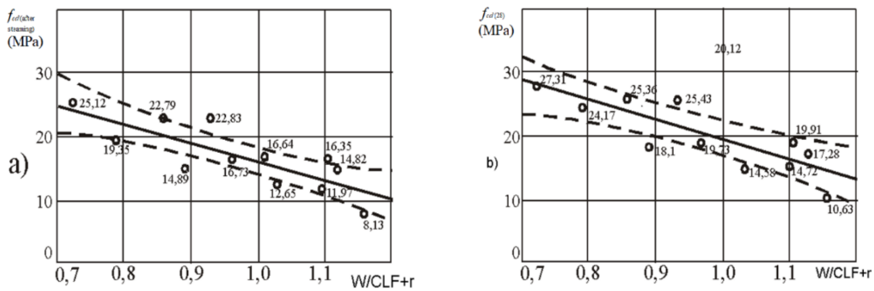

Fig. 3. The dependence of the prismatic strength of the expanded clay concrete on the generalized composition factor

a) after steaming; b) 28 days

For the transition from a cubic strength f_c to a prism strength f_{cd}, which is directly applied in the structural calculations, the prism strength coefficient shall be used $\varphi_c = f_{cd}/f_c$. As shown by numerous studies [12, 1] the value φ_c for light concretes is slightly higher than for heavy, and varies within 0.85... 1.

NOTE: The results of the age 180, 360 days here and later are not given because of the reduction in the volume of the article.

The experimental values of the controlled parameters $f_{c\,(28)}$, $f_{cd\,(28)}$ were used to estimate the influence of the variation of the strength expanded clay concrete on the φ_c smallest squares equation obtained:

$$\varphi_c = 0{,}826 + 0{,}0097x - 0{,}0003x^2. \tag{10}$$

Analytical expressions recommended by various researchers to describe changes in the strength of concrete in time generally do not contain parameters characterizing the composition.

Without contesting the validity of this approach, it should be noted that for light concrete this assumption is not always justified. For them, the recommended time dependency structure should be improved by introducing the composition factors that most significantly affect strength.

Summary

1. Expanded clay concrete on quartz sand and cement-lime-fly ash binder with a strength of 15, 20, 25 MPa can be recommended as a construction material for the manufacture of concrete and reinforced concrete structures.

2. Studies of the strength of expanded clay concrete on quartz sand, made on the basis of CLF -binding and determined:

- bulk mass;
- cubic and prism strength and their change in time;
- the value of the prism strength coefficient.

3. Density ρ, strength f_c, f_{cd} expanded clay concrete in ages 1(a.s), 28, 180, 360 days is recommended to use simple linear regression equations.

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