Expanded clay concrete mixtures and concretes on carbonate sand property improvement

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Abstract. Results of researches of properties of expanded clay concrete on carbonate sand, mixtures and concrete, as well as a technique for selecting optimal concrete compositions for monolithic load-bearing and enclosing structures of residential and public buildings and structures are given.

1. Introduction
Today one of the main directions of building development is reduction of labour intensity and material consumption at building materials and structures manufacturing, reduction of their energy intensity and use of local materials.

Lightweight concrete on porous aggregates is a universal building material that allows, with its rational use, to solve many actual tasks of modern construction and simultaneously solve environmental, resource-saving and economic problems through technological and man-made waste when using and manufacturing local porous aggregates.

Additional economic effect can be reached at lightweight concretes on local aggregates of south of Ukraine (expanded clay, keralite, carbonate sand) and structures on their base use for buildings and structures construction.

Deficiency of fine aggregates for concrete in many regions of the country can be replenished by a wide application for their production of carbonate rock waste (porous limestone and shell limestone). Previous studies have shown the technical feasibility and economic feasibility of using limestone (carbonate) sand in concrete on artificial porous aggregates, and first of all in expanded clay aggregate, which makes up about 70% of the total volume of lightweight concrete.

2. Analysis of previous studies
Over the past years, in the laboratory of the Department of Reinforced Concrete and Stone OSACEA, research has been conducted on the use of rock-stone waste from various deposits in the south of Ukraine as a filler in the manufacture of concrete and reinforced concrete structures, including prestressed ones. These studies are ongoing.

3. Materials
The study of expanded clay concrete on carbonate sand and structures based on it was carried out in laboratory and production conditions.

In researches were used:
- Portland cement grade 400;
- expanded clay gravel of fractions 5…10 and 10…20 in the ratio by volume $V_{5…10}/V_{10…20}=1.5$;
- carbonate sand obtained from waste of shell limestone sawing.

Physic and mechanical characteristics of expanded clay gravel are shown in table 1.
As a fine aggregate carbonate sand was used. I was obtained as a result of crushing and reasoning of waste of stone-cutting and pieces of low-strength shell stone. Applying of such sand as a fine aggregate for different concretes, including lightweight concretes, is regulated by RST USSR 5014-82 [1] and confirmed in numerous studies.

The chemical composition of limestone-shells of this deposit and averaged data on the deposits of Ukraine are given in Table 2.

According to the chemical composition used in the study, limestones-shells of the Orel deposit can be attributed to pure limestones. The carbonate sands obtained from them do not contain harmful impurities: they are pure and suitable for use.

As studies [2] had shown, the carbonate aggregate is not an inert material, but enters into an active physicochemical interaction with clinker cement. This positive property of carbonate aggregates is complemented by their ability to create a self-priming effect, which leads to an increase in strength in concrete, both the sand itself and the contact layer with cement stone. In addition, it should be noted that the carbonate dust of the fraction (<0.14 mm) plays the role of a microfiller of cement, since it has not only a chemical similarity with it, but it is also close in particle size.

Taking into account this circumstance, it is possible to reduce cement consumption in concretes of equal strength, improve the workability of the concrete mix and increase the waterproofness of concrete.

Main physical and mechanical properties of carbonate sand are determined by DSTU B V.2.7-232:2010 [3]. Before the test, a fraction of more than 5 mm, whose content averaged 4% of the mass, was eliminated.

The average results of tests of carbonate sand batches, given in Table 3, showed that such sand meets the requirements of standards [1, 3] and can be used to produce expanded clay concrete with strength up to 30 MPa.

### Table 1. Physic and mechanical properties of expanded clay gravel.

| Fraction dimensions, mm | Strength (at squeezing in cylinder), R₀, MPa | Bulk density, ρₘ, kg/m³ | Ratio of structure quality, Kₖₖ | Specific density, ρₛ, g/cm³ | The density in the cement paste, ρₚₛ, kg/m³ | Water absorption w, % | Volume of intergranular voids, Vn, % | The content of chopped grains, % by weight | Gravel grades by bulk density (DSTU B V.2.7-95) |
|-------------------------|----------------------------------------|-----------------------|--------------------------------|--------------------------|-----------------------------------|-------------------|---------------------------------|----------------------------------------|------------------------------------------|
| 5 – 10                  | 2.8-4.67                              | 504-583               | 559-801                        | 2.31-2.48                | 955-1507                          | 16.2-22.7         | 30-38.2                        | 6.2                                    | 550-600                                  |
| 10 – 20                 | 2.4-2.91                              | 462-541               | 519-538                        | 2.31-2.48                | 890-1493                          | 20.8-24.9         | 38-41.1                        | 8.7                                    | 500-550                                  |
| Mixture                 | 2.5-3.96                              | 474-569               | 429-696                        | 2.31-2.48                | 946-1502                          | 18.2-24.1         | 33-40.1                        | 7.9                                    | 500-600                                  |

### Table 2. Chemical composition of limestone-shells, % by mass.

| Deposit | SiO₂  | Al₂O₃ | Fe₂O₃ | CaO   | MgO   | SO₃   | Loss on ignition |
|---------|-------|-------|-------|-------|-------|-------|-----------------|
| Orel    | 3.36  | 2.68  | 0.82  | 51.0  | 1.34  | 0.07  | 40.7            |
| Glavan  | 4.2   | 2.82  | 0.9   | 50.2  | 1.0   | 0.06  | 41.8            |
| Averaged by Ukraine | 1.7 | 1.21 | 1.21 | 53.3 | 0.92 | 0.67 | 42.4            |
4. Properties study

Experimental studies of the basic properties of expanded clay-concrete on carbonate sand mixtures and concrete were carried out according to the procedure of the planned experiment.

Experimental studies consisted of two stages.

On the first stage the influence of prescriptive (consumption of cement and aggregate-structural factor) and technological (workability, mixing time of the mixture in the mixer and the time of its vibrocompaction) factors on the basic physical and mechanical properties of expanded clay mixture (porosity, delamination, density) and concrete (strength, density, strength uniformity and uniformity in density).

Table 3. General physical and mechanical properties of Orel deposit carbonate sand.

| Grading | Private residues on control sieves, % | Strength of the original rock R_o,p, MPa | Strength of sand when squeezed in a cylinder R_c, MPa | Bulk density ρ_b, kg/m³ | Density in a cement test ρ_c.t, kg/m³ | Hollowness H, % | Water Absorption W, % | The size module Mk | Specific Gravity ρ_sp, g/cm³ | The content of separately clay particles, % |
|---------|--------------------------------------|----------------------------------------|-----------------------------------------------|--------------------------|---------------------------------------|----------------|----------------------|------------------|--------------------------|------------------------------------------|
|         | 2,5                                  | 1.25                                   | 0.63                                          | 0.315                    | 0.14                                  | less than 0.14 | 0.14                 | 1.6              | 1160                     | 2390                       | 42                       | 5.4                   | 2.38                       | 2.99                       | 0.48                   |
|         | 17.4                                 | 12.4                                   | 17.0                                          | 15.7                     | 17.4                                  | 19.8           | 0.9                  | 1.6              | 1160                     | 2390                       | 42                       | 5.4                   | 2.38                       | 2.99                       | 0.48                   |

As controlled parameters were chosen:
1. The volume of intergranular voids Vп, the index of delamination of the Пр and the density of the expanded clay-concrete mixture ρ₀.
2. The water flow rate to achieve the desired workability of the mixture.
3. Cubic strength R (28) and density of expanded clay concrete dried to a constant mass in a state of ρ.
4. The dispersion of strength S²R и density S²ρ of expanded clay concrete.

In addition, at the first stage, studies were made of the effect of prescription factors (cement consumption and aggregate-structural factor) on the mobility of the mixture over time. As the controlled parameter, the mobility of the mixture is accepted at predetermined intervals after its manufacture ОК.

At the second stage, the strength and deformation characteristics of expanded clay concrete on carbonate sand under loads of different duration and intensity, adhesion of reinforcement to concrete, as well as the work of compressed concrete and bent reinforced concrete structures, including prestressed ones, were studied.

In the experimental studies conducted using the technique of a planned experiment, the following were chosen as the main controlled parameters:
1. Cubic R(28) and prism Rₚ strength in the age of 7, 28, 115, 300, 500 days.
2. Modulus of elasticity Eₐ(t) in the same ages.
3. Ultimate compressive deformation εₘₚ of expanded clay concrete at short-term load loading.
4. Parametric levels of microcracks RЄCRC and RЄCRC at short-term load loading.
5. Relative shrinkage strain εЄCRC (t, tw). Start time countdown tₛ corresponded to the end of the concrete setting time.
6. Relative creep strains εЄCRC (σ, t, t₀) of expanded clay concrete loaded at ages t₀ = 7, 28, 115 days with load equal to 0.2Rₛ; 0.6Rₛ; 0.8Rₛ.
5. Optimum compositions selection

Selection of the optimal composition of structural lightweight concrete, was carried out by the calculation and experimental method. Unlike conventional concrete, for lightweight concrete, in addition to the requirements for the strength of concrete and the workability of the mixture, it is necessary to ensure the requirement for a given density of concrete [2,4].

As a result of implementation of first stage of experimental studies (test and test results analysis) on developed technology there are achieved optimal by given criteria technological parameters for each studied composition of expanded clay concrete on carbonate sand, caused by prescription factors and the level of their variation.

The results of our preliminary experiments allowed us to select the following factors and assign the levels of their variation:

1. Cement consumption \( C_c \), kg/m\(^3\) – \( X_1 \).
   
   Cement consumption (O) at main level is accepted as \( C_c = 375 \text{ kg/m}^3 \). Interval of variation \( \pm 175 \text{ kg/m}^3 \).

2. Aggregate-structural factor \( r \) – \( X_2 \).
   
   The value of the aggregate-structural factor \( r \) at the main (O) level was chosen equal to 0.65. The variation interval is \( \pm 0.35 \).

3. Mixture workability – \( X_3 \).
   
   The value of the workability index of the mixture at the main (O) level was chosen to be \( G = 35 \text{ s} \). Variation interval \( \pm 31 \text{ s} \).

4. Mixing time of keralite concrete mixture \( t_n \), min. – \( X_4 \).
   
   The value of the mixing time at the main (O) level was chosen to be \( t_n = 5 \text{ min} \). Variation interval \( \pm 3 \text{ min} \).

5. Time of vibrocompaction of keralite concrete mixture \( t_v \), s – \( X_5 \).
   
   Time of vibrocompaction at the main (O) level was chosen to be \( t_v = 105 \text{ s} \). Variation interval \( \pm 75 \text{ s} \).

The optimal composition of structural expanded clay concrete should provide the specified strength, minimum possible density and the lowest possible cost. Obviously, the last two requirements cannot be ensured simultaneously, since a reduction in the density of expanded clay concrete leads to an increase in its cost, and vice versa.

To optimize expanded clay concrete, taking into account the economic criterion based on the experimental data on the actual compositions, their costs were calculated, processing the results of these calculations allowed to obtain with 95% reliability, the quadratic regression equation linking the cost of 1 m\(^3\) expanded clay concrete with the costs of its components.

The resulting equation, taking into account only statistically significant coefficients, has the form:

\[
C = 128.6 + 13.2X_1 - 37.6X_2 + 5.2X_1X_2 - 3.1X_2^2
\]  

(1)

As seen from this equation, aggregate-structural factor \( r \) (\( X_2 \)) has a somewhat greater influence on cost than cement flow (\( X_1 \)).

In the presence of a priori information on the nature and power of the influence of composition factors on the main operational characteristics of concrete, it is most expedient to select the optimal compositions for the isolines constructed for each of these characteristics.

Isolines for main characteristics of expanded clay concrete \( R_{(28)} \), \( \rho \), \( C \) were built in axes “\( C_c – r \)” using according equations of regression.

\[
R_{(28)} = 26.9 + 14.3X_1 - 7.2X_2 + 3.7X_3 - 2.2X_1^2 - 3.3X_2^2 - 1.3X_1X_2 + 1.7X_4X_5, \quad (2)
\]

\[
\rho = 1740 + 57X_1 + 156X_2 + 11X_4 - 26X_2^2 - 23X_1X_2 + 8X_4X_5. \quad (3)
\]

At the same time, the values of factors \( X_3 \) (workability of the mixture) were taken at the lower level corresponding to \( OK = 6 \text{ cm} \), and the values of factors \( X_4 \) (\( t_n \)) and \( X_5 \) (\( t_v \)) were fixed at zero levels.

The integrated nomogram (Figure 1) allows for the given mobility of the mixture (\( OK = 6 \text{ cm} \)) to obtain optimal compositions of expanded clay concrete (except for water flow).
The procedure for selecting the optimal compositions includes the following steps:

1. Calculation of strength values of expanded clay concrete $R_{(28)}$, corresponding to a given class of concrete for compressive strength, taking into account specific production conditions $(C_{VR})$, according to formula

$$R_{(28)} = B/(1 - 1.64C_{VR}) \quad (4)$$

2. According to the complex nomogram, a group of compositions (cement consumption $C_c$ and value $r$) that satisfy the strength $R_{(28)}$ is established.

3. According to the complex nomogram for each of the compositions satisfying the strength $R_{(28)}$, the density of expanded clay concrete $\rho$ is determined.

4. For each of composites on achieved cement consumptions $C_c$ and values $r$ it is calculated preliminary the water flow by equation:

$$B = 259 + 5X_1 + 14X_2 - 19X_3 + 14X_4^2 + 9X_1X_2 + 9X_2X_3 \quad (5)$$

5. For each composite on accepted cement consumption $C_c$ and value $r$ it is determined the concrete cost $C$.

6. If the density of concrete is not specified, then the optimal composition is selected by choosing from the established group the composition that provides the minimum cost of concrete. Otherwise, from the established group of compositions, a composition satisfying the given strength and density is selected. The assigned composition is adopted as the initial optimal composition.

![Figure 1. Nomogram for optimal compositions of expanded clay concrete on carbonate sand selection.](image)

Based on the obtained dependencies and graphs, and also based on the requirements for lightweight concrete, the optimal composition of expanded clay concrete on carbonate sand was assigned.

The optimal composition of structural claydite concrete should provide the specified strength, minimum possible density and the lowest possible cost.

Optimal compositions of expanded clay concrete on carbonate sand with strength of 10…30 MPa are given in Table 4.
Table 4. Optimal compositions of expanded clay concrete on carbonate sand.

| Designed strength, MPa | Materials consumptions on 1 m³ of concrete | Concrete density ρ, kg/m³ |
|-------------------------|-------------------------------------------|---------------------------|
|                         | Cement Cc, kg/l | Sand M, kg/l | Expanded clay K, kg/l | Water B, l |                           |
| 10                      | 250/80.6       | 1194/506    | 211/468               | 202       | 1685                      |
| 15                      | 280/90.3       | 1025/434    | 342/760               | 178       | 1675                      |
| 20                      | 360/116.1      | 975/413     | 325/722               | 192       | 1690                      |
| 25                      | 455/146.7      | 919/389     | 306/680               | 203       | 1710                      |
| 30                      | 540/174.2      | 870/368     | 290/644               | 210       | 1730                      |

6. Use in elements and structures

From expanded clay concrete on carbonate sand, experimental batches of wall stones, wall blocks, slabs and coatings were made and tested.

Test results:

1. Average strength of SKU-1 stones was 3.01 MPa. Average strength of SKU-2 stones was 3.08 MPa. Average strength of control cubes was 3.12 MPa. Average strength of control prisms was 3.0 MPa. Frost resistance – F25.

2. Average value of blocks strength is 8.3 MPa, of cubes and prisms are respectively 10.6 MPa and 9.7 MPa, of modulus of elasticity is 7650 MPa, Poisson’s ratio – 0.23. Cracks appears at load 0.92 \( N_{destr} \). Density in a dry state is 1140 kg/m³.

3. Floor slabs and coatings are prestressed on series 1.141-1, issue 63, mark P63.15-8At-Vl, of continuous section from keralite concrete, class on compressive strength is B12.5 and density D1600. Average results of tests: cube strength is R=16.3 MPa, prism strength \( R_6=14.2 \) MPa, \( E_6=13630 \) MPa, \( \rho=1570 \) kg/m³. Control destructive load is \( q^e_p=1310 \) kg/m², experimental destructive load on the nine floor was \( q^e_{destr}=1616 \) kg/m², control deflection at control load \( q^c_e=593 \) kg/m² is \( f^c_k=14.8 \) mm. Actual deflection at control load \( q^c_k \) is \( f^c_{exp}=7.95 \) mm. First cracks appeared at load \( q^e_{exp}=1422 \) kg/m².

The experience of numerous domestic and foreign studies, practical experience shows that lightweight concretes on porous aggregates of various types are still an effective material of structural, structural heat-insulating and heat-insulating purpose.

The results of the research have proved the possibility of applying expanded clay concrete on carbonate sand as well as in monolithic load-bearing and enclosing structures.

7. Conclusions

1. The economic efficiency of using expanded clay concrete on carbonate sand is obvious, since the raw material for concrete is the waste from the stone-cutting of limestone shells.

2. Lightweight concretes on local porous aggregates of the south of Ukraine, both large and small, can be recommended for the manufacture of concrete and reinforced concrete structures with a concrete strength of 5 ... 30 MPa.
3. The conducted studies confirmed the high efficiency of lightweight concretes on porous aggregates, considerable savings in Portland cement, the expediency of using previously listed lightweight concretes for prefabricated and monolithic structures of residential and public buildings.

4. To optimize the composition of keralit concrete on carbonate sand, it is recommended to use the developed method of complex approach, which allows to obtain cost-effective compositions.

5. Researches proved the possibility of applying of expanded clay concrete on carbonate sand in monolithic load-bearing and enclosing structures and in reinforced concrete elements and structures.

References:
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