Temperature dependence of dynamic and static modulus of elasticity of lightweight expanded clay aggregate concrete

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Abstract. The paper presents experimental research the static and dynamic modulus of elasticity of lightweight expanded clay aggregate concrete with averaged density of 1000 kg/m$^3$. The static and dynamic modulus are obtained depending on the influence of temperature in the range from 5 to 50 °C with a step of 15 °C. The dynamic modulus was determined without pre-compression with a testing machine Asphalt Mixture Performance Tester. Besides the modulus of elasticity of lightweight concrete, the temperature dependence of unconfined compressive strength was also determined. Analysis of experimental data showed that with an increase in temperature, strength and modulus of elasticity slightly decrease, which is typical for concretes. For all cases, the temperature dependence can be characterized according to the linear law. Comparison of the static and dynamic modulus of elasticity showed that the dynamic modulus is 60-74% greater than the static modulus over the entire range of the studied temperatures.

1. Introduction
Lightweight expanded clay aggregate concrete widely used in structural and road construction applications. Such lightweight concrete is mainly used to reduce the load from the weight of concrete structures in building construction. In road construction lightweight expanded clay aggregate concrete usually used for lightweight embankment. The use of such a material implies knowledge of its mechanical and elastic properties. Properties such as compressive strength, tensile strength, static modulus of elasticity, durability and others are investigated [1-5]. The dynamic properties of lightweight expanded clay aggregate concrete are very important when designing roads, especially for high-speed road [6]. Also mechanical and elasticity properties of lightweight concrete obtained by experimental methods are very important for creating analytical models [7]. Usually, studies of properties are carried out at room temperature, but in reality the material is exposed to temperature effects and it are desirable to know the mechanical properties of lightweight concrete at different temperatures during its operation.

In this paper presented study of temperature dependence of dynamic and static modulus of elasticity of lightweight expanded clay aggregate concrete. The temperature range of the studies was 5 to 50 °C with a step of 15 °C. The dynamic modulus of elasticity was obtained using a cyclic sinusoidal load without pre-compression with a servo-hydraulically controlled testing machine. Unconfined compressive strength of lightweight expanded clay aggregate concrete are also obtained for the corresponding temperatures.
2. Materials and methods
To determine the mechanical (compressive strength) and elastic properties (static and dynamic modulus) of the lightweight expanded clay aggregate concrete the cylinder specimens were produced. The diameter and height of specimens were 94 mm and 150 mm, respectively. An ordinary Portland cement of class CEM I 42.5 N as per GOST Standard 31108-2016 “Cements for general construction. Technical conditions” was used as a binder. Expanded clay aggregates (LECA) were used as a lightweight aggregate. The average particle dry density of LECA was 337 kg/m$^3$. Also sand and water were added to mixture during the production of lightweight concrete. The dry density, $\rho$, of lightweight concrete averaged 1000 kg/m$^3$. All tests were performed on 90-day after producing and curing.

Before testing all specimens dried and kept at the required temperatures. The range of temperatures was from 5 to 50 °C with a step of 15 °C (5, 20, 35 and 50 °C). Before determinate the static modulus and compressive strength the dynamic modulus of specimens were determined. The dynamic modulus was determined without pre-compression with a servo-hydraulically controlled testing machine Asphalt Mixture Performance Tester (AMPT) (see figure 1). In this test the dynamic modulus it is absolute value obtained by dividing the maximum (total) stress on the maximum (total) elastic deformation of the material subjected to sinusoidal load [8]. The dynamic modulus for all specimens was determined for the next frequencies: 25 Hz, 20 Hz, 10 Hz, 5 Hz, 2 Hz, 1 Hz, 0.5 Hz, 0.2 Hz, 0.1 Hz, and 0.01 Hz. Before testing, sensors were glued to the samples on three sides of the cylinder. The initial static modulus and compressive strength of specimens were determined with GCTS testing machine. Before testing the samples were glued to the sensors on two sides of the cylinder. The loading rate was 0.1 ± 0.05 MPa/s.

3. Results
Figure 2 shows temperature dependence of compressive strength for experimental results and fitted linear curve. There is a slight drop in compressive strength with increasing temperature which is typical for all types of concrete. The mean value of compressive strength, $f_c$, at a temperature of 20 °C is 4.0 MPa.
Figure 2. Temperature dependence of compressive strength.

The initial static modulus results shown on figure 3. As for the compressive strength, there is a slight decrease in the elastic modulus with increasing temperature. At a temperature of 20 °C, the mean value of the experimental static elastic modulus is 2915 MPa, which is quite close to the value 2720 MPa calculated by equation (1) [1, 9]:

\[ E_s = 0.043 \rho^{3/2} \sqrt{f_c} \]  

Figure 3. Temperature dependence of static modulus.

Figure 4 shows temperature dependence of the dynamic modulus of elasticity for 10 Hz and 0.1 Hz dynamic load. For both cases, a decrease in the magnitude of the modulus is observed with an increase in temperature. At the same time, there is no strong difference between the two frequencies of the dynamic load, and this is observed for all frequencies of the experiment. Figure 4 also shows the results of the static modulus of elasticity. The dynamic modulus of elasticity is about 60-74%, depending on the temperature, more than the static modulus. At the same time, the temperature dependences for both modules are similar. Mean value of experimental data of compressive strength, static and dynamic modulus of elasticity also shown on table 1.
Figure 4. Temperature dependence of dynamic and static modulus.

Table 1. Experimental data.

| Temperature, °C | Compressive strength, MPa | Static modulus, MPa | Dynamic modulus, MPa |
|----------------|---------------------------|---------------------|----------------------|
|                | 10 Hz                     | 0.1 Hz              |
| 5              | 4.4                       | 3172                | 5441                 |
| 20             | 4.0                       | 2915                | 5067                 |
| 35             | 3.9                       | 2820                | 4897                 |
| 50             | 3.8                       | 2707                | 4347                 |

4. Conclusion
As a result of the studies, temperature dependences of dynamic and static modulus of elasticity of lightweight expanded clay aggregate concrete with density of 1000 kg/m$^3$ were obtained. The temperature range of the studies was 5 to 50 °C. The dynamic modulus determined it is absolute value obtained by dividing the maximum (total) stress on the maximum (total) elastic deformation of the material subjected to harmonic load. As a result, the dynamic modulus of elasticity is about 60-74%, depending on the temperature, more than the static modulus. For the static and for the dynamic modulus of elasticity, a slight decrease in the values is observed with increasing temperature.

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