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Influence of Preheating on Thermomechanical Properties of Heat-Resistant Ceramsite Concrete Based on Composite Binding Agent

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***Abstract* – The paper studies the influence of preheating on thermomechanical properties of heat-resistant ceramsite concrete based on activated composite binding agent. The basic composition of heat-resistant ceramsite concrete was used in the study. This composition included a ceramsite gravel of the Kizilyurt Ceramsite Plant as a large and small filler, as well as the composite binding composition of portland cement + impalpable ceramsite sand with the activation on a planetary mill *Activator – 4M*. The use of light heat-resistant concrete instead of single-piece refractory materials in kilns of various thermal units will allow decreasing the material consumption by 30-40% and reducing heat losses by 25-35%. [8]. The use of local construction materials allows increasing the efficiency of concrete in comparison with imported refractory materials. The composition of light heat-resistant concrete with large and small fillers from ceramsite gravel of the Kizilyurt Ceramsite Plant and the activated composite binding agent based on the portland cement of the Buynaksk Cement Plant with impalpable ceramsite sand is developed for the study. The activation of a composite binding agent effectively increases the reaction capacity of a binding agent and reduces the water cement ratio, which improves the performance of concrete [1, 2, 10] due to the reduction of chemically unbound water in concrete. We believe that the preheating of a mixture prior to drying at a temperature of 105°C effectively affects the performance of concrete and reduces its destruction due to the presence of chemically unbound water. This reduces the number of microcracks in the structure of a concrete due to intensified hydration of the activated composite binding agent. The optimum mode of preheating and its influence on thermomechanical characteristics of concrete is defined. The influence of a concrete mixture preheating on its thermomechanical properties and efficiency of the accepted method is analyzed.**

Keywords - preheating; heat-resistant; ceramsite; concrete; composite; binding agent; thermomechanical.

I. INTRODUCTION

Research and development of new construction materials and modernization of existing ones due to new and improved manufacturing construction technologies is a relevant task and one of the most important directions of economic development of the Russian Federation. It is advisable to use local mineral raw materials to develop new construction materials. The program on a cluster for construction materials on the basis of the Caspian Sheet Glass Plant and the Marabi Ceramic Tiles Plant implies the construction of new plants for the production of various ceramic wall materials based on modern innovative technologies. All construction industry enterprises make the best use of construction materials on the basis of local mineral raw materials, including in the production of heat-resistant concrete. The distinctive feature of heat-resistant concrete is the possibility of thermal lining of units with various design and shape.

Not only expensive fire-resistant materials, but also standard available cheap fillers, such as ceramsite, perlite, vermiculite, as well as secondary materials – slags, refractory materials, scrap ceramic brick and others are used in the production of heat-resistant concrete [4, 5, 6, 9]. The use of materials based on local mineral raw materials of ceramsite gravel of the Kizilyurt Ceramsite Plant and the activated composite binding agent based on portland cement and impalpable ceramsite sand of the Buynaksk Cement Plant allows receiving heat-resistant concrete and its products with low labor inputs and costs in comparison with expensive imported fire-resistant products.

II. PROBLEM STATEMENT

It is critical to determine the influence of preheating on thermomechanical properties of heat-resistant concrete with ceramsite filler on the basis of activated composite binding agent in order to increase the performance of heat-resistant concrete. The preheating ensures concrete strength due to reduced quantity of microcracks within partitions of concrete structure by removing chemically unbound water. Concrete in thermal units is under simultaneous influence of high temperatures, dynamic and statistical loads. One of methods used to define the tension of the deformed state of refractory-lined products close to service conditions are thermomechanical studies that make it possible to receive reliable data on the dependence of compression strength on deformation $\varepsilon \cdot 10^{-3}$ at different heating temperatures.

III. Research Questions

Preheating has positive impact on thermomechanical properties of heat-resistant concrete. As it is specified in work [3] when heated at the temperature from 20 to 80-90ºC the air expands by 22-25% (at invariable pressure), water – by 2.7-3% and solid components – by only 0.15-0.2% [3]. Such unequal expansion results in high local concrete stress at the initial stage of structurization and therefore it is not able to resist the destructive action of this tension.

High local stress of concrete during the temperature rise is also triggered by the transformation of some amount of the mixing water into steam. It is known from physics that the generation of steam is followed by the increase in volume by 1600-2000 times [3].

The generation of steam having approximately the same expansion coefficient as air considerably increases the volume of gaseous fraction capable of the greatest expansion while heated.

Air desorption from the mixing water also contributes to the increase of the steam-air mixture in concrete. At optimum thermal treatment modes, the increase of volume and consequently, of stress in the system is partly compensated by the gain in strength since the maximum expansion of steam-air mixture and water takes place when the concrete is already able to resist it. Their redistribution in the system occurs due to slow growth of local stress. Thus caused structural failures are bound to temperature influence, reduce the intensity of destruction to some extent and hence cannot be recommended for heat treatment of products from dense concrete despite more optimal conditions. Preheating is preferable for heat treatment of concrete with low strength indicators, such as ceramsite concrete, which is not so much affected by harmful consequences of preheating.

The increase of thermomechanical characteristics due to preheating is caused by the intensification of hydration reaction with simultaneous CaO binding of a cement stone with silicon dioxide of impalpable SiO_2 additive. When free calcium oxide of a cement stone is bound, the CaO to SiO2 diffusion begins due to its content in two-calcic silicate of a cement stone. The transition process of $2CaO \cdot SiO_2$ into $CaO \cdot SiO_2$ is followed by caking of a cement stone and a microfiller, and concrete begins to develop ceramic strength. The comparative analysis of the influence of preheating on thermomechanical properties of concrete is carried out after testing in S.T.S. unit developed by the Institute of Mechanics of the Lomonosov Moscow State University, which is installed in the Laboratory of Construction Materials of Dagestan State Technical University thus defining the stress-strain behavior of concrete samples.

IV. Purpose of the Study

The purpose of the study is to define the influence of preheating on thermomechanical properties (on stress-strain behavior) of concrete, i.e. testing of concrete samples in the form of a cylinder for monoaxial compression by effort from 0 to 5000 kg at axisymmetric heated state in the range of temperatures from 20 to 1000°C. Figures 1 and 2 show the layout of the facility.

Fig. 1. General view of the testing machine STS 10/1150

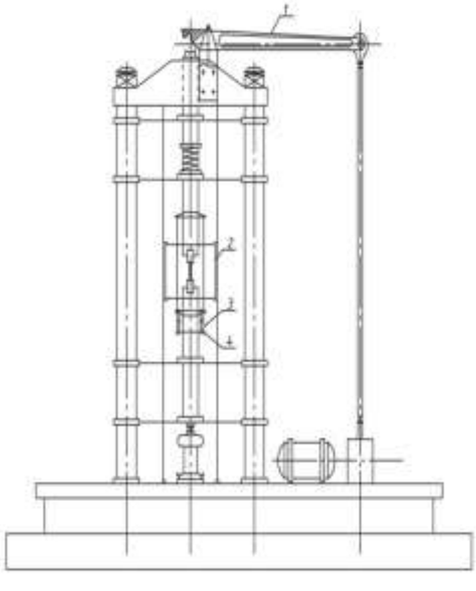

Fig. 2. Scheme of the testing machine STS 10/1150. 1 – power system; 2 – sample heating system; 3 – pressure force value; 4 – test sample.

V. Methods and Materials

To solve the objective, the cylinder samples in a diameter of 25 mm and height of 85 mm were made from cube samples with the size of 10×10×10 cm, which were preheated at a temperature of 90°C. Heating was carried out according to the scheme shown in Figure 2 following the technique suggested in work [7].

Universal automatic unit STS (Fig. 1) consists of the following basic elements and systems: power system; sample heating system serving the power source, electronic device regulating the temperature of heaters; sample measuring devices; automatic programming and registering systems.

Loading of samples and automatic control of temperature in the range from 90 to 1500°C with an accuracy of ±1°C is carried out by operating units. Registration units continuously record the diagrams tension load R-Δl (Δl) or compression load to an accuracy of not more than 2%. Initial charts (“stress-movement”, “movement-time”) after processing are transformed into the diagrams with the given characteristics “stress-deformation, deformation-time”. Within experiments these values in simple samples at simple loading and uniform heating are defined by the following ratios:

$$\sigma_i = \frac{P_i}{F_i}; \quad \varepsilon \frac{\Delta l}{L_0}; \quad \epsilon_{п} = \frac{\Delta l_{п}}{L_0}$$

According to diagrams designed via the loading program it is possible to determine thermomechanical properties and the nature of behavior of concrete [6]. To define elasticity or plasticity the loading program is made so that partial loading and unloading of a sample is repeated. If when loading a sample by force P_y its sizes are restored up to the tension corresponding to this force the material has the properties of elasticity, and the corresponding tension and deformation ($\sigma_{пу}$ and $\epsilon_{пу}$) characterize the elasticity limit [6].

VI. Results

Table 1 shows sample diagrams of dependence of concrete compression strength in a heated state on deformation at various heating temperatures of a basic composition of concrete. Figures 3 and 4 show the calculation of the optimum composition of concrete before and after preheating according to the technique given in work [11].

TABLE I. Basic composition of a heat-resistant ceramsite concrete based on activated composite binding agent

No	**Material consumption per 1 m³ of concrete**						
	portland cement, kg	**in % of portland cement**	**impalpable additive**	**filler, l**			**Additive SP-1, kg**
			ceramsite sand, kg	*fractions 5-10 mm*	*fractions 2-5 mm*	*fractions up to 2 mm*	
1	2	3	4	5	6	7	8
2	315	30	135	360	360	580	0.68

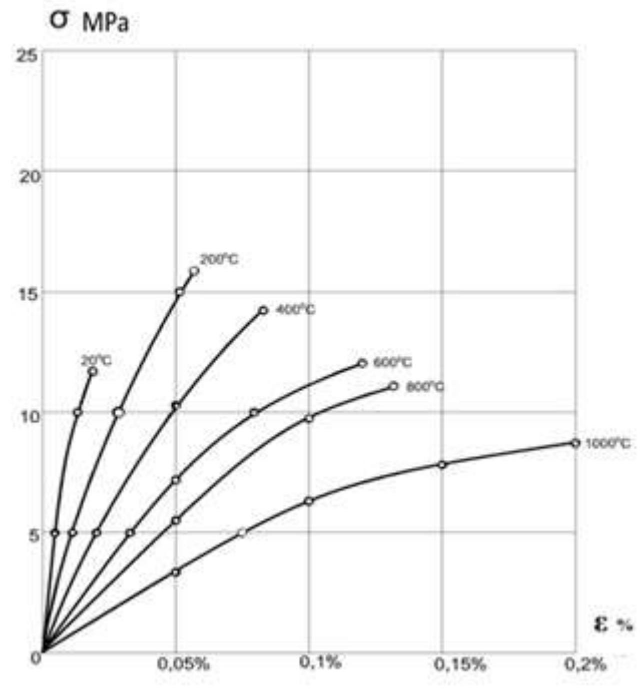

Fig. 3. Dependence of strength σ in a heated state on deformation ε at various heating temperatures without preheating

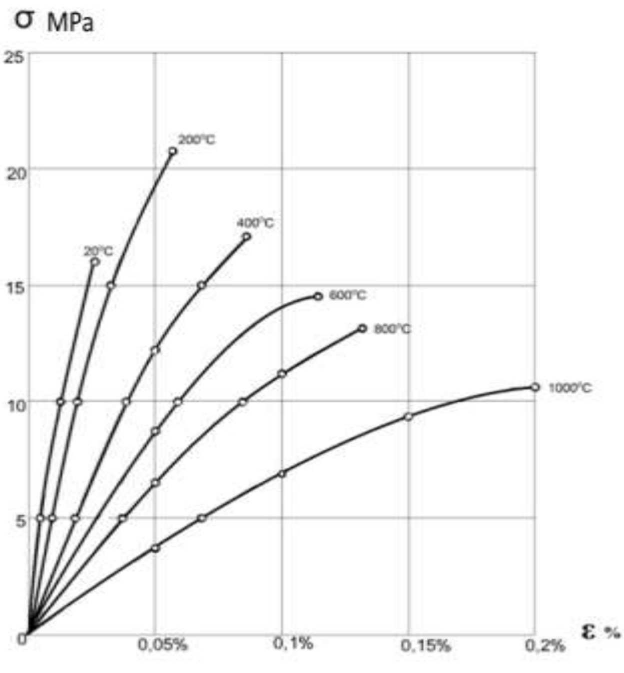

Fig. 4. Dependence of concrete strength σ in a heated state on deformation ε at various heating temperatures after preheating

The samples were tested for monoaxial compression in a heated state after isothermal endurance at temperatures from 20°C to 1000°C. The dependence of strength on temperature (Fig. 3) demonstrates that the strength of concrete after drying at 20°C and heated to 1000°C decreases with the increase of testing temperature up to 1000°C, at the same time the strength of heat-resistant ceramsite concrete with preheating at a temperature of 90°C is more than the strength without preheating by 4-5 MPa. After 800°C the strength of all samples decreases rather sharply up to 1000°C.

The increase and content of a liquid phase in a concrete up to the temperature of 1000°C and above is explained by the reduction of concrete strength at temperatures above 800°C.

The obtained data correspond well to results of the study in work [4].

The study of thermomechanical properties of heat-resistant ceramsite concrete based on activated composite binding agent made it possible to define the value of the static elasticity module and deformation at various temperatures (Figure 5). This choice is made since the definition of the dynamic module ensures higher distribution of values though this indicator is considered more “structural sensitive”, for example, for unburnt concrete.

The ceramsite concrete is characterized by initially high elasticity module $E=112\cdot10^3$ kg/cm^2, at a temperature of 600°C the elasticity module decreases and equals $29.2\cdot10^3$ kg/cm^2 and then it is stabilized at a temperature of up to 1000°C and equals $E=38.7\cdot10^3$.

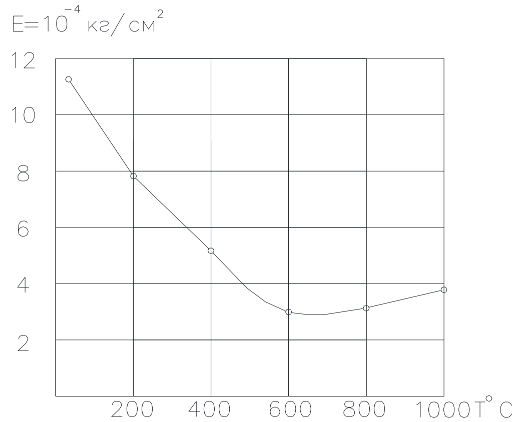

Fig. 5. Change of the elasticity module of heat-resistant ceramsite concrete based on activated composite binding agent depending on heating temperature

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