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Article

Effect of heat treatment of expanded polystyrene concrete on its compressive strength

Murat Rakhimov[1], Galiya Rakhimova[1], Tatyana Samoilova[1,*], Nurlan Zhangabay[2]

[1]Department of Construction Materials and Technologies, Abylkas Saginov Karaganda Technical University Karaganda, Kazakhstan
[2]Department «Architecture and urban planning», South-Kazakhstan University named after M. Auezov, Shymkent, Kazakhstan
*Correspondence: tanya.fedulova.18@mail.ru

Abstract. The purpose of this research was to identify the effect of heat treatment of heat-insulating concrete on its compressive strength. For comparison, samples of normal hardening and samples that have undergone heat treatment were used. Lightweight heat-insulating concrete based on cement, polystyrene, and industrial waste was used as the subject of the research. A steaming chamber was used for steaming concrete; tests of the mechanical strength of concrete were carried out on a hydraulic press. All tests were carried out under laboratory conditions. Studies have shown that the density of polystyrene concrete after heat treatment is 7% lower than that of polystyrene concrete hardened under normal conditions. During heat treatment, the crystal structure of the material changes, which affects its final properties. This is proved by the fact that the strength of polystyrene concrete after heat treatment is 30% higher.

Keywords: thermal insulation materials, polystyrene concrete, heat treatment of concrete products, steam chamber, mechanical strength.

1. Introduction

Currently, there are several studies devoted to the production of concrete products without heat treatment [1]. The main goal of these studies is to reduce the cost of finished products by reducing the cost of heating them. However, it seems possible to do this without heat treatment of products under certain environmental temperature conditions. As a rule, the acceptable temperature limit to avoid heat treatment is 20°C. At lower temperatures, the hydration process is significantly reduced, and when water reaches the freezing point, this process stops completely [2]. Given the fact that the production process of thermal insulation products is year-round, in the conditions of the sharply continental climate of the Republic of Kazakhstan, especially in the northern regions of the country, it is not possible to do this without steaming concrete.

It should be noted that much more research has been devoted to steaming heavy concrete, while heat treatment of light concrete has not been studied enough.

The purpose of this research was to identify the effect of heat treatment of heat-insulating concrete on its compressive strength.

To achieve the goal, samples of the same composition were produced, but with different hardening conditions: in a steaming chamber and under normal hardening conditions. Samples in the steaming chamber were subjected to mechanical compressive strength tests immediately after steaming (in less than 1 day), and samples hardening under normal conditions were tested after 1, 3, 7, and 28 days.

There are several factors influencing the rate of hydration:

- Water-Cement ratio (W/C): the low W/C leads to faster hardening in the initial period. This is because less water in the mixture allows the cement to hydrate faster.

- Mobility: the concrete mixture mobility directly affects the machinery and equipment used in production. A more mobile mixture requires different installation conditions and the use of special equipment.
- Chemical additives: hardening accelerator additives are widely used to accelerate the hardening process [2–4]. They are especially important in cold conditions when the rate of hardening is significantly reduced.

For thermal insulation products, the hardening process must begin before the concrete mixture begins to compact and delaminate. Thus, heat treatment of concrete is an important stage in the production of many thermal insulation products. It improves mechanical properties such as strength, rigidity, and resistance to deformation [5–8].

Another important feature of heat and moisture treatment is its ability to change thermophysical characteristics. These include increased thermal conductivity and decreased heat transfer coefficient. Through heat treatment, the structure of the material changes, which affects its final properties; crystallization and the creation of new phases occur. Heat treatment can improve the material's resistance to high temperatures [9].

The main types of heat treatment include:

- Annealing – prolonged heating at a certain temperature followed by slow cooling. Used to relieve internal stress, improve ductility, and increase corrosion resistance;
- Hardening – rapid cooling after heating to high temperatures. Used to increase hardness and strength;
- Tempering – heating the hardened material to a temperature below the transition point followed by cooling. Used to reduce the fragility of hardened materials;
- Normalization – heating the material to a temperature above the transition point followed by slow cooling in air. It is used to improve the homogeneity of the structure and reduce internal stresses [10].

Heat treatment is used in thermal insulation products with various fillers. Annealing glass wool products improves their mechanical properties and increases resistance to moisture. Annealing basalt wool increases its heat resistance and resistance to deformation. As for the heat treatment of expanded polystyrene, it can be used to increase the strength of the material and at the same time give the material additional porosity. The phenomenon described above is the subject of the study described in this article.

It is important to note that the choice of heat treatment type depends on the thermal insulation material, its purpose, and the required properties. Incorrectly performed heat treatment can lead to the deterioration of the properties of the material. When choosing heat treatment, it is necessary to take into account the characteristics of each specific product. Steaming products in chambers, autoclaves, stands, and forming units is a standard method in factory conditions. Continuous research into the use of new additives and optimization of heat treatment of concrete makes it possible to increase its strength and hardening rate. Understanding the various factors influencing the hardening of concrete allows us to optimize its production and operation in various climatic conditions.

2. Methods

The production of the concrete mixture was carried out using the following materials:

- Cement I 42.5B, with specific effective activity of natural radionuclides for raw materials of 57 Bq/kg [11];
- Blast furnace slag crushed in a ball mill [12];
- Expanded polystyrene gravel, 2.5-5 mm fraction;
- Additives: air entrainment (Master Air 200) and superplasticizer (Master Rheobuild 270);
- Water.

The concrete mix was made by [13] (Figure 1).

Figure 1 – Concrete mix

The manufacturing technology is as follows: the dosed components were mixed in a container for 1 minute using an immersion mixer. After the introduction of additives, the mixture was mixed for another 1 minute, after which it was molded in molds with side dimensions of 10×10×10 cm [14]. A total of 30 samples were produced: 15 for each type of hardening (Figure 2).

Figure 2 – Polystyrene concrete samples for research

For a comparative analysis of the effect of heat treatment, a steaming chamber with a steam temperature from 18 to 100°C with a power of 4 kW was used. This chamber is designed to work in enclosed spaces with a temperature of at least + 5°C and humidity up to 80% [14] (Figure 3).

Figure 3 – Preparation of samples for steaming

Concrete steaming took place under the following conditions presented in Figure 4 below.

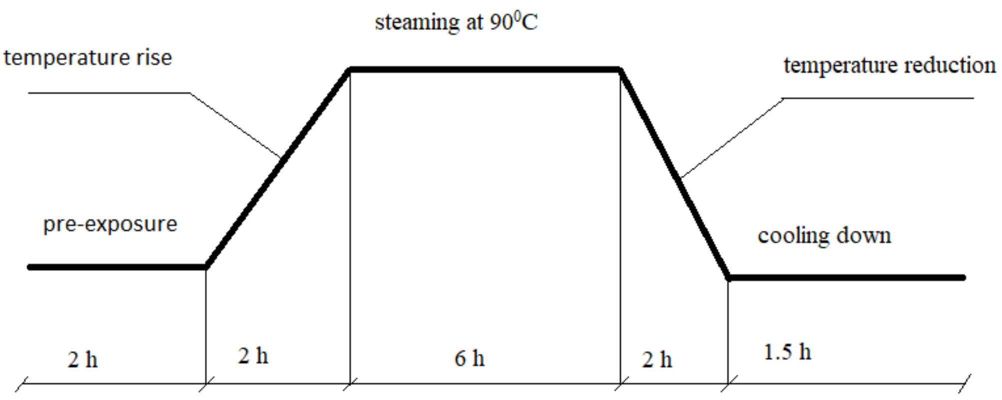

Figure 4 – Concrete heat treatment schedule

When steaming products, it should first withstand them and gradually increase the temperature, this will avoid cracks, then also gradually reduce the temperature. The entire steaming process takes approximately 13.5 hours. To determine the mechanical compressive strength, a hydraulic press for light concrete with a force of 10 tons was used (Figure 5).

Figure 5 – Mechanical compressive strength test

All samples were subjected to mechanical compressive strength tests at the ages of 1, 3, 7, 14, and 28 days.

3. Results and Discussion

Studies of the mechanical strength of polystyrene concrete hardened under normal conditions and in samples hardened in a steaming chamber at the ages of 1, 3, 7, 14, and 28 days were carried out. As can be seen from Figure 5, the heat treatment mode can significantly reduce the time of hydration and strength gain of finished products.

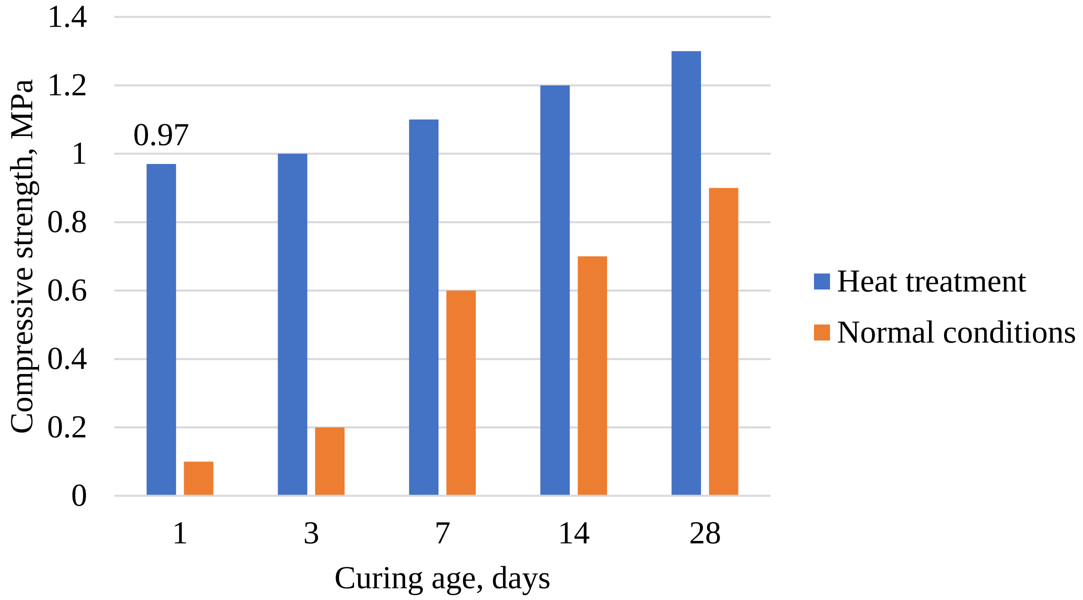

Figure 5 – Strengthening of samples

As shown above, the steamed polystyrene concrete exhibits consistently higher strength from day 1 through day 28 compared to regular polystyrene concrete, gaining 0.97 MPa strength for only 1 day of curing. The strength of heat-treated concrete turned 30% higher than that of concrete hardened under normal conditions. Figure 6 below shows the polynomial calibration dependence of the strength of concrete hardened during heat treatment and concrete hardened under normal conditions.

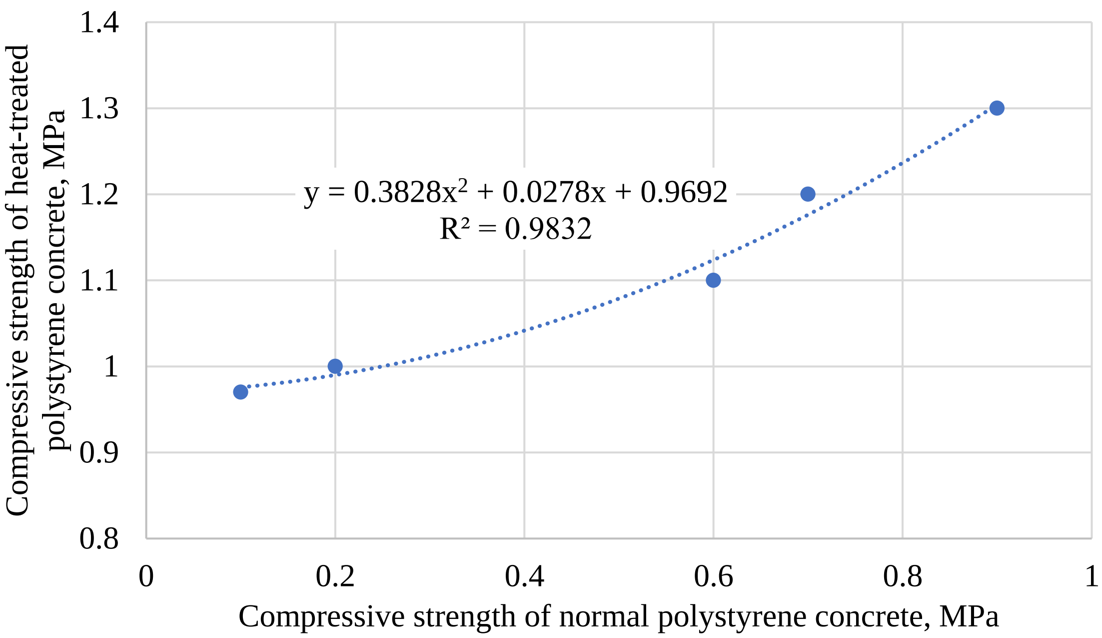

Figure 6 – Calibration dependence of the strengths of two types of samples

During the heating process of polystyrene concrete, air trapped in the mixture is released, as well as gaseous isopentane from expanded polystyrene. Air and isopentane form a vapor-air mixture in the liquid phase of the cement paste. At the initial stage of heating, this steam-air mixture is removed from the cement paste, creating channels for its entrainment. This occurs due to the expansion of the mixture and the presence of technological seams in the molds [15]. This is confirmed by a decrease in its density by 7% (Table 1).

Table 1 – Density of polystyrene concrete

Concrete hardening condition	The standard value of density, kg/m^3	Actual density, kg/m^3
Heat treatment	350-400	370
Normal conditions	350-400	398

The positive side of heat treatment is also manifested in the environmental component. The removal of the gas-forming agent (isopentane) from the mixture to the edges of the mold increases the environmental friendliness of the material [15].

4. Conclusions

1. The choice of heat treatment type depends on the thermal insulation material, its purpose, and the required properties. Incorrectly performed heat treatment can lead to deterioration of the properties of the material;

2. The heat treatment mode reduces the time of hydration and strength gain of finished products: the strength gain of concrete that has undergone heat treatment was less than 1 day, while concrete that hardened under normal conditions gained the required strength only for 28 days. The strength of warmed concrete is 30% higher than that of concrete hardened under normal conditions;

3. During the heating process of polystyrene concrete, isopentane is released from expanded polystyrene. At the initial stage of heating, this steam-air mixture is removed from the cement paste, creating channels for its entrainment. Therefore, polystyrene concrete is an environmentally safe material;

4. The density of polystyrene concrete after heat treatment is lower than that of polystyrene concrete hardened under normal conditions. This is due to the intense release of isopentane from polystyrene granules.

Thus, the density of polystyrene concrete after heat treatment is lower than that of polystyrene concrete hardened under normal conditions by 7%.

The results obtained will allow further research on the possibility of using the proposed composition of polystyrene concrete in the enclosing structures of large-panel housing, as well as on the effect of heat treatment on the properties of concrete.

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Information about authors:
Murat Rakhimov – Candidate of Technical Sciences, Associate Professor, Department of Construction Materials and Technologies, Abylkas Saginov Karaganda Technical University, Karaganda, Kazakhstan, m.rakhimov@kstu.kz
Galiya Rakhimova – Candidate of Technical Sciences, Associate Professor, Department of Construction materials and Technologies, Abylkas Saginov Karaganda Technical University, Karaganda, Kazakhstan, g.rakhimova@kstu.kz
Tatyana Samoilova – PhD Student, Department of Construction Materials and Technologies, Abylkas Saginov Karaganda Technical University, Karaganda, Kazakhstan, tanya.fedulova.18@mail.ru
Nurlan Zhangabay – Candidate of Technical Sciences, Associate Professor, Department «Architecture and urban planning», South-Kazakhstan University named after M. Auezov, Shymkent, Kazakhstan, nurlan.zhanabay777@mail.ru

Author Contributions:
Murat Rakhimov – methodology, analysis, interpretation, drafting, editing.
Galiya Rakhimova – methodology, analysis, interpretation, drafting, editing.
Tatyana Samoilova – concept, methodology, resources, data collection, testing, analysis, visualization, drafting, funding acquisition
Nurlan Zhangabay – methodology, analysis, interpretation, drafting, editing.

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