Heat treatment of concrete products and structures: issues of strength and efficiencies

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Abstract. The article describes the study of the possibility of heliothermic treatment of concrete products in the climatic conditions of a particular region. Sufficient intensity of solar radiation in the summer months, including the observed significant clouds accompanied by precipitation, allows establishing a thermal regime in the solar cells of the covering type, which provides the required strength set for shipment during the day. The subsequent tests showed high strength characteristics of the manufactured products of samples whose numerical values are not inferior to those obtained by traditional heat treatment. The introduction of solar thermal treatment in the production of concrete products will save energy for 180-200 R/m\(^3\) of products.

1. Introduction

The construction materials industry belongs to the material-intensive sectors of the national economy. The share of costs for raw materials, fuel and energy is 50% in the structure of the cost of production \([1-3]\). Reducing production costs is becoming the most important challenge posed by the broader challenge of improving the efficiency and competitiveness of the industry.

2. Analytical and theoretical information

High specific costs for heat treatment of concrete and reinforced concrete products and structures attract attention in the structure of material costs. Research of questions of decrease in energy consumption of production of fine products and the tests carried out in this direction for various climatic conditions \([4-9]\), allow to consider as one of possible ways of increase of efficiency of technology of construction materials replacement of traditional power-consuming process of heat treatment by influence of solar radiation in the warm period of year. At the same time, the existing opinion on the decrease in the strength of the product due to uneven heating and intensive drying in the absorption of solar radiation, creates certain restrictions in the use of such a locally available renewable energy source. To confirm the possibility of solar energy utilization in the technological process, it is required, along with the study of the generated thermal regimes, to evaluate the achieved strength characteristics of concrete products with an alternative method of heating them.
The study of possible negative deviations in the strength characteristics of concrete samples was carried out on the basis of a series of tests in the Central black earth region. So, on the basis of the Voronezh state technical University in the pre-made quite economical translucent shelters (Fig. 1), belonging to the class of flat solar collectors, solar thermal treatment of elements made of heavy concrete of class b 22.5 was carried out. Test samples were placed in a small chamber the size of 464x388x140 mm. In this case, the joints of the formwork forms were treated with silicone, and the walls were impregnated with machine oil to eliminate the processes of moisture absorption by the material of the forms.

**Figure 1.** Appearance solar forms hardening of concrete samples in conditions of high clouds in the morning hours: a, b, b-translucent fencing, respectively, of silicate glass, polyethylene film and polycarbonate.

3. Experimental study

To identify the possible effect of the properties of translucent fences on the thermal regime of concrete massifs, three types of upper transparent coatings were used: a - silicate glass with a thickness of 4 mm; b - polyethylene film; c - polycarbonate with a thickness of 4 mm (see Fig. 1).

Experimental studies in the warm period of 2015 were conducted under different weather conditions:

1) in sunlight and relatively high outdoor temperature;
2) at moderate temperature;
3) with high clouds, accompanied by frequent short-term precipitation.

The study of thermal conditions of concrete massifs was carried out during the first and subsequent days by means of thermocouples. At the same time, the shelter of small-sized solar chambers was not provided with any heat-insulating material at night.

As shown by the measurements and their processing [10], for thermal regimes generated by solar radiation, characterized by harmonic temperature fluctuations of each element of the hardening structure during the day. The maximum values in the concrete temperature reaches with a shift in time by 3-4 hours from the solar radiation intensity reached at noon, which is also consistent with a sufficiently high convergence with the results of mathematical modelling [11], taking into account the influence of thermal inertia of the array.

The results of temperature measurements in the examined concrete elements placed in helioscopes with glass, plastic film and the polycarbonate cell (Figure 2, 3, 4), under favourable weather conditions with intense solar radiation, allow us to conclude about the possibility of creating polygons in the territory of the Central black earth region for solar thermal treatment on an industrial scale. At higher outdoor temperatures, which have been recorded over the past ten years of meteorological observations in the territory of the Russian Federation, the efficiency of heat treatment can be increased by 20-30 %, which will reduce the process of strength gain in time to 12-20 hours. In the case of high clouds, accompanied by precipitation, and at an outdoor temperature not exceeding 15 °C, arising under the influence of solar radiation, the thermal regime also contributes to the set of the
necessary for shipment and transportation of seventy percent strength after the second day of processing.

Figure 2. The temperature regime of hardening concrete by curing under glass.

Figure 3. Temperature regime of hardening concrete while maintaining under the plastic film.
Figure 4. The temperature regime of hardening concrete by curing under cellular polycarbonate.

Simultaneously generated by solar radiation thermal regimes in concrete samples (see Figure 1), allowed to evaluate the lighting parameters of the used covering materials. From the basic thermal performance of heat treatment in table 1, it follows that the most intense heat and mass transfer processes in the first hours of concrete hardening is exposed to the surface layer. At a depth of 0.05 cm, the maximum rate of temperature rise is 10 deg/h, the minimum - 3 deg/h.

Comparing the temperature conditions in the hardening concrete when it is kept under a polyethylene film, glass 4 mm thick and cellular polycarbonate of the same thickness, having a relatively equivalent capacity, it can be noted that with high clouds and precipitation, the greatest heating of the products was achieved in a device with silicate glass. This is due to the better optical properties of transparency and better wettability of glass compared to polycarbonate, which evenly reduces the thickness of the water film on the surface, absorbing solar radiation. In the absence of clouds and precipitation, the maximum temperature recorded under the polycarbonate fence.

Table 1. The basic thermo physical parameters of the curing process of concrete elements while maintaining the under translucent materials with different optical properties.

| Type of covering material | Values of thermo physical parameters depending on duration of hardening |
|---------------------------|------------------------------------------------------------------------|
|                           | maximum heating temperature of concrete in the surface layer, °C | temperature °C rise rate in the surface layer, °C/hour | daily amplitude of temperature fluctuations in the surface layer, °C/hour |
| Glass                     | 62  56  10  8  44  39                                               |
| Polyethylene film          | 54  49  8   8  38  34                                               |
| transparent               | 69  56  10  9  41  40                                               |
| Polycarbonate             | 69  56  10  9  41  40                                               |
Table 2. Thermal conductivity properties of materials recommended for use as a translucent enclosure for helioform.

| The thickness of the translucent material, mm | Heat transfer coefficient, W/(m²·°C) |
|-----------------------------------------------|-------------------------------------|
|                                               | Glass | Polycarbonate | Polycarbonate |
|                                               | monolithic | honeycomb    | honeycomb    |
| 4                                             | 5.82  | 5.34          | 3.9          |
| 6                                             | 5.77  | 5.09          | 3.6          |
| 8                                             | 5.71  | 4.85          | 3.4          |
| 10                                            | 5.65  | 4.65          | 3.1          |
| 16                                            | -     | 4.1           | 2.4          |
| 25                                            | -     | -             | 1.75         |

The achieved indicators in the generated thermal conditions allowed to assume that the strength characteristics of concrete elements should correspond to the required values. To test the strength of the obtained products was about conducting sample tests at the age of 9 months, the compression and bending on the system equipment INSTRON 600KN at a speed of impact of from 0.1 to 200 mm/min. A considerable period of time after the successful solar thermal treatment has put all the following elements in approximately the same conditions, including from the standpoint of the negative impact of the weather conditions of the cold period of the year. Software Bluehill3 system INSTRON 600KN during the tests allowed us to trace changes arising at loading for tabular data and graphs. Fixed indicators of concrete strength (Fig. 5), indicate that the products subject to solar thermal treatment, in their strength characteristics able to compete with products produced by traditional technology. Displacements and deformations manifested under the influence of loads (see Fig. 6) in concrete samples can be approximated by the following dependencies

$$l = 0.4919 \cdot H^{0.3524}$$  \hspace{1cm} (1)

$$\delta = 0.0353H^{0.7569}$$ \hspace{1cm} (2)

where $l$ - displacement, mm; $\delta$ - deformation,%; $H$ - load, kN.

Figure 5. Changes in concrete samples under bending load (a) and compression (b).

The dependence (1) is valid for loads not exceeding 26 kN, and the expression (2) within 800 kN. As a rule, the impact above the designated boundaries led to the destruction of the samples.

A sufficiently high strength is obtained through solar thermal concrete products are the result, in particular, and the observed lower total macro porosity, which replaced a high content of smaller size
pores. It should be noted that the fracture resistance of concrete reaches the maximum values in samples subjected to heat treatment in solar forms with polycarbonate translucent coating. In addition, as shown in the temperature generated in the arrays at different solar radiation intensity, polycarbonate coating allows you to create the best modes for hardening in climatic zones with unstable weather conditions.

Taking into account the achieved results of solar energy utilization at the test site, it can be concluded that the solar thermal treatment of concrete and reinforced concrete products can be carried out not only in the southern regions and the Central black earth region, but also in the middle zone, including the more Northern latitudes of the Russian Federation. Using cellular polycarbonate with a thickness of at least 10 mm in the covering type chambers, it is possible to increase the temperature potential of the generated modes by 1.2-1.8 times, which will provide a set of strength of products within one light day and expand the seasonality of effective utilization of solar energy. For a significant increase in the calendar duration of operation of solar polygons, the practice of [12] a combined method of processing the sun with heat and electricity of construction products can be used.

However, despite the relatively high competitiveness of solar thermal treatment in comparison with traditional TVO concrete and reinforced concrete products, the introduction of this method in production practice is accompanied by a number of difficulties. First, for solar and heat treatment will need to find additional space on the territory of the construction industry, which is not always feasible. This problem can be solved if the enterprise already has an open polygon in its structure. Secondly, it will be necessary to produce a sufficiently large number of solar forms, which, taking into account the durability of the materials used for this (polycarbonate, glass, etc.) will have a fairly short service life.

These provisions lead to an increase in the cost of production, at least under the item of depreciation of fixed assets, and in the case of an increase in the area of the plant of reinforced concrete products and the amount of land tax.

Thus, the economic effect of the introduction of solar thermal treatment will be obtained only when the reduction in steam costs exceeds the increase in depreciation costs and the additional amount of land tax per unit of production, in other words, the condition must be met

$$\Delta S = \Delta S_\text{r} - \Delta S_\text{a} - \Delta S_\text{n} > 1,$$

where $\Delta S$ – the total change in the cost of production; $\Delta S_\text{r}$ – reduction of costs for couples in the implementation of heat treatment; $\Delta S_\text{a}$ – increase in depreciation costs of fixed assets as a result of the formation of a fleet of forms for solar thermal treatment; $\Delta S_\text{n}$ – increase in the amount of land tax.

In addition, as a result of the formation of a fleet of forms for solar thermal treatment of concrete products, the value of the enterprise's property will increase, and, consequently, the value of the property tax, which is paid from profit, will increase.

4. Conclusion

In conclusion, it should be emphasized that the heat treatment of concrete products provides the necessary release strength of the products within a day while reducing the cost of energy for 180–200 p/m³. This method of heat treatment should be recommended for small enterprises of the construction industry-plants of reinforced concrete products with a capacity of up to 20 thousand m³, located or under construction in areas with poorly developed infrastructure and (or) remote from traditional fuel sources, as well as for plants with open landfills in their structure.

References

[1] Akulova I I 2016 Forecasting of regional construction complex development: theory, methodology and applied problems: monograph (Voronezh: Voronezh state technical University) p 162

[2] Chernyshov E M, Akulova I I 2002 To the development of an information system to support management decisions in the problems of development of the regional production base of housing Construction materials, equipment, technology of the XXI century 12 36–37
[3] Akulova I I and Chernyshov E M 2003 Problems, methodology and strategy of management of production base development of regional housing and construction complex Bulletin of Belgorod state technological University 7 82–84

[4] Podgornov N So 2011 Heat treatment using solar energy (M.: Association of construction universities (DIA)) p 328

[5] Aruova L B, Bisenov K A, Damjanov N T, Aripova Z S, Utkelbaev A O 2014 Technology of using solar energy in production of various types Beto-ne Technology of concrete 9 45–47

[6] Damjanov N T 2016 The efficiency of the complex heat treatment of products made of foamed concrete depending on the massiveness of the products in the conditions of low positive temperature Building materials, equipment, technologies of XXI century 11-12 29–31

[7] Turdieva E N, Iranoff N A Taitokerau G Z 2016 The Use of solar energy in the production of concrete and precast concrete structures Proceedings of the Osh technological University 2 87–90

[8] Shchukina T V, Akopyan AV, Semenova E Yu 2015 Resources of solar energy of CZR for use in the production of construction products Construction materials, equipment, technologies of the XXI century 1(192) 22–24

[9] O’Hegarty Richard, Kinnane Oliver, McCormack Sarah J 2017 Parametric investigation of concrete solar collectors for façade integration Solar Energy pp 396–413

[10] Semenov B A 2013 Engineering experiment in industrial heat engineering, heat power engineering and heat technologies (SPb: Publishing House “LAN”) p 400

[11] Shchukina T V 2008 Increase of energoactivity heat treatment construction products Construction and building materials 10 20–23

[12] Krylov B A, Aruova L B 2007 Combined solar thermal treatment of reinforced concrete products in the Republic of Kazakhstan Concrete and reinforced concrete 4 11–13