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Research paper

Materials and Construction of Transparent Cover of Formwork for Heat Treatment of Concrete with Employment of Solar Energy

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Abstract

Heat treatment of concrete is one of the operations during manufacturing of concrete elements at the plants. It allows speeding up the process of concrete curing and getting complete product in a short time. Concrete is heated under the temperature, which can be obtained in solar energy equipment. It allows replacing fossil fuels by solar energy partly or completely and reducing costs for manufacturing of concrete elements. The efficiency of employment of solar energy depends on materials and construction of the solar energy equipment. The object of research is formwork, equipped by transparent cover, which is a simple type of the solar energy equipment. The research work is devoted to determination of optimal material and number of layers of transparent cover. The obtained results allow increasing efficiency of employment of solar energy for heat treatment of concrete and reducing costs for manufacturing of the solar energy equipment.

Keywords: *Concrete, Heat Treatment, Solar Energy, Transparent Cover.*

1. Introduction

Concrete is heated up to 60-80 °C during its heat treatment [1]. Possibility to obtain such temperatures in the solar energy equipment allows using the solar energy for heat treatment of concrete. The research on development of different types of solar energy equipment is carried out in different countries [2-3]. At present, the most common type is a solar collector. Solar collectors are widely used in different fields, such as household equipment systems, hot water production [4-5].

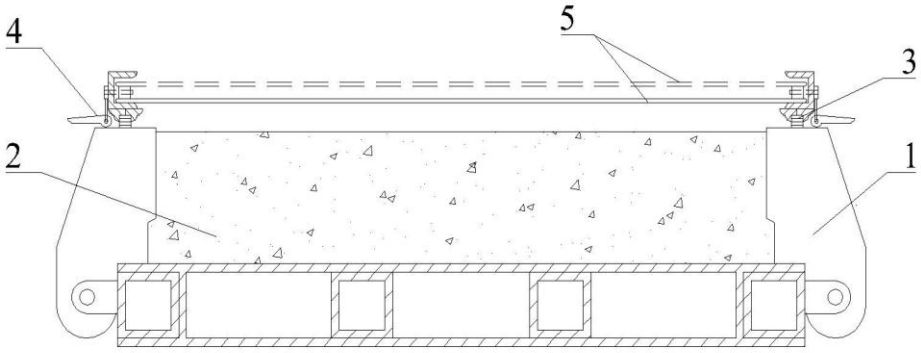

Fig. 1. Principal scheme of formwork, equipped by inventory frame with transparent cover.
1 – formwork, 2 – concrete element, 3 – flexible sealing seal, 4 – clip-lock, 5 – one or two layer transparent cover.

The solar energy equipment like solar collector is a formwork with transparent cover, which is comparable with solar collector for thermo-physical processes, taking place in it. (fig. 1). Our research results shows that it can be used for heat treatment of concrete with employment of solar energy within 5 months for Moscow region (φ=56° N) and 7 months for South of Russia (φ=45° N). The manufacturing period does not exceed 24 hours during this time [6].

However, the efficiency of heat treatment of concrete with employment of solar energy in formworks, equipped by transparent cover, depends on materials and construction of the cover, especially, number of layers.

2. Method of Research

The increase of the layers number reduces the amount of heat, consumed by concrete, due to reduction of coefficient of the solar radiation transmission and the growth of the shaded area of the concrete element (1).

$$C_{tr} = C_{shade} + C_{dust} \cdot C_{\text{cover}}^{\text{int}} - 1$$

where C_{tr} – coefficient of the solar radiation transmission; C_{shade} – coefficient of shading; C_{dust} – coefficient of dusting; $C_{\text{cover}}^{\text{int}}$ – integral coefficient of the transparent cover transmission.

At the same time, the increase of the layers number reduces heat loss from concrete in the environment through the transparent cover (2).

$$U_{loss} = \left(\frac{1}{h_{con}^{e} + h_{rad}^{e}} + \frac{1}{h_{con}^{t_1 - t_2} + h_{rad}^{t_1 - t_2}} + \ldots + \frac{1}{h_{con}^{t_{n-1} - t_n} + h_{rad}^{t_{n-1} - t_n}} + \frac{1}{h_{con}^{c} + h_{rad}^{c}} \right)^{-1}$$

where U_{loss} – coefficient of heat loss through the transparent cover, W/(°C·m^2); h_{con}^{e} and h_{rad}^{e} – convective and radiation coefficients of heat transfer between the transparent cover and the environment, W/(°C·m^2); $h_{con}^{t_1 - t_2}$, $h_{con}^{t_{n-1} - t_n}$, $h_{rad}^{t_1 - t_2}$, $h_{rad}^{t_{n-1} - t_n}$ – convective and radiation coefficients of heat transfer between layers of the transparent cover, W/(°C·m^2); h_{con}^{c} and h_{rad}^{c} – convective and radiation coefficients of heat transfer between the concrete element and the transparent cover, W/(°C·m^2).

The experimental research is made to verify the calculation model. The temperature and humidity conditions of subtropical climate are simulated in climatic camera. The intensity of solar radiation changes according to parabolic law with the maximum value of 1300 W/m^2 in the camera. The air temperature changes according to sine law in the range of 24-50 °C, the air humidity – 6-39% in the camera.

The main materials of transparent cover are the following: glass, polymer foil, polycarbonate, acrylic glass [7]. Polymer foils have a number of advantages as compared with other materials, the main are: the price and usability. Polyethyleneterephthalate foil with integral coefficient of the transmission of 0.88-0.85 and polyethylene foil with integral coefficient of the transmission of 0.92-0.94 are chosen as the most suitable types after the comparison of the polymer foils characteristics.

3. Analysis and Discussion

The calculation of concrete temperature and strength was carried out for conditions of subtropical (table 1) and temperate continental climate (table 2) to determine the advantages of one or two layer transparent cover. Q_{abs} and Q_{loss} in the tables are the amount of heat, absorbed by concrete during the day and lost through the transparent cover.

One and two layer transparent covers are chosen for this study because the research results of many scientists testify to inefficiency of using more than two layers in construction of the cover of the solar energy equipment such as solar collectors [7-9]

The analysis of the research results shows that concrete is heated more intensively under one-layer transparent cover during the day. Its maximum temperature 1.5-2 °C more than under two-layer cover.

Table 1. Concrete curing in formwork, equipped by one and two layer transparent cover, in the climate conditions: φ=44° N, July

One-layer transparent cover					Two-layer transparent cover				
Time of day	Q_{abs} [kJ]	U_{loss} [W/(°C·m^2)]	Q_{loss} [kJ]	$t_{concrete}$ [°C]	Time of day	Q_{abs} [kJ]	U_{loss} [W/(°C·m^2)]	Q_{loss} [kJ]	$t_{concrete}$ [°C]
10:00	52.6	0.94	-16	12	10:00	41.1	0.38	-13	12
11:00	63	0.97	-16	15.7	11:00	54.4	0.39	-14	15
12:00	70.6	1	-15	20.7	12:00	65.5	0.4	-13	18.9
13:00	75.5	1.02	-12	25.3	13:00	74.4	0.41	-11	23.6
14:00	70.8	1.03	-8	31.7	14:00	65.4	0.43	-8	29.9
15:00	63.4	1	-3	38	15:00	54.3	0.44	-4.2	35.8
16:00	51.7	1.38	3	44.9	16:00	40.9	0.43	0.2	42.3
17:00	41.8	6.68	36.3	49.8	17:00	26	2.86	17.1	46.7
18:00	27.1	5.95	37.1	54.2	18:00	9.4	3.03	15.2	51.1
19:00	11	5.78	37.3	56.6	19:00	1.5	3.08	17.5	53.7
20:00	-	5.72	39.2	57.4	20:00	-	3.13	23	55.4
21:00	-	5.69	44.7	58.3	21:00	-	3.17	27.7	56.4
22:00	-	5.68	48.5	58.5	22:00	-	3.2	31.3	57
23:00	-	5.67	51.1	57.6	23:00	-	3.21	34	57.2
24:00	-	5.66	52.5	57	24:00	-	3.23	35.9	57.4
1:00	-	5.65	52.7	56.2	1:00	-	3.23	36.9	57.4
2:00	-	5.66	51.3	55	2:00	-	3.19	35.2	57.1
3:00	-	5.67	48.5	53.6	3:00	-	3.23	35.7	56.4
4:00	-	5.69	44.8	52.1	4:00	-	3.22	33.8	55.5
5:00	-	5.73	40.3	50.6	5:00	-	3.2	31.3	54.6
6:00	-	5.79	35.2	49.5	6:00	-	3.18	28.2	54
7:00	11	5.87	35.1	48.4	7:00	1.5	3.15	24.9	53.2
8:00	27.1	5.98	38.4	47.8	8:00	9.2	3.12	25.2	52.8
9:00	42	6.12	41.8	48.1	9:00	25.1	3.09	30.1	52.6
Maturity of concrete [°C-hours]				1097	Maturity of concrete [°C-hours]				1106
Strength of concrete [% from reference standard]				72.4	Strength of concrete [% from reference standard]				73.2

Note: size of concrete sample 20x20x20(h) cm; temperature ($t_{concrete}$) is in the middle of concrete sample; reference standard is concrete B25 (compressive strength in the age of 28 days is 29.8 MPa); material of transparent cover is polyethylene-terephthalate foil.

However, concrete temperature under one-layer cover starts decreasing after sundown, while it continues increasing under two-layer cover. The coefficient of heat loss (U_{loss}) of two-layer cover decreases almost in 2 times as compared with one-layer cover. The temperature of concrete decreases slower under two-layer cover at nighttime. The maximum excess of the concrete temperature is from 3-5 °C (table 1) until 8-10 °C (table 2) as compared with one-layer cover.

Maturity of concrete, which is total sum of numerical values of concrete temperatures over the period of concrete curing, is almost the same for the subtropical climate conditions (table 1). Nevertheless, it is more for the concrete samples, curing under two-layer cover in the temperate continental climate conditions (table 2).

The results of calculation and experimental research of the concrete temperature in conditions of subtropical climate are shown in fig. 2. The similarity of graphs, obtained by the calculation and the experimental research, testifies to adequacy of chosen calculation model. Strength of concrete, curing in formwork, equipped by two-layer transparent cover, is better in both climate conditions. However, the difference in the values of the concrete strength decreases with increasing the average air temperature and intensity of solar radiation.

Table 2. Concrete curing in formwork, equipped by one and two layer transparent cover, in the climate conditions: φ=56° N, July

One-layer transparent cover					Two-layer transparent cover				
Time of day	Q_{abs} [kJ]	U_{loss} [W/(°C·m^2)]	Q_{loss} [kJ]	$t_{concrete}$ [°C]	Time of day	Q_{abs} [kJ]	U_{loss} [W/(°C·m^2)]	Q_{loss} [kJ]	$t_{concrete}$ [°C]
10:00	36.7	1.13	7.5	21	10:00	28.6	0.42	5.8	21
11:00	44.1	1.15	8.2	23.9	11:00	40.1	0.42	6	22.8
12:00	53.6	15.2	20.5	27.1	12:00	43.4	2.62	27.6	25.3
13:00	60.2	11.2	49.9	30.2	13:00	51.1	3.38	33.2	27.3
14:00	57.9	10.5	51.2	32.3	14:00	42.8	3.61	31.5	29.4
15:00	52.7	10.1	52.9	34.2	15:00	32.9	3.74	29.1	31.4
16:00	44.8	9.93	53.7	36.1	16:00	21.9	3.84	26.6	33.2
17:00	33.7	9.83	52.9	37.4	17:00	7.4	3.94	22.7	35.3
18:00	20.4	9.77	50.7	38.3	18:00	4.8	4.03	21.7	37
19:00	7.2	9.74	48.1	38.8	19:00	3.5	4.11	25.3	38.2
20:00	2.6	9.72	49.6	38.9	20:00	2.1	4.18	28.7	38.9
21:00	0.7	9.7	52.1	38.3	21:00	0.6	4.23	31.6	39.6
22:00	-	9.68	52.9	37.5	22:00	-	4.26	33.7	40.6
23:00	-	9.68	52.5	35.8	23:00	-	4.29	35.2	40.3
24:00	-	9.68	51.5	34.3	24:00	-	4.3	36.2	39.9
1:00	-	9.68	49.6	32.6	1:00	-	4.31	36.6	39.4
2:00	-	9.69	47	31.2	2:00	-	4.3	36.1	39
3:00	-	9.72	43.8	29.7	3:00	-	4.28	35	38.5
4:00	-	9.77	39.9	28.5	4:00	-	4.26	33.7	38.2
5:00	0.7	9.85	35.5	27.3	5:00	0.6	4.24	32	37.9
6:00	2.4	9.99	31	26.4	6:00	2.1	4.21	29.9	37.5
7:00	6.9	10.21	28.2	25.8	7:00	3.6	4.17	27.7	37.3
8:00	19.7	10.57	30.8	25.8	8:00	5	4.13	25.4	37.1
9:00	32.5	11.06	34.7	26.3	9:00	11.9	4.08	27.8	37.1
Maturity of concrete [°C-hours]				757.7	Maturity of concrete [°C-hours]				842
Strength of concrete [% from reference standard]				50	Strength of concrete [% from reference standard]				53

Note: size of concrete sample 20x20x20(h) cm; temperature ($t_{concrete}$) is in the middle of concrete sample; reference standard is concrete B25 (compressive strength in the age of 28 days is 29.8 MPa); material of transparent cover is polyethylene foil.

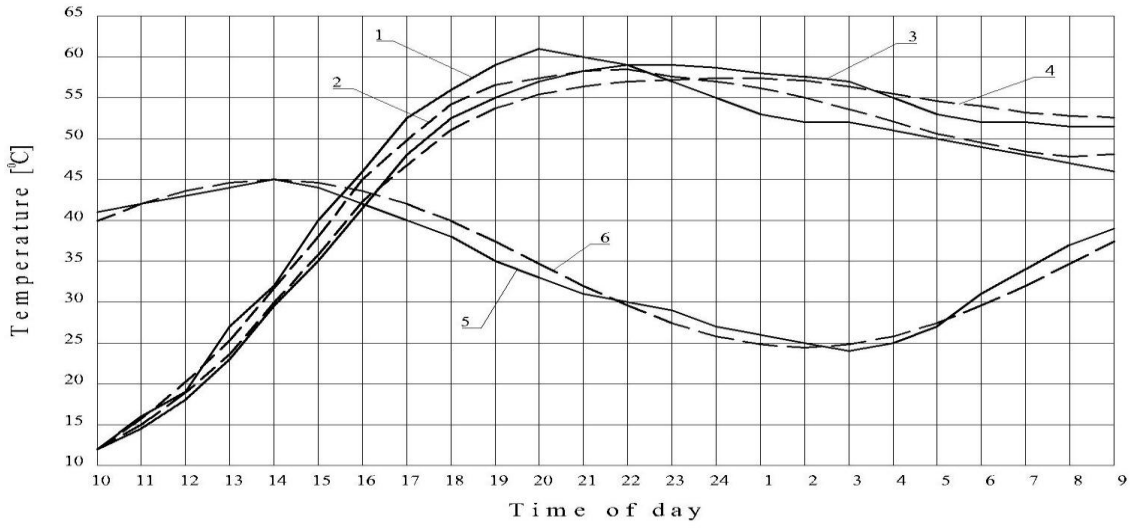

Fig. 2. Temperature of concrete sample, curing in formwork, equipped by one and two layer transparent cover in climate conditions: φ=44° N, July

1 and 3 – experimental concrete temperature under one-layer and two-layer cover; 2 and 4 – calculated concrete temperature under one-layer and two-layer cover; 5 – actual air temperature during the experiment; 6 – calculated air temperature.

4. Conclusion

The research results shows that the increase of layers of transparent cover in the subtropical climate conditions does not improve the values of strength and maturity of concrete. It testifies to inefficiency of two-layer cover in such climate conditions. In spite of better values of strength and maturity of concrete, curing in formwork, equipped by two-layer transparent

cover in the temperate continental climate conditions, we have to admit its inefficiency. This is because we have to take into account the economic component, connected with the equipment costs. The increase of the concrete strength by 1-4% does not justify the increase of the equipment price, connected with addition of one more layer of transparent cover at the time of manufacturing and operation of the equipment.

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