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CALCULATION OF THE PROCESS OF HEAT TRANSFER DURING CURING OF CAOUTCHOUC CONCRETE

Problem statement. It is common place that modern building manufacture requires designing new materials with top operational characteristics. According to this requirement new material, caoutchouc concrete, was obtained in Voronezh State University of Architecture and Civil Engineering. The aim of the paper is to study heat transfer process during curing of this new material.
Results and conclusions. An effective method of arrangement of caoutchouc concrete ground coatings by electric curing of caoutchouc concrete with application of heating wire is introduced. A mathematical model of spreading of temperature field within vulcanized caoutchouc concrete depending on boundary conditions such as a type of heat-generating device, its temperature and ambient temperature, is developed.

Keywords: caoutchouc concrete, electric curing, mathematical modeling, temperature field, vulcanization, structure formation.

Introduction

Modern building manufacture requires designing new materials with top operational characteristics as well as a strong resistance to a variety of hostile environments. In Voronezh State University of Architecture and Civil Engineering a material to be called caoutchouc concrete was obtained based on low molecular diene olygomers that belong to the liquid resin type. The physical and mechanical properties of the material enable its use in a wide variety of applications and, furthermore, due to its strong resistance to hostile environments it can be used as a viable construction and insulation material [1]. Caoutchouc concrete is advisable to use in different building structures: floors in the hostile environment of industrial facilities and cattle farms, protective pipe coating utilized in tough climatic conditions of the Extreme North, etc.

1. Caoutchouc concrete curing

Caoutchouc concrete is obtained by solidification (vulcanization) of caoutchouc and concrete mixture with the following ratio of the constituents, mass %:

- low molecular oligodien — 8÷11;
- sulphur — 3÷6.5;
- tiuram — 0.3÷0.7;
- zinc oxide — 1.5÷5.0;
- calcium oxide — 0.3÷0.6;
- fly ash from heat power stations (HPS) — 7÷10;
- filler (sand, rubber chips and crumbs) — the rest.

A necessary condition for a regular vulcanization to occur is creating and maintaining specified temperature fields across the surface and section of the material by introducing heat energy.

For surfacing of an area, an efficient method of heat treatment of caoutchouc by means of electric curing using a heat cable [2] was proposed. The suggested principal schematic of electric curing of a caoutchouc concrete area using a heat cable is shown in Fig. 1. Rational temperature modes of heat impact on caoutchouc concrete in the process of the design of the area were defined. Heat treatment is to be performed in 2 stages (Fig. 2):

- stage 1: 55—65 min to ensure the temperature of 85—95 ^{0}C of a surface layer for initial structural bonds to occur in the material.
- stage 2: 180—200 min to maintain the temperature of 115—125 ^{0}C in a surfacing layer to complete vulcanization and to form a solid and homogeneous structure of the material.

A run of a heating wire with the diameter of 1 mm can vary in the range of 8—15 mm. The use of a heating cable with a run of no less than 8 mm does not have a significant effect on heat treatment of caoutchouc and an increase in a run of over 15 mm and more causes uneven heating of a vulcanizate and thereby to a non-homogeneous structure of the yielded material. This is due to a low heat conductivity of a caoutchouc and concrete mixture λ = 0.3…0.5 Watt/(m $\cdot^0$C).

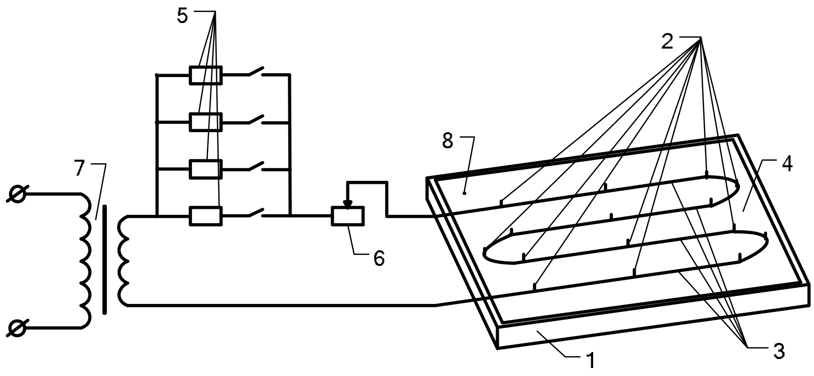

Fig. 1. Principal schematic of electric curing of a caoutchouc concrete area using a heat cable:
1 — bearing layer; 2 — pins; 3 — non-insulated steel heat cables;
4 — a surfacing layer; 5 — loading resistors; 6 — rheostat; 7 — step-down transformer

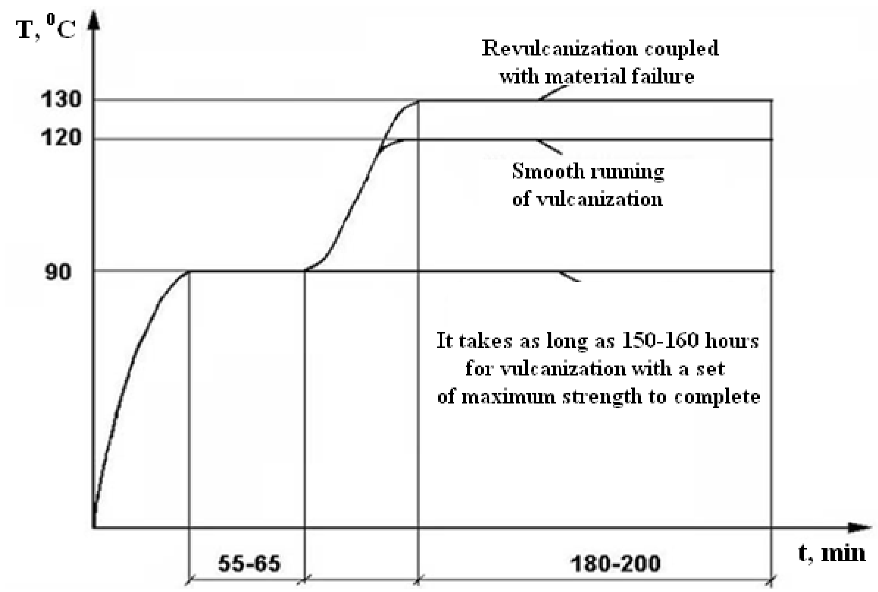

Fig. 2. Graph of caoutchouc heat treatment during vulcanization by means of a heating cable

In order to avoid a material failure due to intense gasification coupled with vulcanization, a temperature gain rate during heat treatment of a caoutchouc and concrete mixture using a heating cable should not be 1 ^{0}C per minute.

2. Non-one dimensional problem of heat conductivity

In order to examine how the temperature distributes along the vulcanizate, a mathematical model of the distribution of a temperature field in a vulcanizate was developed depending on boundary conditions: a type of a heat generating device, its temperature and that of the environment.

Due to complexity and labour costs associated with a non-one dimensional problem of heat conductivity involving analytical methods, a finite difference method was applied which is based on a differential heat conductivity equation and boundary conditions. With this method used, a segment of a section of an area vulcanized, whose temperature field needed to be defined, was broken into basic volumes of a unit thickness. An assumption is made that a mass of this basic volume is focused in its centre called a node. The position of each node (cell) on the plane is arbitrary defined according to the horizontal layer and the vertical column (Fig. 3).

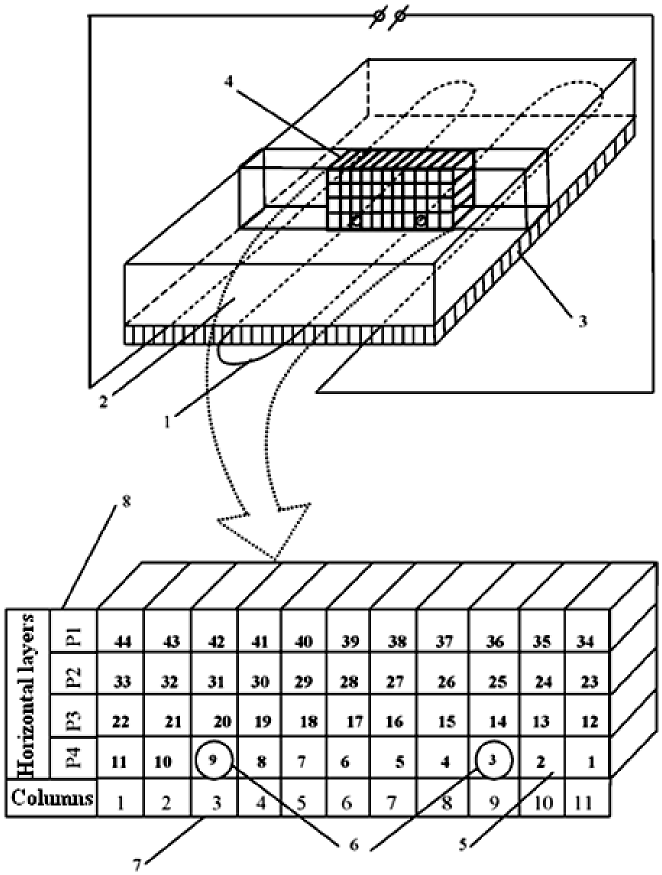

Fig. 3. A way of breaking a unit of thickness of a segment of a section of an area vulcanized into basic volumes: 1 — heating cable; 2 — vulcanizate; 3 — major areas; 4 — a segment of a section of an area vulcanized of a unit of thickness; 5 — basic volumes of a unit of thickness; 6 — basic volume of a unit of thickness with a heating cable; 7 — vertical columns; 8 — horizontal layers

For each node a heat balance equation is produced based on the law of conservation of energy which includes values of all the heat flows on the volume boundaries (cells). For cells making contact with the environment the expressions for determining heat flows include boundary conditions, i. e. consider heat exchange between body and environment. Algebraic equations for the temperature in each node are obtained as a result of transforming the heat balance equations. Since a number of nodes and cells is the same, the resulting system of algebraic equations is a finite difference analogue of a differential equation of heat conductivity and substitutes it with corresponding boundary conditions.

The solution of the system of linear algebraic equations can be obtained using a range of standard software programs including MS EXCEL by means of built-in matrix functions, for which the initial system is presented as a matrix equation. The solutions of the system of linear equations provide understanding of how temperature field is distributed in a vulcanizate (Fig. 4).

Boundary conditions
1. Temperature of an outer surface of the vulcanizate — 118 ^{0}C
2. Temperature of heating cable — 125 ^{0}C
3. Temperature of the base — 123 ^{0}C

Temperature distribution in a section of the vulcanizate												
Vertical columns		1	2	3	4	5	6	7	8	9	10	11
Horizontal layers	P1	**119,3**	**119,3**	**119,4**	**119,3**	**119,3**	**119,2**	**119,3**	**119,3**	**119,4**	**119,3**	**119,3**
	P2	**120,6**	**120,7**	**120,8**	**120,6**	**120,5**	**120,4**	**120,5**	**120,6**	**120,8**	**120,7**	**120,6**
	P3	**121,7**	**122**	**122,4**	**121,9**	**121,6**	**121,5**	**121,6**	**121,9**	**122,4**	**122**	**121,7**
	P4	**122,6**	**123,2**	**125**	**123,1**	**122,5**	**122,4**	**122,5**	**123,1**	**125**	**123,2**	**122,6**

Characteristics of a temperature field
1. Maximum temperature value — 125 ^{0}C
2. Average temperature value — 121.3 ^{0}C
3. Minimum temperature value — 118 ^{0}C
4. Dispersion value of a temperature field — 2.8372 ^{0}C

Fig. 4. Analytical form of presenting solutions of the problem of temperature field distribution in a transverse section of the vulcanizate when using a heat cable as a heat generating device

The analysis of a temperature field allow one to obtain the odds of caoutchouc concrete structure forming along the entire volume of an area vulcanized. A temperature field of an area vulcanized (See Fig. 4) has a small dispersion and is in a specified temperature range of 120—130 ^{0}C, which provides an even curing of the vulcanizate and smooth running of structure formation processes occurring inside it.

The efficiency of vulcanization and caoutchouc concrete structure formation can be improved by extra heat treatment of an outer coating surface thus creating a more even distribution of temperature field across the surface and volume of a structure warmed. As a result of the analysis of heat generating devices, an infrared generator (Fig. 5) was chosen as an extra heat energy source. This device performs directional heating of the surface and has a high coefficient of efficiency of 65 %.

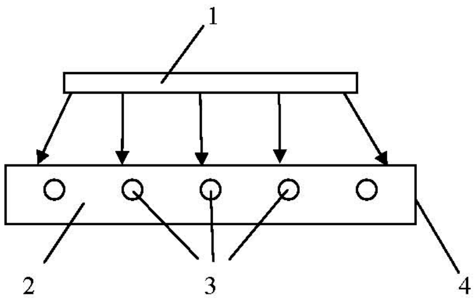

Fig. 5. Schematic of positioning of heating devices during a complex curing of caoutchouc concrete using a heating cable and infrared generator: 1 — infrared generator; 2 — caoutchouc concrete; 3 — heating cable; 4 — mould

With an extra impact of infrared radiation upon an outer surface of the area, a more even field of specified temperature boundaries of 118—125 ^{0}C was obtained across the entire volume of the material with a double increase in a run of a heating cable compared to pure electrical curing. The distribution of temperature field for this case is shown in Fig. 6.

<table>
<tr><th colspan="13">Boundary conditions</th></tr>
<tr><td colspan="13">1. Temperature of an outer surface of the vulcanizate — 118 ^{0}C</td></tr>
<tr><td colspan="13">2. Temperature of heating cable — 125 ^{0}C</td></tr>
<tr><td colspan="13">3. Temperature of the base — 120 ^{0}C</td></tr>
<tr><th colspan="13">Temperature distribution in a section of the vulcanizate</th></tr>
<tr><td colspan="2">Vertical columns</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td></tr>
<tr><td rowspan="4">Horizontal layers</td><td>P1</td><td>119,1</td><td>119</td><td>118,8</td><td>118,7</td><td>118,6</td><td>118,6</td><td>118,6</td><td>118,7</td><td>118,8</td><td>119</td><td>119,1</td></tr>
<tr><td>P2</td><td>120,4</td><td>120</td><td>119,6</td><td>119,3</td><td>119,1</td><td>119,1</td><td>119,1</td><td>119,3</td><td>119,6</td><td>120</td><td>120,4</td></tr>
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<tr><td>P4</td><td>125</td><td>121,6</td><td>120,5</td><td>120</td><td>119,8</td><td>119,8</td><td>119,8</td><td>120</td><td>120,5</td><td>121,6</td><td>125</td></tr>
<tr><th colspan="13">Characteristics of a temperature field</th></tr>
<tr><td colspan="13">1. Maximum temperature value — 125 ^{0}C</td></tr>
<tr><td colspan="13">2. Average temperature value — 120.1 ^{0}C</td></tr>
<tr><td colspan="13">3. Minimum temperature value — 118 ^{0}C</td></tr>
<tr><td colspan="13">4. Dispersion value of a temperature field — 2.53 ^{0}C</td></tr>
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Fig. 6. Distribution of temperature field in a transverse section of the vulcanizate using a heating cable as a heat generating device with extra impact of infrared radiation

Conclusions

So, rational technological modes of structure formation of caoutchouc and concrete were defined under heat impact of a heating cable and infrared radiation that include a heating temperature of 120—130 ^{0}C with treatment time as long as 450 min.

Using specified temperature modes and rational heat treatment methods in structure formation of caoutchouc concrete has promising prospects for the implementation in building and manufacturing technologies for the construction of building structures and insulation coatings operated in hostile environments.

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