MODELLING OF THE HEAT TRANSFER IN THE PROCESS OF JOINING BY VULCANISATION OF CONVEYOR BELTS

Dan DOBROTĂ[1] and Valentin PETRESCU[2]

ABSTRACT: The problem of heat transfer in the process of joining by vulcanization of conveyor belts has a special importance given the fact that an homogeneity of the temperature in the area of the joining of the rubber belt ensures an homogeneity of the mechanical properties. The analysis presented in the paper targeted the determination of a modelling that would reflect the manner of transferring the heat from the heating plate of the vulcanization installation so that the optimal vulcanization temperature of the rubber and an adequate adherence between rubber and insertion can be reached. Also, there has been realised a calculus programme that would allow the obtaining of the modelling of the heat transfer during the vulcanization of the conveyor belts. The targeted conveyor belt vulcanization installation was a DSLQ installation, which is very often used in practice and uses electric current to work.

KEY WORDS: modelling, heat transfer, vulcanisation, rubber

1 INTRODUCTION

The joining of belts with metallic and textile insertions is a very important operation in the realising and maintenance of belt conveyors. The productivity of a conveyor being very much influenced by the stationing time needed for carrying out reparations and especially redoing the joints or replacing belt portions that require new joints, it is desirable to keep this time as short as possible. The manner in which a joint is executed is essential for obtaining a tensile strength of the belt that is as close as possible to the tensile strength of the whole belt (Dobrotă, 2013). Knowing and precisely following the operations and of the manner of executing the joining are absolutely necessary conditions for its success. By accumulating experience, there can be continuously perfected both the organisation of operations and the materials and the execution of the joining (Manas, Stanek, Manas, Ovsik, Pata, Cerny, 2011).

The procedure for joining the belts is composed of a succession of relatively simple operations, the difficulty of the work being due to the large amount of work, to the weight of the vulcanisation press, implying a pre-eminence of the physical work depending of climatic conditions.

[1] Constantin Brancusi University of Targu Jiu Department of Systems Engineering and Management Technology, Targu Jiu, Calea Eroilor 30, Romania,

[2] "Lucian Blaga" University of Sibiu, Faculty of Engineering/Department of Industrial Engineering and Management, Bd-ul. Victoriei, Nr.10, Sibiu, 550024 Romania

E-mail: ddan@utgjiu.ro; valentin.petrescu@ulbsibiu.ro

The vulcanisation can be used for rubber belts with insertions of fabric, nylon or steel cables. There can be also used the special vulcanisation of anticorrosive and heat resistant belts.

In the joining area of two belts it is necessary to obtain a structure that is as close as possible to that of the initial belt. Given the fact that the insertion is the strength base of the segment that is being formed. the placement of the cables within the joint determines the joining system.

The joining system is determined by the diameter of cables or by the number of fabrics, being recommended certain strength classes. The international standards, such as DIN 22129, recommend to execute the joining, function of the strength class, in one, two, three and four stages.

The rubber and the rubber-like mixtures are ideal materials not only for the outer shell of the conveyor belts but also for manufacture of other products strictly necessary for the human activity. Brought up in 1910 from Brazil in natural form and becoming in time indispensable for the industry, there started to be studied its replacing with an artificial product.

Since the rubber cannot meet on its own all technical imperatives necessary for the obtaining of an adequate conveyor belt, it is necessary to use other materials which, in turn, must meet additional requirements: the combination of different materials should not lead to mutual damage; it must be retardant and antistatic and also, not toxic. From the above, it results that the materials that make up a conveyor belt can be divided into two broad categories: materials for cover plates or outer coating and materials constituting the strengthening structure, called insertions.

The use of the rubber as a material for the manufacturing of the conveyor belts is imposed by the most important technical requirements which met by them, namely: the conveyor belts are permanently subjected to the phenomenon of wear and to high tensile forces, so they must be made of a material that can display resistance in this regard; the conveyor belts must be elastic, but have a low coefficient of stretching; they must be flexible, i.e. to present a resistance as small as possible to the bending forces; it must be mechanically, chemically and bacteriologically resistant, in accordance with the transported materials; it should not be sensitive to humidity and should not lose its properties under any circumstances, even when in combination with other materials.

The durability of the joining by hot vulcanisation of conveyor belts depends on the adherence realised between the joining surfaces. Decisive for the obtaining of strength values in the joining area that would be as close as possible to the nominal strength of the whole belt is the adequate dimensioning of the vulcanisation length and of the joining steps (Matthias, Stark, 2009).

For the belts ST 800, ST 1000, ST 1250 and ST 1600, the standards recommend the joining in one step, for ST 2000, ST 2500 and ST 3150 in two steps, for ST 3500, ST 4000 and ST 4500 in three steps, while for ST 5000 and ST 5400 in four steps. A special role is held by the installations for the vulcanisation of belts.

The quality of vulcanisation (joining) of the belt will directly affect the force and durability of the belt. Therefore, it is important and necessary that the vulcanisation machine is used also for the installation of new belts (Liang, Lu, Wu, Zhang, 2005).

The three essential factors for the process of vulcanisation of rubber belts are:

- even, optimised temperature;
- sufficiently high pressure force, evenly distributed;
- accuracy of the vulcanisation duration.

The duration of vulcanization also decreases with the increasing of temperature; at the raising of the temperature by vulcanization, the strength of conveyor belt is nonetheless reduced. During the vulcanization, the conveyor belt is subjected to specific pressures of 2 – 2.5 N/mm^2, which is why there were created performing presses, with the downforce by several thousand tonnes and equipped with control devices and control of the temperature and pressure, satisfy the vulcanization process in itself (Dobrotă, 2010).

2 EMPLOYED MATERIALS AND EQUIPMENTS

Generally, the joining by vulcanisation of various rubber products, but especially of conveyor belts, generates in the joining area weaker mechanical characteristics than in the rest of the product, this leading to a decrease of the product's life duration (Manas, Stanek, Manas, Ovsik, Pata, Cerny, 2011). Therefore it is sought to find a technical solution that would allow the homogenisation of the properties of the materials from the joining area with those of the material from the actual product.

Any vulcanisation of a rubber product is currently realised by adjusting three technological parameters, namely:

- the vulcanisation time;
- the vulcanisation temperature;
- the pressure on the product's ends.

The adjustment of the vulcanisation time of rubber products for their joining is realised function of the thickness of the rubber in the joining area. For adjusting the vulcanisation time, one must take into account the type of rubber used in the vulcanisation process, while the pressure is determined function of the rubber thickness and its structure (Hasan, Sulistyo, Honggokusumo, 2013).

The three aforementioned parameters can take different values function of the rubber product type and if the adjustment of these parameters is not done to optimal values, the results obtained with regard to the characteristics of the joining area are not satisfactory. The unsatisfactory results are determined especially by the presence in the joining area of a high porosity of the joining materials, this determining a decrease of the mechanical characteristics of the joints.

The reduction of porosity in the joining area can be obtained through an adequate adjustment of the three technological parameters to optimal values (Armasoiu, Dobrota, Petrescu, 2015). In the process of joining by vulcanisation, temperature is a parameter of great importance. So far, there exist various opinions on the influence of the temperature, but the researches carried out refer especially to metallic materials and less to materials like rubber or composite materials with rubber matrix.

The vulcanisation installation for conveyor belts, type DSLQ (also called a vulcanisation machine) is an installation that is very often used in practice and uses electric current to work. The structural components of this machine are realised mainly of aluminium alloys. The main constructive characteristics of the DSLQ vulcanisation machine are:

- it is compact, lightweight, reliable and easy to operate;
- the resistors are fed in triangle connection and the distribution of heat is even throughout the work area;
- the pressure is realised by means of a hydraulic installation, so the pressure forces are large and evenly distributed on the whole area that needs to be vulcanised;
- the thermal inertia is small due to the heating plates made of aluminium;
- a small electricity consumption and a high heating efficiency through the usage of electric energy, through thermostats and control of the vulcanisation times;
- the vulcanisation machine can be used for the vulcanisation of belts made of rubber, fabric, nylon or steel cables. There can also be used for the special vulcanisation of anticorrosive and heat-resistant belts. It can be used in metallurgy, mining, powerplants. ports and places where there are no explosive or corrosive gases;

With regard to the main technical specifications of the vulcanisation installation, these are as follows:

- vulcanisation pressure: 1.5 MPa. There exists also a variant with a pressure of 1.8 MPa;
- vulcanisation temperature: 145°C (adjustable);
- temperature difference on the heating plate : +5 °C - -5 °C;
- heating time (from room temperature to vulcanisation temperature): no more than 50 min;
- electric parameters: 380 V, 50 Hz (triphased with 4 wires) or 660 V;
- voltage at the output of the electric control box: 380 V, 50 Hz, with reserve voltage: 220 V, 50 Hz.
- current at the output of the electric control box: max. 30 A;
- temperature adjustment range: 0-300 °C;
- time adjustment range: 0-99 min;
- difference between heating plate and lower plate after pressing: no more than 0.5 mm.

The structure of a DSLQ vulcanisation installation is presented in Figure 1.

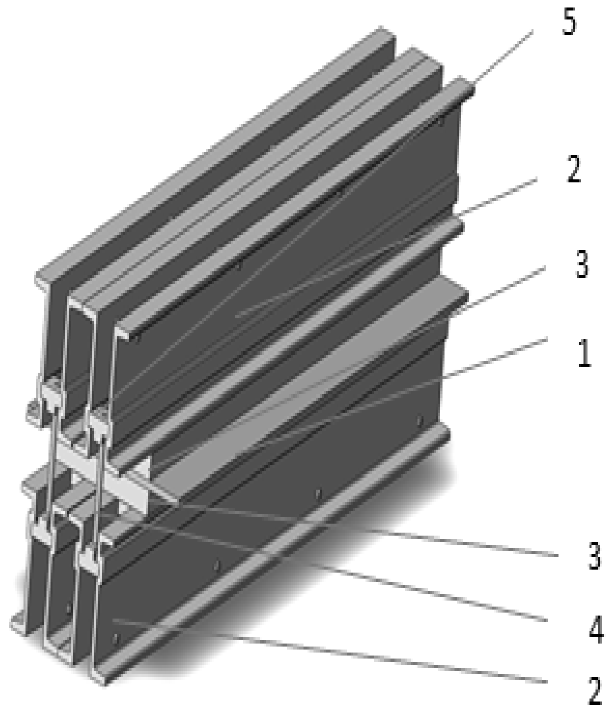

Figure 1. General scheme of the joining installation: 1 - conveyor belt; 2 - beam; 3 - heating plate; 4 - system for fastening the beam; 5 - hydraulic pistons for maintaining the pressing pressure

3 MODELLING OF THE HEAT TRANSFER IN THE VULCANISATION PROCESS

In the vulcanisation process, the thermal conductivity has a great importance for the materials. The heat transfer occurs from the heating plates made of aluminium to the conveyor belt made of a composite material that has in its structure rubber and a textile or metallic insertion. By definition, the thermal conductivity λ results from the equation:

$$Q = -\lambda \frac{dT}{dx} dt \qquad (1)$$

where:

Q is the heat flow or the amount of energy that traverses an area unit;

dx – gradient of the temperature along the direction x of the flow;

T – temperature;

t – time.

The minus sign indicates that the heat flow is directed from an area of high temperature towards an area of low temperature.

In a metallic material such as the aluminium of the heating plates, the thermal flow is transported by the ionic network through its vibrations (sonic thermal conductivity), by the electron gas (electronic thermal conductivity) and by the vibrations of the grain and phase separation areas (supersonic thermal conductivity).

Consequently, the total thermal conductivity of a material, λ, can be determined as:

$$\lambda = \lambda_e + \lambda_i + \lambda_l \quad (2)$$

where:

λ_e is the conductivity due to the electrons' thermal agitation;

λ_i – conductivity due to the ions' thermal agitation;

λ_l – conductivity due to the thermal agitation of the grain limits and sublimits generated by the propagation of ultrasonic waves.

The whole heat transfer from the heating plates to the conveyor belt is done by thermal conduction in a stationary regime through a wall with constant properties and a temperature distribution *t(x)* and can be written as:

$$q_s = -\lambda \frac{dt}{dx} \ [\text{w/m}^2] \quad (3)$$

In the case of the heat transfer from the heating plate to the rubber of the conveyor belt, the density of the heat flux q_s can be written as:

$$q_s = -\lambda \frac{dt}{dx} \pm \lambda_l \frac{dt}{dx} \ [\text{w/m}^2] \quad (4)$$

where:

dt / dx is the temperature gradient;

λ_l – supersonic conductivity.

The problem which arises is the determining a function whose minimum T = T (x, y, z) satisfies the differential equation given by the expression:

$$\pi(T) = \frac{x}{2}\left[\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2\right] - QT \quad (5)$$

which has been associated with the function J (t), given by the expression:

$$J(T) = \int_V \Pi(T)dT \quad (6)$$

The Euler-Ostrogradski equation was built, attached to the function and the result was compared with that obtained by experimental modeling. For this, it was calculated in succession:

$\Pi_T = -Q$

$$\Pi_{Tx} = \lambda \frac{\partial T}{\partial x}; \Pi_{Ty} = \lambda \frac{\partial T}{\partial y}; \Pi_{Tz} = \lambda \frac{\partial T}{\partial z} \quad (7)$$

In these conditions, the Ostrogradski Euler equation can be written as:

$$-Q - \lambda \frac{\partial^2 T}{\partial x^2} - \lambda \frac{\partial^2 T}{\partial y^2} - \lambda \frac{\partial^2 T}{\partial z^2} = 0 \quad (8)$$

It is noted that equation (5) is identical to equation (8) and therefore, the function:

$$J(T) = \int_V \left\{ \frac{\lambda}{2}\left[\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2\right]\right\} dV \quad (9)$$

accepts a minimum T = T (x, y, z) which is exactly the solution of equation (6).

The function (9) has the disadvantage that it can model only problems with Dirichlet boundary conditions or in the general case, on the border A may be imposed also other boundary conditions such as convection heat transfer for which the convection coefficient is known and the outdoor temperature or transfer with heat flow imposed.

In order to determine a function which can operate in these conditions of heat transfer, following notations are used: A_1 are the surfaces on which the temperature T_1 is imposed (Dirichlet boundary conditions); A_2 - the surfaces through which the convective heat transfer of coefficient α, known, is realised the; T_2 is the rubber temperature that must also be known and given by the relationship:

$$\lambda \frac{dT}{dn} = -\alpha(T - T_2) \quad (10)$$

where: *n* is the orthogonal at the frontier A_2 (Neumann boundary conditions).

The function and the equation for the heat transfer in stationary regime on a frontier A is:

$$\lambda\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + Q = 0 \ [\text{w/m}^2] \quad (11)$$

The differential equation of the conductivity through a material volume can be written as:

$$\rho c \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(\lambda_x \frac{\partial \theta}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda_y \frac{\partial \theta}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda_z \frac{\partial \theta}{\partial z}\right) \quad (12)$$

where:

θ is the temperature;

λ - thermal conductivity;

c - specific heat;

ρ - density;

t - time;

x, y, z - independent variables determining the position of a point M from the material volume in which the temperature is θ.

For applications specific for the vulcanisation processes there is adopted the hypothesis of constant thermophasic coefficients. Then, λ, the product $\rho \cdot c$ and the convection coefficient α are selected for the temperature 130...150°C, which is the most common case in practice.

The limit and initial conditions refer to the temperature's distribution in the conveyor belt and to the heat exchange from the heating plates to the conveyor belt.

The initial distribution of temperature (at t = 0) can be expressed as:

$$\theta(x, y, z, 0) = \theta_0(x, y, z) \tag{13}$$

which, if $\theta_0 = 0$ indicates the fact that the process of heat transmission can be due to internal or external heat sources.

For the vulcanisation process following limit conditions are accepted:

- the temperature at the body's surface θ_s can be written as:

$$\theta_s = \theta_s(x, y, z, t) \tag{14}$$

which, in the case of an isothermal surface becomes θ_s = const;

- the heat flow through the side surface of the body q_s can be written as:

$$q_s = q_s(x, y, z, t) = const., \quad or \quad \left.\frac{\partial \theta}{\partial n}\right|_S = const. \tag{15}$$

A particular case is represented by the adiabatic wall, when the equation occurs:

$$q_s = 0 \quad or \quad \left.\frac{\partial \theta}{\partial n}\right|_S = 0 \tag{16}$$

- the heat flow through the side surface of the body can be expressed with Newton's formula:

$$q_s = \alpha(\theta_s - \theta_0) \tag{17}$$

where:

θ_0 is the temperature of the outer environment;

α - convection coefficient;

θ_s - temperature of the body's surface.

In the study of the conductivity there can be used analytical methods and numerical methods. The analytical methods include the Fourier method, the method of heat sources and the method of operators. The determination of the temperature at the thermal phenomena typical for vulcanisation processes of conveyor belts there is applied with good results the method of heat sources.

As the heat Q_t is transmitted through the conveyor belt, the temperature in various points changes, but the heat amount stays the same, equal to Q_t. For the plane source ($Q_2(J/m)$) placed in the plane Oyz, the variation of the temperature $\theta(x, t)$ along the Ox axis is determined with the formula:

$$\theta(x, t) = \frac{Q_t}{\rho c (4\pi a t)^{1/2}} e^{-\frac{x^2}{4at}} \tag{16}$$

For determining the variation of the temperature in the structure of the conveyor belt subjected to vulcanisation there has been developed a calculus programme whose structure is presented in Figure 2.

INTRODUCTION OF INITIAL DATA

$T_{vulcanisation}$

c

ρ

λ

x

t

$\mathbf{Q_t}$

↓

PRELIMINARY CALCULATIONS

a = λ / ρ c

E = x^2 / (4 a t)

↓

FINAL CALCULATIONS

$$\theta(x, t) = \frac{Q_t}{\rho c (4\pi a t)^{1/2}} e^{-\frac{x^2}{4at}}$$

↓

PRINTINTING OF THE RESULTS OF THE FINAL CALCULATIONS

$$\theta(x, t) = \frac{Q_t}{\rho c (4\pi a t)^{1/2}} e^{-\frac{x^2}{4at}}$$

↓

GRAPH

$$\theta(x, t) = \frac{Q_t}{\rho c (4\pi a t)^{1/2}} e^{-\frac{x^2}{4at}}$$

Figure 2. Structure of the calculus programme used for the modelling of the heat transfer at the vulcanisation of conveyor belts

The preliminary calculated data, needed for the modelling of the heat transfer from the heating plates to the conveyor belt are presented in Table 1, while the initial calculated data are given in Table 2.

Table 1. Preliminary calculated data for the modelling of the heat transfer

Parameter	Formula
A	$a = \lambda / \rho c$
E	$x^2 / (4 a t)$

Table 2. Initial data for the modelling of the heat transfer

Parameter	Symbol
Density	ρ
Specific heat	c
Heat conductivity	λ
Distance x	x
Time	t
Heat flow	Q_0

4 CONCLUDING REMARKS

- the process of joining rubber conveyor belts through vulcanisation is characterised by a very important parameter, namely the vulcanisation temperature;
- in order to obtain a homogeneity of the properties in the joining area of the conveyor belts, it is necessary to provide an even temperature in the whole joining area;
- for the optimisation of the temperature and of the heat distribution in the joining area, it is necessary to realise a modelling of the thermal transfer process, good results being obtained by using the sources method;
- the whole thermal transfer from the heating plates to the conveyor belt is realised through thermal conduction in stationary regime through a wall with constant properties;
- for a correct modelling there need to be taken into account the limit conditions and the initial conditions referring to the distribution of temperature in the conveyor belt and to the heat exchange from the heating plates to the conveyor belt.

5 REFERENCES

►Armăşoiu P., Dobrotă D., Petrescu V. (2013). *Analysis of metallographic structure and hardness of aluminum alloy 3L59 from the structure of vulcanization equipment*, Metalurgija, Vol. 54, No. 3, pp. 547-550

► Dobrotă D., *Adhesion degradation of rubber and steel insert for conveyor belts*, J. of Adh. Science and Technology, Vol. 27. No. 2, pp. 125-135

►Dobrotă D. (2010). *Researches regarding the improvment of the mechanical characteristics of curing bonding of conveyor belts*, Annals of the "Constantin Brancusi" of Targu-Jiu, Engineering series, no. 4, ISSN 1842-4856, pp. 245-256

►Hasan A., Sulistyo R. H., Honggokusumo S. (2013). *Vulcanization kinetics of natural rubber based on free sulfur determination,* Indo. J. Chem., Vol 13, pp. 21-27

►Liang Y-R., Lu Y-L., Wu Y-P, Zhang Li-Q. (2005). *Pressure, the critical factor governing final microstructures of cured rubber/clay nanocomposites*, Micromolecular rapid communications, Vol. 26, No. 11, pp. 926-931,

►Manas D., Stanek M., Manas M., Ovsik M., Pata V., Cerny J. (2011). *Visualization of tire tread behaviour at wear process*, Proceedings of the 22nd International DAAAM Symposium, Vol. 22 pp. 0415 – 0416, (2011)

►Matthias J., Stark W. (2009). *Monitoring the vulcanization of rubber with ultrasound: Influence of material thickness and temperature*, Polymer Testing, Vol. 28 pp. 901-906

►Ovsik M., Manas D., Stanek M., Manas M., Cerny J., Bendarik M., Mizera A. (2011). *The chemical cross-linking or rubber vulcanization is normally induced by the effect of heating after processing with the presence of a curing age*nt, Proceedings of the 22nd International DAAAM Symposium, Vol 22, pp. 1187 – 1188.

6 NOTATION

The following symbols are used in this paper:

Q = heat flow or the amount of energy that traverses an area unit;

dx = gradient of the temperature along the direction x of the flow;

T = temperature;

t = time;

λ_e = conductivity due to the electrons' thermal agitation;

λ_i = conductivity due to the ions' thermal agitation;

λ_l = conductivity due to the thermal agitation of the grain limits and sublimits generated by the propagation of ultrasonic waves.

dt/dx = is the temperature gradient;

θ = temperature;

λ = thermal conductivity;

c = specific heat;

ρ = density;

θ_0 = temperature of the outer environment;

α = convection coefficient;

θ_s = temperature of the body's surface.