EAN 2018
56th conference on experimental stress analysis

Modeling andEexperimental Measurement on Heated Lamination Cylinder for Optimization of Heat Flows

MARTINEC Tomáš[1,a], PETRŮ Michal[1,b] and NOVÁK Ondřej[1,c]

[1] Technical university of Liberec, Studentská 1402/2, Czech Republic

[a]tomas.martinec@tul.cz, [b]michal.petru@tul.cz, [c]novak.ondra1@seznam.cz

Keywords: Heat lamination, numerical modeling, experiment, heat flow

Abstract. Quality and complete distribution of temperature field on the cylinder for lamination is a critical parameter of a lamination process. Currently, this is done by using an infrared tube of the same length as a heated cylinder, heating by the circulating oil or heating segments to achieve a more even temperature distribution on the cylinder surface. However, these solutions do not offer improved energy balances for individual paper widths because heat energy is not transmitted to the surface of the cylinder steadily to the places where it is needed. Based on numerical simulations a working prototype of multi-zone heating system that would allow temperature control for the width of the paper was designed. Experimental measurements were performed on a functional prototype and compared with simulations. The results of numerical simulations, which were influenced by the boundary and initial conditions for non-stationary heat conduction, showed good correlation with experiments.

Introduction

Lamination process is a very old technology, but even older are various technical solutions for a roller heated. The oldest patent of the heated cylinder, which uses hot water as a medium, dates back to 1921 [1]. At present, the laminating rolls for a heating uses mainly resistive, infrareds and induction heating or some suitable medium (e.g. oil). Due to increasing requirements for the quality of heat and reducing of energy consumption, laminating machines constantly need the study of the thermal distribution on the rolls during lamination.

Problems of Modelling and Measurement of Heat Flows on a Heated Roller

The quality of the temperature field distribution on the cylinder is a critical parameter of the lamination process. For optimization purposes, a numerical analysis (Fig.1) of the new prototype heating [2] was performed followed by experiment on the real machine (Fig.2). This is a complex problem where the simulation and the measurement can be divided into static (the cylinder is heated without rotation and temperatures at discrete points are measured) and dynamic (the temperature is measured during production directly on the machine). A numerical model establishing of a model for the study and comparability of heated rollers must be based on the nature of phenomenon that occurs in the cylinder in terms of energy, ie. what is its energy balance. Therefore, the creation of models based on the Fourier law, which is described with parabolic partial differential equation (1).

$$c\rho \frac{\partial T(x,t)}{\partial t} = \lambda \Delta T(x,t) + Q \,. \tag{1}$$

Where: c is the specific heat capacity[J.kg^{-1}.K^{-1}], ρ is a density [kg.m^{-3}], λ is thermal conductivity [W.m^{-1}.K^{-1}], T is temperature [K], Q volume heat source [W.m^{-3}]. To solve the equation (1) it is necessary to introduce initial and boundary conditions for the spatial and time temperature distribution. The solution lies in the determination of boundary conditions (BC) at known temperature distributions at different time levels. Then it is necessary these boundary conditions to verify with the real measurements. The boundary conditions implying a characteristic heat distribution can be defined by the Dirichlet boundary condition, which determines the temperature distribution on the surface of the studied part of the heated cylinder construction, and the Newton boundary condition, which involves the exchange of heat energy between the cylinder and the surrounding environment. For the verification and calibration and experimental comparison of the model a functional prototype of a multi-zone heater was designed and constructed. An experiment on the machine simulating the course of the lamination process consists in heating of the cylinder to the desired temperature, then this temperature is maintained for a certain time period and then the heating is stopped. The heating to the working temperature was the first 2.5 minutes at full power, and then it was controlled manually. The maximum winding temperature during initial heating was 430 °C. For maintain a cylinder temperature of 120° C the power was 40 % and temperature of the winding was 220 °C. After approx. 12 minutes the heating was switched off and the temperature rose for another minute by about 1° C.

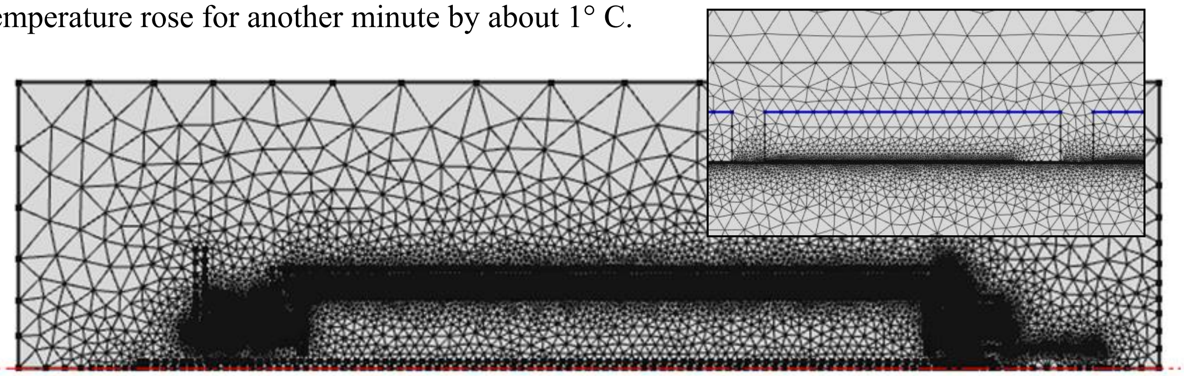


Fig.1: Numerical model of new prototype heating, detail of FE mesh (right)

Fig.2: Experimental measurement (left), measuring device (right)

Results and discussion

Static measurement is simple. The roller does not rotate; there is no need to work with the material (with paper or foil). Only the heating is switched on and the distribution of the temperature is monitored after a heating stabilization. Custom measurements can be performed, for example, by a handheld probe at arbitrarily selected points. The highest temperature is in the middle of the cylinder where the smallest heat dissipation and the accumulation of energy occurs (each point is heated and it has two heated neighbors). On the sides, the temperature decreases and the lowest is at the edge of the cylinder (heat is discharged into the flange). A completely different situation is when the device is operating. The main effect is the removal of heat by the material when the adhesive is activated on the foil (phase transformation occurs). Therefore, temperatures fall in the places that come into contact with the paper that is placed in the foil. Consumed energy must be supplied by the heater to maintain the set setpoint. Therefore, in heated places that are not in contact with the foil (where heat is not consumed) the temperature rises to undesirable values. In practice, the overheated areas of the cylinder, which are near of the working area, cause degradation of the edge of the film. Due to the rotation of the cylinder during dynamic measurements cannot be used the conventional touch sensors. Therefore, the dynamic measurement is currently uncommon and quality of heating is evaluated only indirectly by the quality of lamination. For similar fast temperature measurements in a large area, the thermal camera is very suitable solution. However, the problem is the poorly available curved surface of the cylinder, which is glossy. These are the conditions under which the thermo camera fails. Another possibility is to use the surface of the cylinder as a thermocouple material and to find the corresponding second material to form a sufficiently sensitive thermocouple. This method has been used for example in the automotive industry for the measurement of temperature fields on galvanic molds for the production of artificial skins by Slush technology [3]. The thermocouple is formed between the material of the measured surface and another material that has ideally the known properties in terms of thermoelectric properties depending on temperature. Then just is need to know the temperature and the voltage at one point on the measured object (the reference point) and the other points can be measured with only one wire (so called single-wire thermocouple).

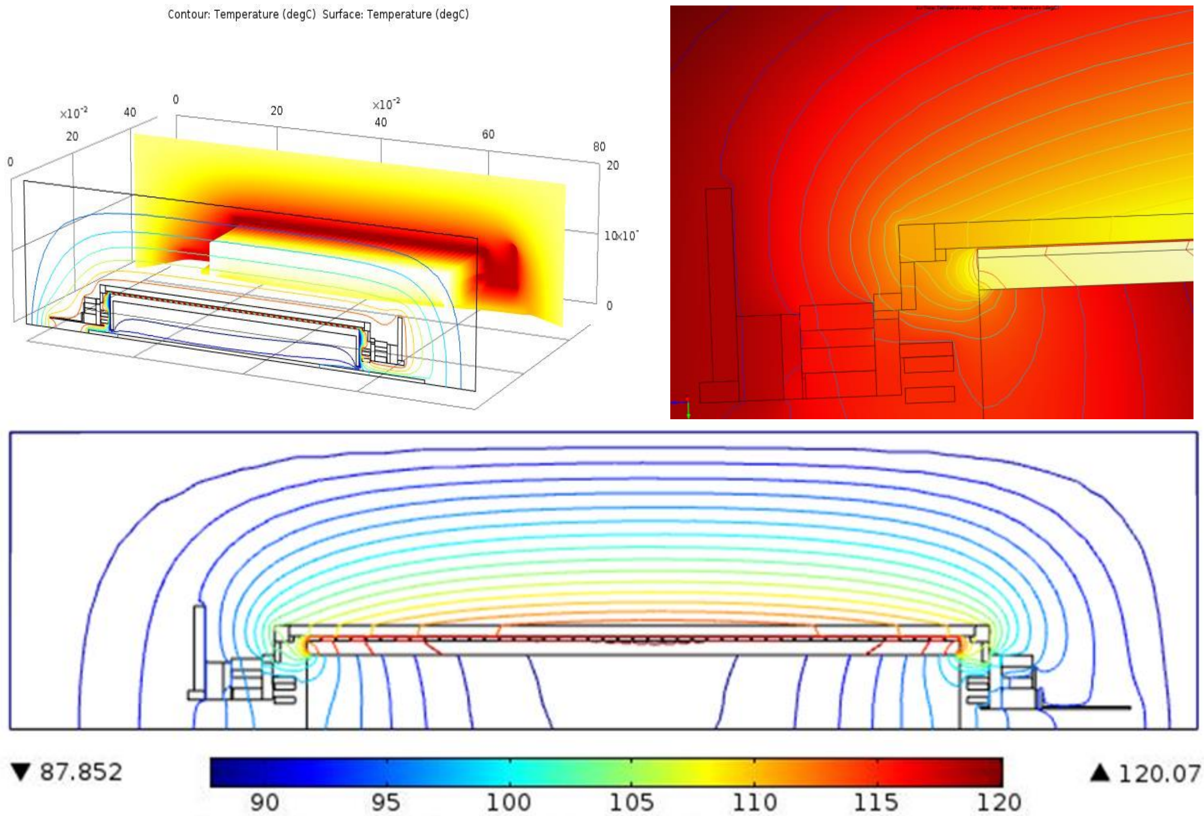
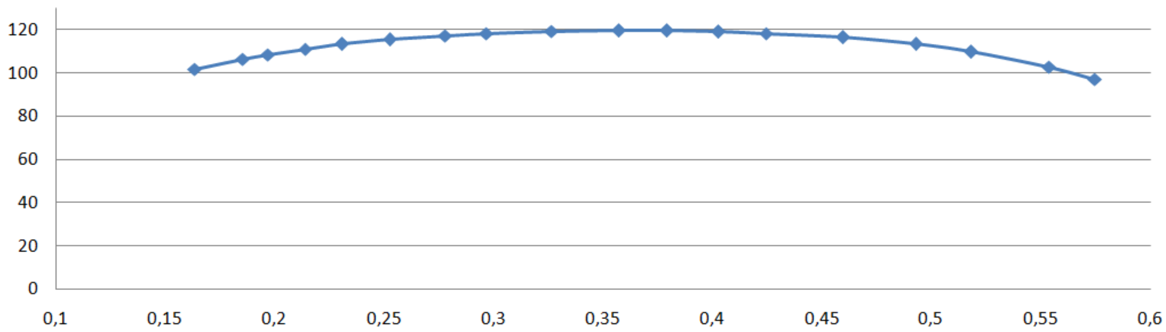


Fig. 3: Numerical model: distribution of the temperature field of a prototype construction.

Experimentally it was shown that the greatest sensitivity to the roller exhibits a negative material from J-type thermocouple. For reliable contact of the measuring wire with the rotating roller, a special caliper was made to hold the wire tensioned by the spring and at the same time with its weight presses the wire to the cylinder. The measured thermocouple voltage then corresponds to the temperature at the point of the contact between the wire and roller. A total 19 calipers were installed. Two of them are at the reference point (positive and negative J wire), other ones are in single-wire measured points. Thus, the total measured points on the cylinder are 18. The calipers are distributed most evenly along the roller, as it allows by the construction of their holders (Fig.2). The data was measured on a slowly rotating roller. The rotation of the cylinder is an interference source, therefore it was necessary to apply the filter with a time constant of 2 seconds. The simulation results are shown in Fig. 3 and the comparison of the temperatures from the numerical simulation and from the experiment are put in Fig. 4.



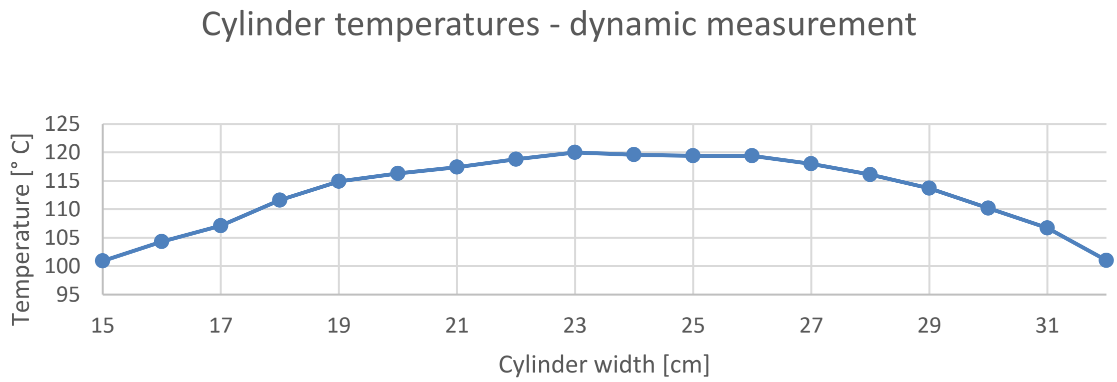


Fig. 4: Temperature distribution on the cylinder surface at dynamic measurement: Numerical model (top), Experiment (bottom).

Conclusions

In the study and modelling of the heating process in laminating machines one of the biggest problems is the measurement of temperature distribution on the cylinder. However, the knowledge of this temperature field is key for a calibrating of mathematical models and subsequently for an evaluating of optimized heating cylinder properties. This article showed one of the possible approaches for the measuring and building the relevant models. Simulation results then show a good agreement with measured data.

Acknowledge

The results of this project No. LO1201 were obtained through the financial support of the Ministry of Education, Youth and Sports, Czech Republic in the framework of the targeted support of the “National Programme for Sustainability I”.

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