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Calculation of the surface temperature of subjected to unilateral heating wood details before their bending

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Abstract: *Calculation of the surface temperature of subjected to unilateral heating wood details before their bending.* A 1D linear mathematical model for the computation of the non-stationary temperature distribution along the thickness of subjected to unilateral heating wood details before their bending has been presented and solved. The model includes a linear version of the partial differential equation of heat conduction with constant initial condition and two types of bondary conditions: from the side of the details' heating – at a prescribed surface temperature, which is equal to the temperature of the metal heating body and from the opposite side – at convective heat exchange between the details' surface and the surrounding air environment.

For the computation of the temperature distribution along the details' thickness at given temperatures of the heating body and of the surrounding air a software program has been prepared in FORTRAN, which has been input in the calculation environment of Visual Fortran Professional. With the help of the program, computations have been carried out for the determination of the 1D temperature distribution along the thickness of spruce details with an initial temperature of 20 ^{o}C, moisture content of 0.15 kg.kg^{-1}, and thicknesses of 6 mm, 8 mm, and 10 mm during their unilateral heating at the temperature of the heating body 100 ^{o}C, 120 ^{o}C, and 140 ^{o}C aimed at plasticizing and bending in the production of stringed music instruments. The obtained results for the details' surface temperature and for the convective heat transfer coefficient are graphically presented and analyzed.

Key words: wood details, unilateral heating, plasticizing, bending, mathematical model, Visual Fortran

INTRODUCTION

An important component of the technologies for production of curved wood details is their plasticizing up to the stage that allows their faultless bending. The duration of the heating of the wood details aimed at their plasticizing before bending depends on many factors: wood specie, thickness and moisture content of the details, temperature of the heating medium, radius of the bending, etc. (Taylor 2001, Angelski 2010, Deliiski and Dzurenda 2010, Gaff and Prokein 2011).

Unilateral heating is applied, for example, in the production of outside parts for the corpses of string music instruments so that they are plasticized before bending. In the practice those details have thicknesses between 5 mm to 10 mm and moisture content around 15%. The technology for plasticizing of such details has been using press equipment with metal band, electrically heated up to the temperature in the range of 100 ºC ÷ 150 ºC (Figure 1).

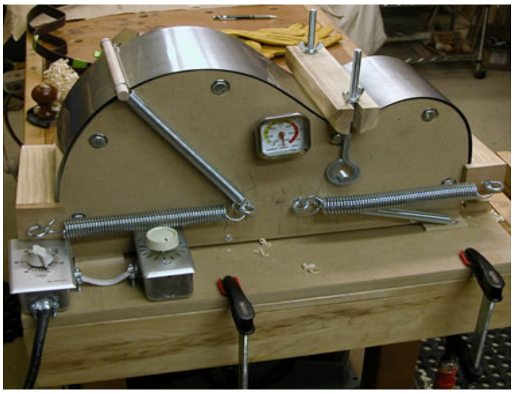

Fig. 1. Equipment with electrically heated band for unilateral heating and bending of flat wood details

The aim of the present work is to present a 1D linear mathematical model for the calculation of the non-stationary temperature distribution along the thickness of subjected to unilateral heating flat wood details and to use this model for calculation of the surface temperature of non-heated sides of spruce details during their plasticizing and bending in the production of outside parts for the corpses of stringed music instruments.

1D MATHEMATICAL MODEL OF THE UNILATERAL HEATING PROCESS OF THE DETAILS

When the width of the wood details exceeds their thickness by at least 3 ÷ 4 times, then the calculation of the change in the temperature only along the thickness of the details during their unilateral heating (i.e. along the coordinate *x*, which coincides with the thickness) can be carried out with the help of the following 1D linear mathematical model (Deliiski 2003):

$$\frac{\partial T(x,\tau)}{\partial \tau} = a(T,u)\frac{\partial^2 T(x,\tau)}{\partial x^2}$$

(1)

with an initial condition

$$T(x,0) = T_0$$

(2)

and following boundary conditions:

• from the side of the heating of the details – at a prescribed surface temperature, which is equal to the temperature of the metal heating body T_{m}:

$$T(0,\tau) = T_{\mathrm{m}}(\tau);$$

(3)

• from the opposite non-heated side of the details – at convective heat exchange between the details' surface and the surrounding air environment

$$\frac{\partial T(X,\tau)}{\partial x} = -\frac{\alpha(\tau)}{\lambda_{\mathrm{s}}(\tau)}\left[T_{\mathrm{a}}(\tau) - T_{\mathrm{s}}(\tau)\right],$$

(4)

where *a* is the temperature conductivity of the details' wood, $m^2.s^{-1}$; *T* – temperature, K; T_0 – initial temperature of the subjected to heating details, K; T_{m} – temperature of the heating metal body, K; T_{s} – temperature on the details' surface at their opposite side during the heating, K; T_{a} – temperature of the air environment near the opposite side during the heating, K; *u* – moisture content of the details' wood, $kg.kg^{-1}$; *x* – coordinate along the thickness of the details: $0 \le x \le X = h$, m; *h* – thickness of the details, m; α – heat transfer coefficient between the details' surface at their opposite side and the surrounding air, $W.m^{-2}.K^{-1}$; λ_s – thermal conductivity of the details' wood on the surface at the non-heated side of the details, $W.m^{-1}.K^{-1}$; τ – time, s.

The opposite side of the details is subjected to cooling in atmospheric conditions of free convection during the heating. For the calculation of the heat transfer coefficient in such conditions of cooling of horizontally situated plates Chudinov (1966) suggests the following equation:

$$\alpha = 3.256\left[T_{\mathrm{s}}(\tau) - T_{\mathrm{a}}(\tau)\right]^{0.25}.$$

(5)

The meaning of the variables in equation (5) has been explained above.

COMPUTATION OF THE 1D CHANGE OF THE TEMPERATURE IN SUBJECTED TO UNILATERAL HEATING SPRUCE DETAILS

The mathematical model, which is presented in common form by the eqs. (1) ÷ (5), has been solved with the help of explicit schemes of the finite difference method. This has been done in a way, analogous to the one used and described in (Deliiski 2003, Deliiski and Dzurenda 2010) for the solution of a model of the heating process of prismatic wood materials. For the solution of the model a software program has been prepared in the calculation environment of Visual Fortran.

With the help of the program computations have been made for the determination of the 1D change of the temperature in subjected to unilateral heating non-frozen spruce (*Picea Abies Karst*) details with thicknesses equal to h = 6 mm, h = 8 mm, h = 10 mm, initial wood temperature equal to t_0 = 20 °C, and wood moisture content equal to $u = 0.15$ kg.kg^{-1} during their 10 min unilateral heating at t_m = 100 °C, t_m = 120 °C, t_m = 140 °C, and t_a = 20 °C.

The computations have been done with average values of the wood temperature conductivity cross-sectional to the fibers, a_c, and of the wood thermal conductivity cross-sectional to the fibers of the spruce details, λ_c, which have been obtained using the mathematical description of a_c and λ_c depending on the temperature, wood moisture content and fiber saturation point of the wood species (Deliiski 2003, 2013, Deliiski and Dzurenda 2010). The calculated values of a_c and λ_c for spruce wood with $u = 0.15$ kg.kg^{-1} and fiber saturation point $u_{fsp} = 0.32$ kg.kg^{-1} (Videlov 2003) in the temperature ranges from 20 °C to 100 °C, to 120 °C, and to 140 °C, are shown in Table 1.

Table 1. Change in a_c and λ_s of spruce wood with $u = 0.15$ kg.kg^{-1}, depending on t (acc. to Deliiski 2003)

Parameter of the wood	Temperature t, °C				Average values of λ_c and a_c for the ranges		
	20	60	100	140	t = 20÷100 °C	t = 20÷120 °C	t = 20÷140 °C
λ_c, W.m^{-1}.K^{-1}	0.2341	0.2664	0.2987	0.3311	0.2664	0.2745	0.2826
$a_c \cdot 10^7$, m^2.s^{-1}	2.5799	2.7412	2.8818	3.0052	2.7309	2.7627	2.7926

Figure 2 presents the constant temperatures of the heating body t_m = 100 °C and t_m = 140 °C, which have been entered based on the input data used for the solution of the 1D model. This figure also shows the calculated by the 1D model change of the temperature on the details' surface t_s during the unilateral heating of details with thicknesses h = 6 mm, h = 8 mm, and h = 10 mm.

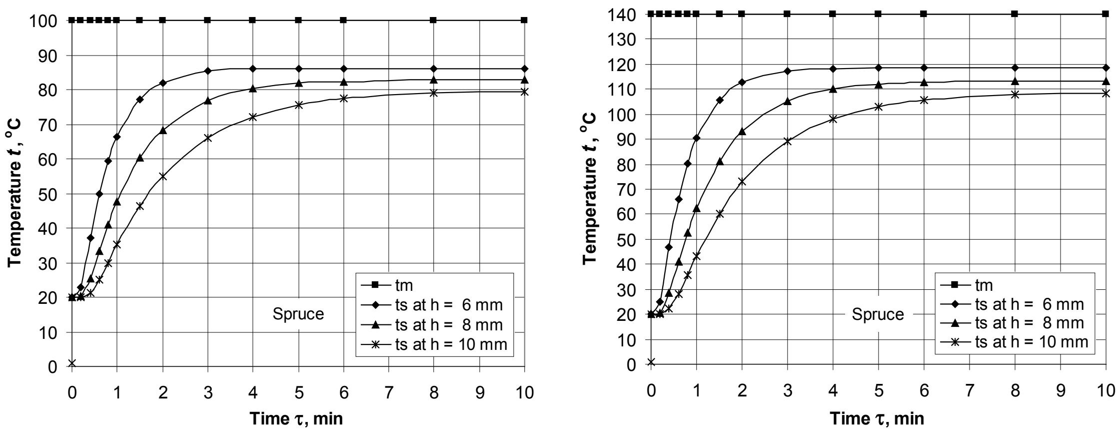

Fig. 2. Change in t_s of spruce details with t_0 = 20 °C and u = 0.15 kg.kg^{-1} during their unilateral heating
at t_m = 100 °C (left), t_m = 140 °C (right) and t_a = 20 °C, depending on h

On Figure 3 the calculated by equation (5) change of the heat transfer coefficient between the details' surface at their non-heated sides and the surrounding air, α, during the unilateral heating of details with studied thicknesses h = 6 mm, h = 8 mm, and h = 10 mm is shown.

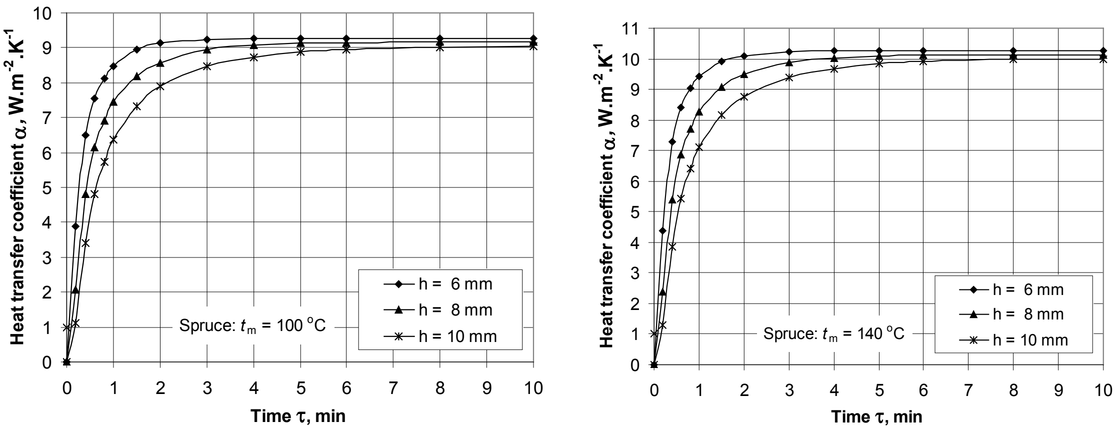

Fig. 3. Change in α during the unilateral heating at t_m = 100 °C (left), t_m = 140 °C (right) and t_a = 20 °C of spruce details with t_0 = 20 °C and u = 0.15 kg.kg^{-1}, depending on h

The obtained results show that through unilateral heating of details the non-stationary change of the temperature t_s and of the heat transfer coefficient α go on according to complex curves, which are very similar to each other. By increasing the heating time the temperature t_s and the coefficient α gradually approach asymptotically their biggest values, decreasingly dependent on the details' thickness. Those biggest values of t_s and α are achieved when a stationary temperature distribution occurs along the details' thickness.

The stationary temperature distribution along the thickness of the studied spruce details (with precision of up to –0.2 °C) occurs upon reaching the following temperature at their non-heated side:

- for details with h = 6 mm: 86.0 °C at t_m = 100 °C and α = 9.28 W.m^{-2}.K^{-1}, 102.7 °C at t_m = 120 °C and α = 9.82 W.m^{-2}.K^{-1}, and 118.5 °C at t_m = 140 °C and α = 10.26 W.m^{-2}.K^{-1};
- for details with h = 8 mm: 82.7 °C at t_m = 100 °C and α = 9.16 W.m^{-2}.K^{-1}, 98.0 °C at t_m = 120 °C and α = 9.67 W.m^{-2}.K^{-1}, and 113.3 °C at t_m = 140 °C and α = 10.12 W.m^{-2}.K^{-1};
- for details with h = 10 mm: 79.7 °C at t_m = 100 °C and α = 9.05 W.m^{-2}.K^{-1}, 94.2 °C at t_m = 120 °C and α = 9.55 W.m^{-2}.K^{-1}, and 108.7 °C at t_m = 140 °C and α = 9.98 W.m^{-2}.K^{-1}.

CONCLUSIONS

The present paper describes a 1D linear mathematical model for the calculation of the non-stationary temperature distribution along the thickness of subjected to unilateral heating flat wood details. A software program has been prepared in the calculation environment of Visual Fortran for the numerical solution of the model at given temperatures of the heating body and of the surrounding air. Using this program, computations have been carried out for the determination of the change in the temperature of the non-heated surface and of the heat transfer coefficient between this surface and the surrounding air of spruce details with an initial temperature of 20 ^oC, moisture content of 0.15 $kg.kg^{-1}$, and thicknesses of 6 mm, 8 mm, and 10 mm during 10 min of their unilateral heating at t_m equal to 100 ^oC, 120 ^oC, 140 ^oC and at t_a = 20 ^oC in the production of outside parts of the corpses of string music instruments so that they are plasticized before bending.

ACKNOWLEDGEMENT

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REFERENCES

1. ANGELSKI, D., 2010: Researches over the processes of plastisization and bending of furniture wood details. PhD Thesis, University of Forestry, Sofia, 2010 (in Bulgarian).
2. CHUDINOV, B. S., 1966: Theoretical research of thermo physical properties and thermal treatment of wood. Dissertation for DSc., SibLTI, Krasnoyarsk, USSR (in Russian).
3. DELIISKI, N., 2003: Modeling and technologies for steaming of wood materials in autoclaves. Dissertation for DSc., University of Forestry, Sofia (in Bulgarian).
4. DELIISKI, N., 2013: Computation of the wood thermal conductivity during defrosting of the wood. Wood Research, 58 (4): 637-650.
5. DELIISKI, N., DZURENDA, L., 2010: Modelling of the thermal processes in the technologies for wood thermal treatment. TU Zvolen, Slovakia, 2010 (in Russian).
6. GAFF, M., PROKEIN, L., 2011: The influence of selected factors on coefficient of bendability. Annals of Warsaw University of Life Sciences, Forestry and Wood Technology, № 74: 78-81.
7. TAYLOR, Z., 2001: Wood bender's handbook. Sterling Publ. Co., Inc., New York.
8. VIDELOV, H., 2003: Drying and thermal treatment of wood, University of Forestry, Sofia, Bulgaria, 2003 (in Bulgarian).

Streszczenie: *Obliczanie temperatury drewna, jednostronnie grzanego przed gięciem.* Zaproponowano liniowy model matematyczny rozkładu temperatury drewna jednostronnie ogrzewanego, przed procesem gięcia. Model zawiera liniową wersję równań różniczkowych przewodności cieplnej pomiędzy ośrodkami granicznymi –ogrzewającym drewno elementem grzejnym, drewnem a otaczającym z drugiej strony powietrzem. W środowisku fortran przeprowadzono symację rozkładu temperatury ogrzewanego drwna świerkowego, przeznaczonego na instrumenty muzyczne, o temperaturze wyjściowej 20 ^{o}C, wilgotności 0.15 kg.kg^{-1}, grubościach 6 mm, 8 mm, I 10 mm podczas jednostronnego grzania uplastyczniającego okładzinami o temperaturze 100 ^{o}C, 120 ^{o}C, i 140 ^{o}C.

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