THE STUDY OF THE CORRELATION BETWEEN THE VARIATION OF SOME THERMO-PHYSICAL CHARACTERISTICS AND THE HEATING TIME OF SOME STEELS.

V. Caţarschi
Technical University „Gh. Asachi" of Iaşi

1. INTRODUCTION

The determination of some PC assisted modern heating technologies for heating the massive steel products (ingots, mill rolls etc.) in view of the plastic deformation or of the heat treatments (annealing, hardenings), is based on mathematical modelling of the heat exchange within the metal. The analytical method used in this respect is based on the sum of Bessel – Fourier infinite sequences (Heiligenstaedt Method) and Biot, Fourier dimensionless criteria, criterion of surface Φ_s and of centre Φ_c.

To be explicit where **λ**, **c** and **a** physical characteristics are involved in the analytical relations of determination of surface $T_{surf.n}$ and of $T_{centr.n}$ centre temperatures for a heated mill roll with equivalent radius R, for the heating mode $T_{furn.n}$ = const., in the conditions when the initial thermal gradient is $\Delta T_0 \neq 0$, the following relations are given:

$$T_{s.n.} = T_{cupt.0} + (T_{s.0.} - T_{cupt.0})\sum_{n=1}^{\infty} M_n J_0(z_n) e^{-z_n^2 Fo} \quad (1)$$

$$T_{c.n} = T_{cupt.0} + (T_{s.0} - T_{cupt.0})\sum_{n=1}^{\infty} M_n e^{-z_n^2 Fo} - \Delta T_0 \sum_{n=1}^{\infty} W_n e^{-z_n^2 \cdot Fo} \quad (2)$$

where: $M_n = \dfrac{2J_1(z_n)}{z_n[J_0^2(z_n) + J_1^2(z_n)]}$ and

$$W_n = \frac{4J_2(z_n)}{z_n^2[J_0^2(z_n) + J_1^2(z_n)]} \quad (3)$$

$J_0(z_n)$; $J_1(z_n)$; $J_2(z_n)$ – Bessel function of 0; 1; 2 order and argument z_n;

$$\frac{J_0(z_n)}{J_1(z_n)} = \frac{z_n}{hR} \qquad n = 1, 2, \ldots, \infty \quad (4)$$

$z_n = m_n R$ are the solutions of the transcendent equation (4) for n = 1, 2, …, ∞.

R – equivalent radius of the mill roll, in mm

$h = \dfrac{\alpha}{\lambda}$ - the relative coefficient of thermal transfer of the steel;

α - heat passing coefficient at the surface of the metal;

λ - thermal conductivity coefficient at the surface in the metal;

$F_0 = \dfrac{a \cdot \tau}{R^2}$ - Fourier's criterion of metal heating;

$a = \dfrac{\lambda}{c \cdot \gamma}$ - thermal diffusivity coefficient;

c – specific heat of heated steel;

τ - heating time, in hours;

γ - specific weight of the metal, depending on its chemical composition;

hR = Bi – Biot's criterion of the metal heating.

In the case of re-heating the massive half–hot products ($T_{centr.0} > T_{surf.0} > 850^0$C), most of the steel brands have an austenitic structure and **λ, c** and **a** coefficients varies with temperature within reduced relative limits. Thus, in calculations for this case can be used constant values for **λ, c** and **a** coefficients.

In the case of heating the cold massive products ($T_{surf.0} = T_{centr.0} = 20^0$C) made of carbon steels and low-alloy steels, the variation of **λ, c** and **a** coefficients with temperature, becomes very important, at the sometime with the thermal gradient:

$\Delta T = T_{surf.} - T_{centr.}$

2. EXPERIMENTAL METHODS

The variation of **λ, c** and coefficients provided by various bibliographical sources are showed in Figure 1, 2, 3, 4, 5 and 6, [3].

In Fig.1 we can see within the 720 – 815^{0}C temperature range an increase in thermal capacity is characteristics, determined by a heat accumulation due to the structural transformation.

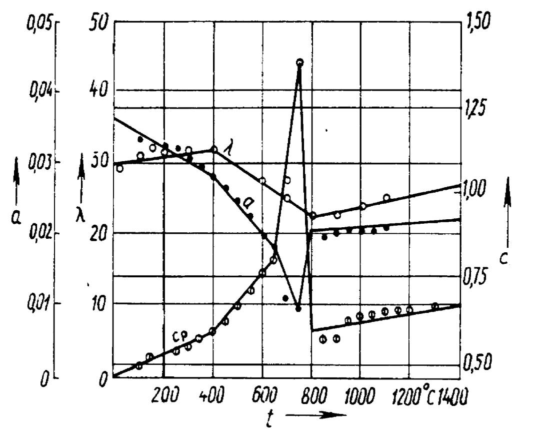

Figure1 Variation of thermo– physical characteristics **λ[W/(mK)], c[kJ/kgK]** and **a[m²/h]** for 13CrNi30 steel [3].

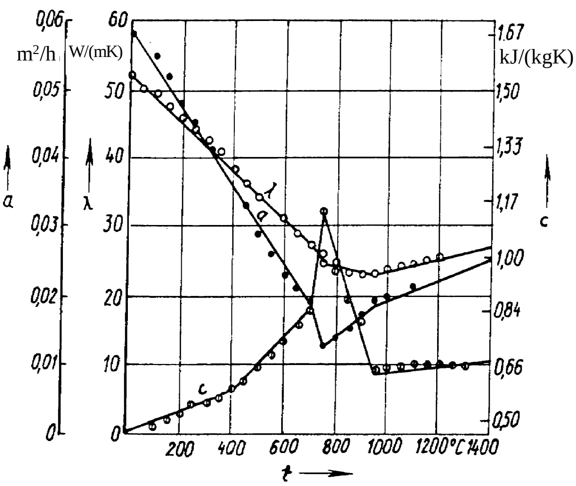

Figure 2. Variation of thermo– physical characteristics **λ[W/(mK)], c[kJ/kgK]** and **a[m²/h]** for OLC10 steel [3].

Experimental determination of **λ, c** and **a** characteristics is accomplished by the methods [2]:

- the thermal conductivity **λ**:

  - between 20-800°C the specific resistance ρ is being measured and **λ=LT/ρ** (L - Lorenz number, T - temperature) with an error less than 13%.

  - between 800-1200°C is being determined with the relation **λ = acD** (D - density), with an error less than 14%.

- the specific heat **c**:

  - between 20-800°C is being measured by calorimetric methods, with an error less than 10%.

  - between 800-1200°C is being measured by means of thermal radiation variations, with an error less than 4%.

- the thermal diffusivity **a**:

  - between 20-800°C is being determined with relation **a = λ /(cD)** with an error less than 16%.

  - between 800-1200°C the thermal radiation variation is being measured, with an error less than 10%.

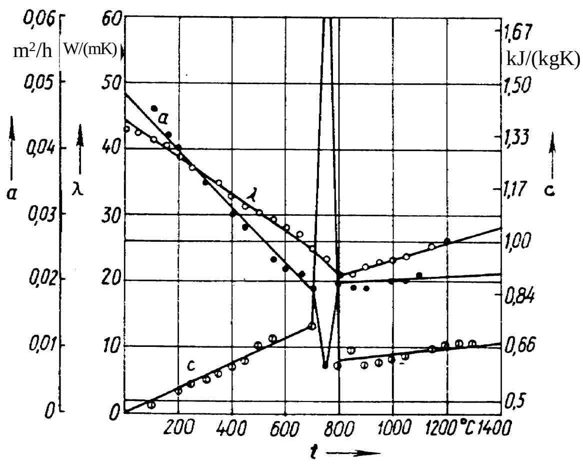

Figure 3. Variation of thermo– physical characteristics **λ[W/(mK)], c[kJ/kgK]** and **a[m²/h]** for OSC8 steel [3].

The influence of **λ, c** and **a** coefficients value on the heating technology of some PC assisted mill rolls, for homogenisation annealing, is shaved in Figure 7 and Figure 8, [7].

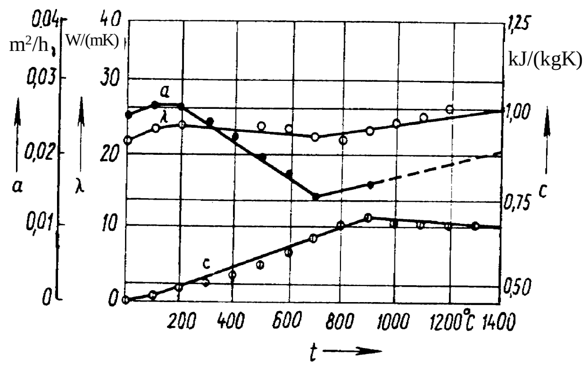

Figure 4. Variation of thermo– physical characteristics **λ[W/(mK)], c[kJ/kgK]** and **a[m²/h]** for 30Cr130 steel [3].

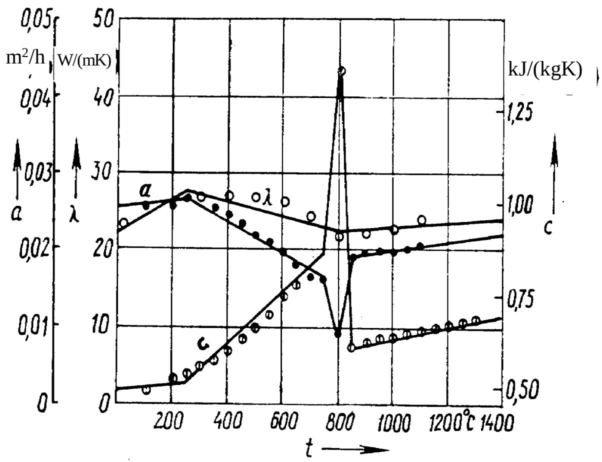

Figure 5. Variation of thermo– physical characteristics **λ[W/(mK)], c[kJ/kgK]** and **a[m²/h]** for 51Si17A steel [3].

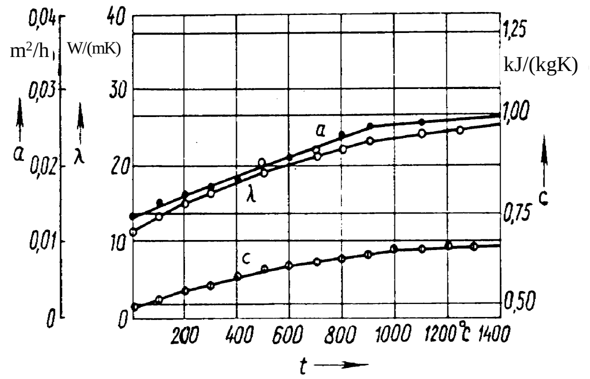

Figure 6. Variation of thermo– physical characteristics **λ[W/(mK)], c[kJ/kgK]** and **a[m²/h]** for 10TiNiCr180 steel [3].

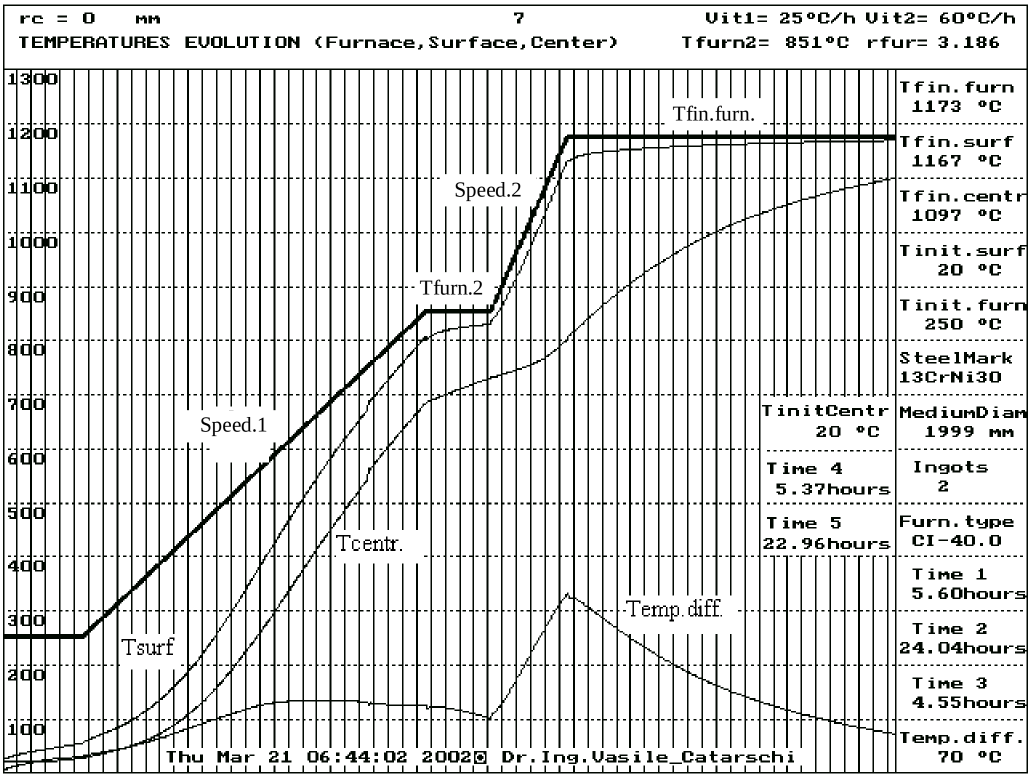

Figure 7. The heating technology of cold ingots after the data from [1]. Integral time 60.52 hours. [7].

3. CONCLUSIONS

The thermo-physical characteristics of steels depends on the temperature, chemical composition and their structure.

For big size parts, as are the steel ingots for forging, the influence of thermal conductivity (**λ**) and of specific heat (**c**) is essential both in the first stage of heating (T_{centre} <1050K), and in the second stage of heating (T_{centre} >1050K) after the finish of structural changes in the steel.

The use of some mathematical relations for determining **λ, c** and **a** values is not valid in the entire temperature range (0…1200^{0}C) and for a large number of steel brands. Therefore, for a higher accuracy of the calculations o PC designed technological diagrams, it is better to use experimentally determined values for **λ, c** and **a** coefficients.

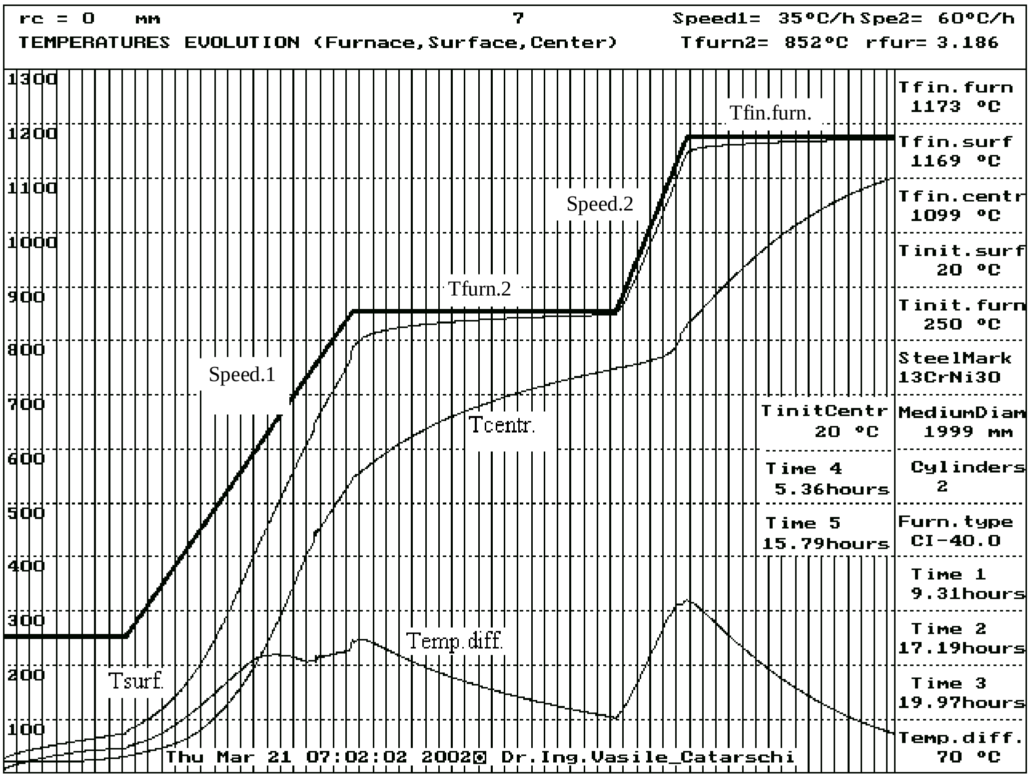

Figure 8 . The heating technology of cold ingots after the data from [3]. Integral time 67.62 hours. [7].

For austenitic steel which have not structural transformation in the 273…1000K range, it is possible the heating calculation using the average values of the thermal range for **λ, c** and **a**.
The values of [1] determine significant increases of the total heating time compared to [2] and [3] (Figure 7 and Figure 8), which is errant and uneconomical in industrial practice.

The diminishing of values for **λ** and **c** with 15 or 30% leads at a visible decreasing of ingots heating in the last stage of heating, at temperatures over 1050K:the temperature in the centre of the ingots "delays" with 45-60K by comparison with the steel with the unchanged values.

Bibliography

1. Mitelea, I., Budau, V. *Studiul metalelor - Indreptar tehnic. Editura "Facla", Cluj, 1987.*

2. Nemzer, G.G. *Teplovie protessy proizvodstva crupnyh pocovoc. Masinostroenie, Leningrad, 1979.*

3. Samoilovici, Iu. A., Timospolskii, V. I. *Nagrev stali:Spravocinoe posobie. Vissaia scola. Minsk, 1990.*

4. Catarschi, V., Ciochina, C., Simionescu, A.- *Contributions to Computer Mathematical Adaptation of the Heating Technologies of Flaw Susceptible Steel Ingots. Buletinul Institutului Politehnic Iasi, Tomul XL (XLIV), Fasc.3-4/1994, sectia IX, pag.704-712.*

5. Catarschi, V., Dima, A, Dănilă, R.& Baciu, M. *Contribution to the Computer Assisted Determination of the Admissible Heating Rate of the Steel Ingot Initially Cold in Forging Furnace. "Metal'2001", The 10th International Metallurgical Symposium, 15…17 May 2001, Ostrava, Czech Republic, pag.2.*

6. Cojocaru, M. *Procese de transfer de energie şi de masă la tratamente termice şi termochimice. I.P.Bucureşti, 1984.*

7. Catarschi, V. *Contribuţii privind modernizarea tehnologiilor de încălzire a unor oteluri susceptibile la fisurare in vederea deformării plastice ulterioare. Teza de doctorat. Universitatea Tehnica „Gh.Asachi", Iasi, 1996.*

8. Roman, E. Maeder. *Programming in Mathematica. Addison Weslei Publishing Company, Redwood City, California, U.S.A., 1991.*