# MODELING AND INVESTIGATION OF HEAT TREATMENT PROCESSES BY FINITE ELEMENT METHOD

Dr. Eng.Shtarbakov V.
„Metal" PLC,Varna, Bulgaria

***Abstract:*** *This paper discusses an optimization method to derive the phase transformation kinetics parameters in heat treatment processes such as quenching. Quenching is a heat treatment process used to improve the mechanical properties of steels. It is consists of raising the steel temperature above a critical value, called austenitizing temperature, and then rapidly cooling it bellow temperature of phase transformation. The resulting microstructures formed in quenching process (ferrite, pearlite, upper bainite, lower bainite and martensite) depend from cooling rate and steel characteristics.*

*By numerical simulation, using finite element method, is possible to be predicted evolution of microstructural changes in order to calculate the mechanical properties of treated steels.*

***Key words:*** *FINITE ELEMENT METHOD; QUENCHING; AUSTENITIZING;RESULTING MICROSTRUCTURE;*

## *1. Introduction*

Steel hardness penetration is the ability of steels to be in-depth quenched. One of the most commonly used methods of investigation is Jomini's. What steel hardness penetration depends on is the chemical structure of steel which determines both its ability to be quenched and its physical properties affecting the mass- and heat-transfer processes. On the other hand, the most important technological parameters influencing steel hardness penetration in a given chemical structure of the steel are the heating temperature (austenitizing temperature), the cooling medium, the temperature and the geometrical form of the part and the type of interaction between the quenching medium and the specimen.

Jomini's method comprehensiveness results in its extensive application for hardness penetration determination. The most important factors such as material heat conduction and the way the heat transfer with the cooling fluid takes place are under control with this method [1]. At the same time, it poses some restrictions in terms of the type of the cooling fluid used leading to the creation of other methodologies presented most comprehensively in [2]. The purpose of the paper is to present a methodology for determining steel hardness penetration comparable with Jomini's method but taking into account the type of the cooling medium and its effect on the process.

## *2. Methodology*

To assess the influence of the cooling medium upon the dynamic change in temperature in each point of the specimeninvestigated, it is necessary to solve the differential equation of heat conduction (1) at given initial and boundary conditions for this particular case:

$$(1), \quad \frac{\delta T}{\delta t} = a\left(\frac{\delta^2 T}{\delta r^2} + \frac{1}{r}\frac{\delta T}{\delta r} + \frac{1}{r^2}\frac{\delta^2 T}{\delta \varphi^2} + \frac{\delta^2 T}{\delta z^2}\right) + h(T_s - T) + q_0$$

where $r$ is a radius-vector; $T$ – temperature; $h$ – heat transfer coefficient; $q_0$ – heat flux; $t$ – time; $a$ – coefficient of thermal conductivity; $Ts$ – external temperature . As an initial condition we assume uniform temperature distribution throughout the solid (2):

$$(2), \quad T(r,\tau) = T_0 = const$$

The boundary conditions are set by the dependence (3):

$$(3), \quad \lambda_c\left(\frac{\delta T}{\delta n}\right)_s = \alpha\left(T_s - T\right)$$

representing the equation between the convection heat transfer and the heat conduction on the surface of the solid.

Expression (4) gives the solution to the differential equation (1) at an initial condition (2) and a boundary condition (3):

$$(4), \quad \vartheta = \theta_0 f\left(F_0; B_i; \frac{x}{l}\right)$$

where:

$$\theta = T_s - T$$

$$\theta_0 = T_{0,s} - T$$

$$F_0 = \frac{at^2}{l} \quad \text{- Fourier criterion;}$$

$$B_i = \alpha\frac{\delta}{\lambda} \quad \text{- Biot criterion;}$$

$$\frac{x}{l} \quad \text{- dimensionless value;}$$

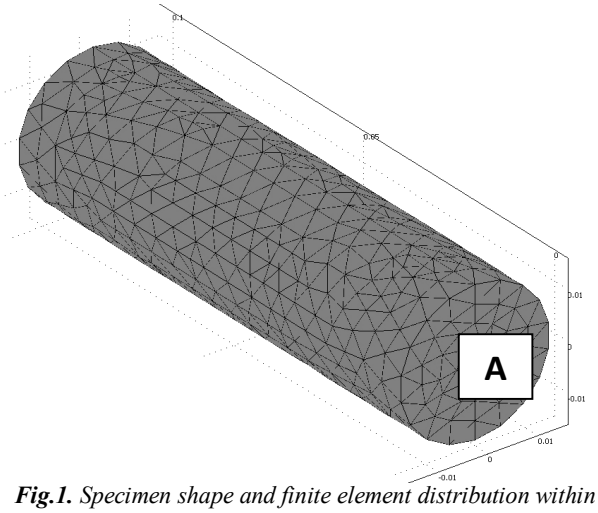


***Fig.1.*** *Specimen shape and finite element distribution within its volume*

The numeric solution to the task is accomplished by using COMSOL software product [3].

A specimen of the dimensions ø30x100mm divided into 16,000 finite elements has been analyzed (fig. 1). Thermal and physical characteristics corresponding to steel 45 have been set to the specimen. These have been taken from [4].

In the area of the front surface "A" (fig.1.)streamlining with a cooling fluid was set for 600 sec., the same operation being accomplished in the standard test by means of Jomini's method. The solution to the task under the initial and boundary conditions given is presented in fig. 2 in relation to time.

Equation (1) and its solving by the finite element method have some limitations in each particular case indicated in papers [5, 6, 7, 8]. It is necessary to show the restrictions for this particular case as well. They are as follows: presented is a solution for a solid of the dimensions given above; the same solution but for a different solid will be limited by the type and the form of the latter and by the possibility of setting the coefficient of heat transfer between the body surfaces and the cooling medium; we assume that heat dissipation by radiative heat transfer in the environment is negligible; the solid is homogenous, internal sources of heat are missing.

## *3. Results and discussion*

Fig. 2 shows the temperature changes in the specimen in relation to time for a period of 0-600 sec. within the whole volume of the specimen under the boundary conditions and the thermal and physical characteristics corresponding to steel 45 discussed in Part 2 Methodology. A model of front water cooling is presented simulating investigation of heat penetration by Jomini's method. Taking into account the initial and the boundary conditions

presented it can be seen that the heat flow is directed towards the surfacestreamlined with the cooling fluid. The flow (fig. 3 – a, b, c, d) has the highest values in the points which are closer to the surface cooled. This holds true even to a greater degree for the temperature gradient (fig. 4 – e, f, g, h). All the above is accompanied by a high speed of cooling the specimen part which is close to the boundary surface cooled by the fluid streamliningit. This is proved by the time-temperature graphs (fig.5.) of points located along the specimen axis at a certain distance to the surface under observation.

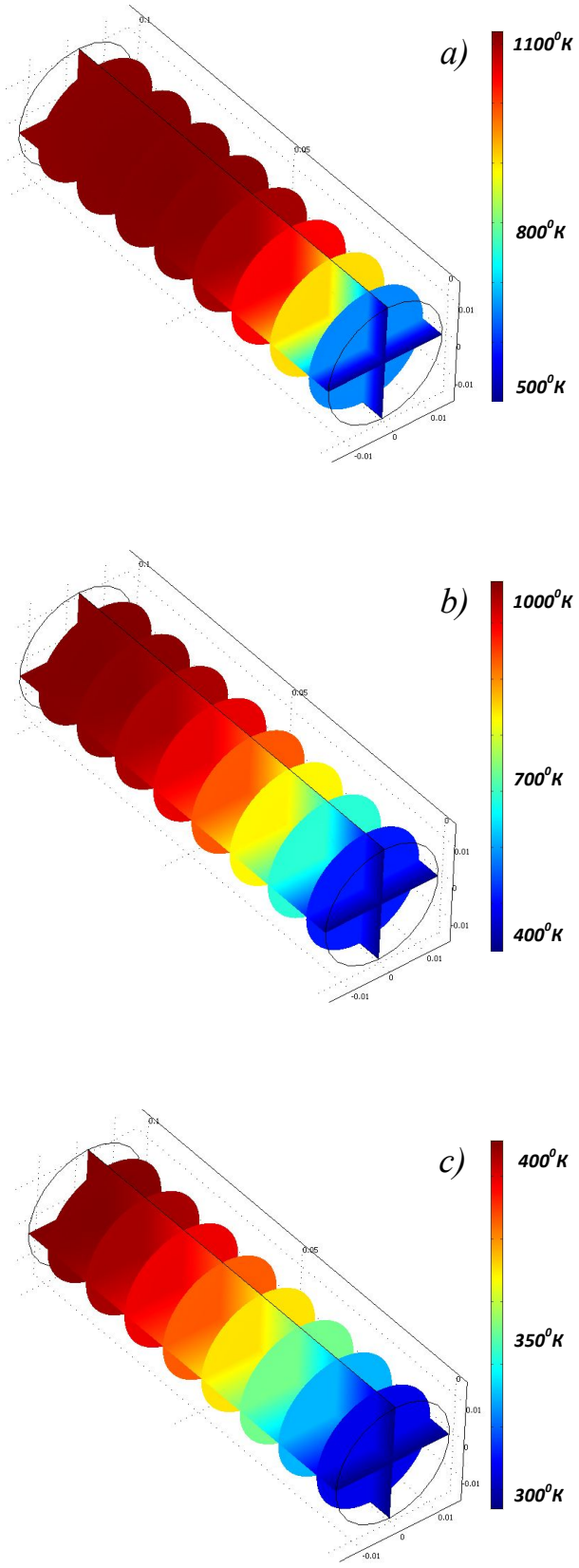


***Fig.2.****Temperature distribution in the specimen volume with relation to time: 20 s-(a); 60 s- (b); 600 s- (c).*

Comparing these results with the diagram of the isothermal conversion of austenite into steel 45 (fig.6.), it is necessary to consider some peculiarities.

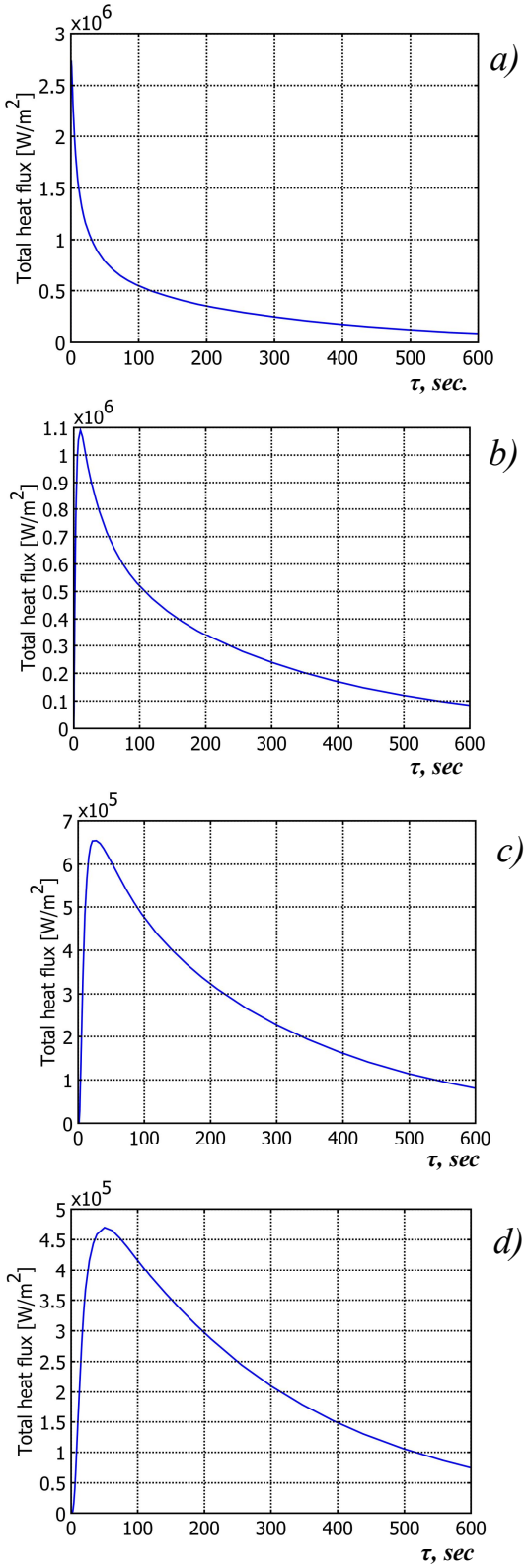


***Fig.3.****Heat flow changes (a, b, c, d) in points along the specimen axis depending on the distance to the surface cooled.*
*a) 1mm;b)10mm;c)20mm;d)30mm;*

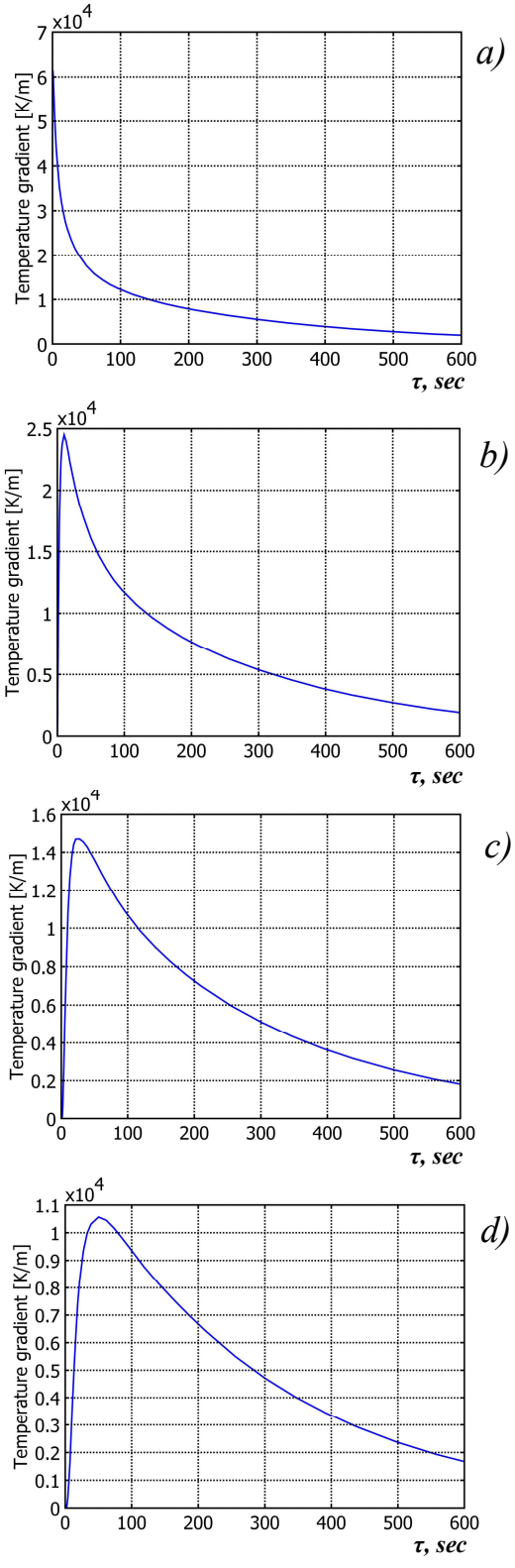


***Fig.4.****Temperature gradient change in points along the specimen axis depending on the distance to the surface cooled.*
*a)1mm;b)10mm;c)20mm;d)30mm*

It is obvious that all points located along the specimen axis at a depth of up to 10-20 mm can betransformed at the required speed of the interval of lowest austenite phase stability. This makes it possible polymorphic transformation to occur in this area. This result is absolutely comparable with the heat penetration of steel 45 specimen presented here [10] and actually determined by Jomini's method. The methodology for heat penetration by the finite element method presented in the paper features a great advantage, namely that it is really possible to be applied to any working medium about

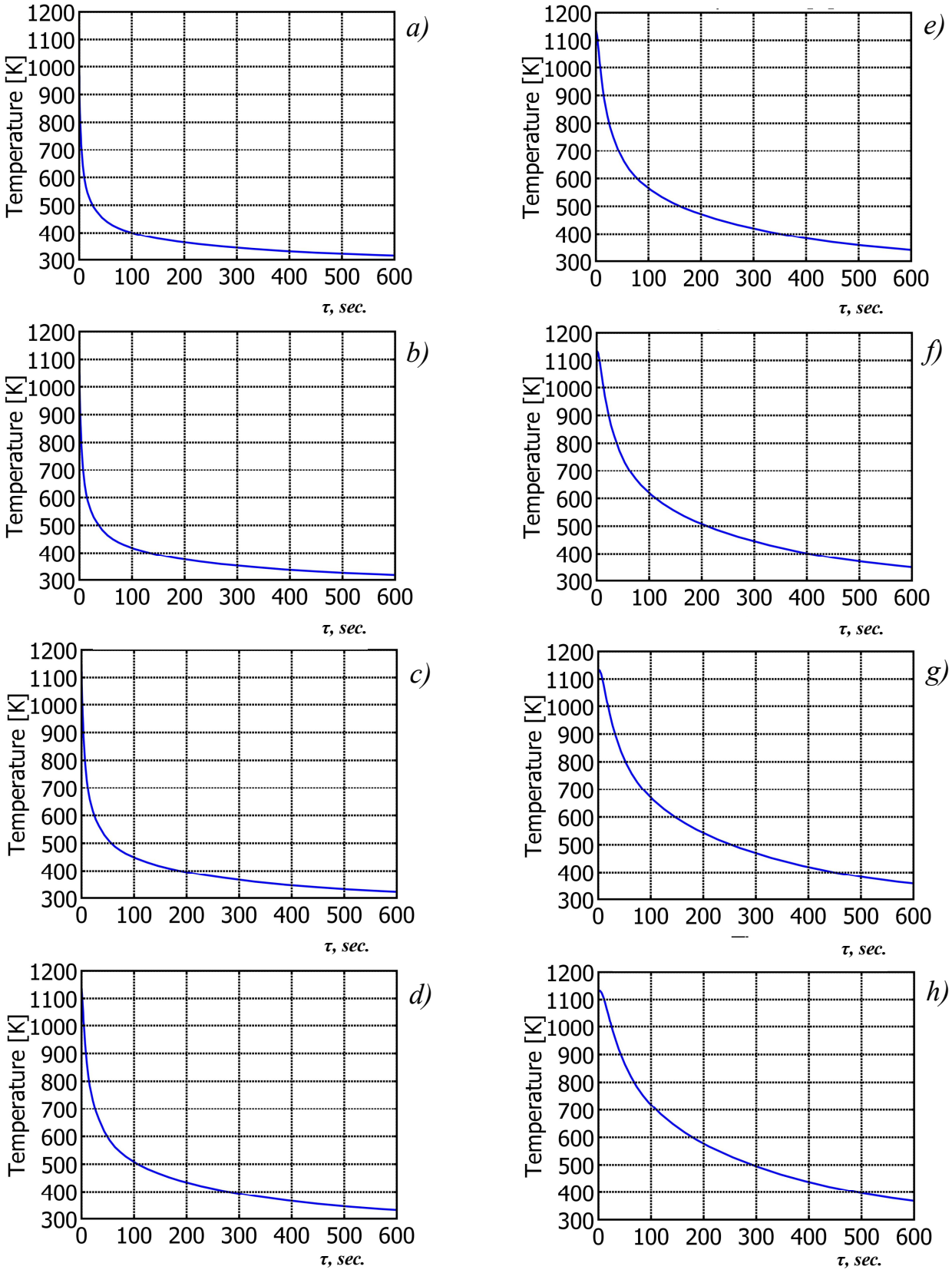


***Fig. 5.****Time-temperature graphs of specimen points located at various distances to the surface cooled. a) 1mm; b) 2.5mm;c) 5mm; d) 10mm;e) 15mm;f) 20mm;g) 25mm;h) 30mm;*

which the coefficient of convection heat transfer is known. The only limitation is the determination of the boundary condition since this coefficient, apart from everything else, depends also on the geometrical form of the specimens.

### *4.Conclusions*

A methodology for investigation and determination of steel heat penetration, as well as of thermokinetic parameters of heat treatment

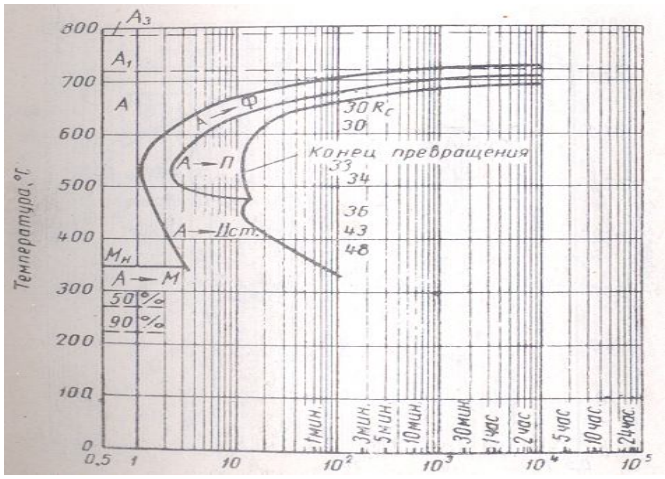


***Fig.6.****Diagram of isothermal austenite conversion [9].*

processes (quenching) has been developed with the help of the finite element method. This methodology takes into account both the heat transfer inside the material irrespectively of its type and the type of the cooling fluid. This provides the opportunity for investigating the quenching process and the Fe-C alloys heat penetration in particular, taking into account the cooling ability of the medium.

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