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Modern gas quenching chambers supported by SimVaCPlus™ expert system

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Abstract

A progress in the field of thermo-chemical and thermal treatments during last years brought the necessity of methods development which improve the construction of furnaces and devices in order to fulfill high requirements. The thermal-flow phenomena analysis in the furnace chamber during charge cooling in gases under high pressure is presented in this paper. The parameters, having influence on cooling rate i.e. furnace chamber geometry, gas pressure, gas flow velocity and configuration of the charge have been analyzed.

Obtained results and acquired during experiments knowledge allowed elaboration of hardness profiles after gas quenching application.

Computer simulation contains the furnace chamber definition option and charge pieces definition procedure leading to decrease of calculation and selection time of the process parameters. Moreover, the application is the essential part of expert system SimVaC™ for optimal process course selection

Keywords

Quenching, carburizing, simulation, hardness

1 Introduction

Vacuum carburizing with quenching in gases under high pressure is one of the most modern and widely applied process in industry. Critical parameters deciding about carburized charge properties after quenching are: cooling efficiency (dependent on the type of cooling media, pressure and velocity of gas flux), chemical composition and thermal properties of treated element , transformations during cooling and arising internal stresses.

The CFD (Computational Fluid Dynamics)[AEA Technology, 1999] software was used to describe phenomena connected with heat transfer during heat treatment, what allowed, is repeatable way, describing thermodynamic conditions for particular heat treatment installation. Discussed, in this paper, SimVacPlus Hardness module is a proposition for modern installations realizing heat treatment processes in which sharply indicated properties of charge after treatment are highly required.

2 Model of the gas cooling under high pressures

To realize the goal of this work we had solve following phenomena, having direct connection with analyzed processes[Dowling, 1997]:

1. describing phenomena accompanying cooling of the charge in side vacuum carburizing furnace chamber, together with elaboration of solution allowing determination characteristic ξ parameter defining intensity of the cooling. It must be mentioned that with regard to cooling chamber geometry, determination of $\alpha(t)$ parameter was connected with necessity of caring out calculations considering both construction parameters and gas velocity fields inside the chamber[Heming, 1999].
2. the influence of the material grade (chemical composition, physical properties) and the properties obtained after heat treatment. The result of these considerations was creation

of database used in carburizing containing characteristic properties necessary for correct defining of the method.

3. describing the influence of the shape, mass and surface area of the charge on the cooling intensity
4. elaboration of the mathematical model allowing determination of the cooling speed of the details in charge, in each point of theirs geometry.

Determining cooling speed in particular distance from the surface of analyzed detail was necessary to calculate hardness profile in carburized layer of particular geometry. To realize this purpose we decided to use solutions based on the superposition method [Cheng, 2003], [Reti,2001], [Serajzadeh, 2004]. These solutions based on the non-established heat flow equation [Taler, 2003], [Wiśniewski, 2000]:

$$\lambda * \frac{\partial^2 T}{\partial z^2} + \lambda * \frac{\partial^2 T}{\partial r^2} + \lambda * \frac{1 \partial T}{\partial z^2} = \rho * c_p * \frac{\partial T}{\partial t}$$

at boundary conditions given by:

$$\frac{\partial T}{\partial n}\Big|_{\Gamma} = \alpha(T) * (Tp - Tg)$$

where:

T – temperature[K], Tp – surface temperature[K], Tg – cooling gas temperature[K], t – time[s], λ(T) – heat conductivity[W/m*K], ρ(T) - density[kg/m3], cp(T) – specific heat[J/kg*K], α(T) – heat transfer coefficient [W/m2*K].

To assure accuracy o calculations, values λ, ρ and cp were taken as a temperature dependent. Coefficient α(t) in given above equations determines the intensity of heat exchange between details and the cooling media. The distribution of temperature and filed of gas velocity in the furnace chamber are necessary to know in processes of heat treatment in gases under elevated pressures to determine heat transfer from charge to flowing gas. Fixing these parameters in correlation with known properties of materials as well as gas ones is the base for accurate simulation of real heat treatment conditions [Heming, 1999], [Górecki, 2003], [Atraszkiewicz, 2005].

Results of numerical analysis of furnace chamber considering gas flow velocity field are presented in figure 1.

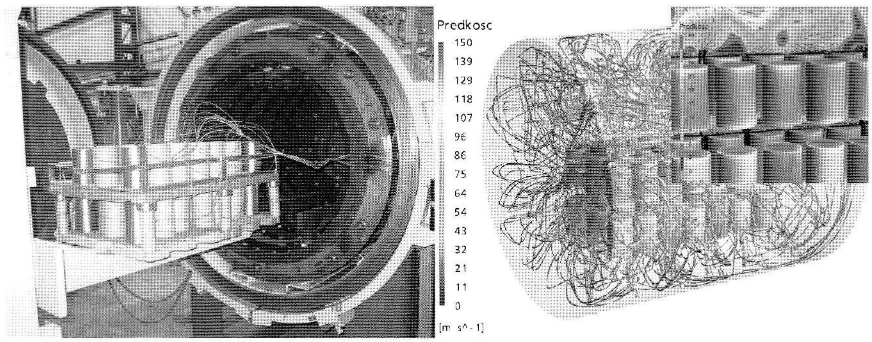

Fig. 1 Furnace charge of Ø100mm specimens with installed thermocouples and gas velocity lines during quenching for time step t=10s.

The dependences for heat transfer coefficient α(t) (fig. 2) were determined for each carried out analysis and on this base, using integration the surface under the curve method, the ξ(T) parameter was fixed which characterizes the cooling intensity of the charge for particular configuration of the load and particular pressure inside the chamber.

Calculation of the ξ parameter allowed determination of the characteristics in which this parameter was surface area and mass of the charge dependent. These characteristics were named maps of furnace cooling capability. Example of such a map is presented in figure 3.

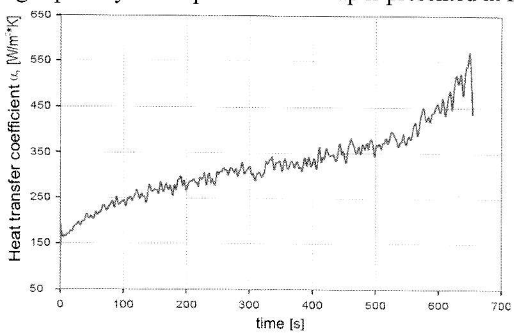

Fig. 2 Changing time dependence of heat transfer coefficient.

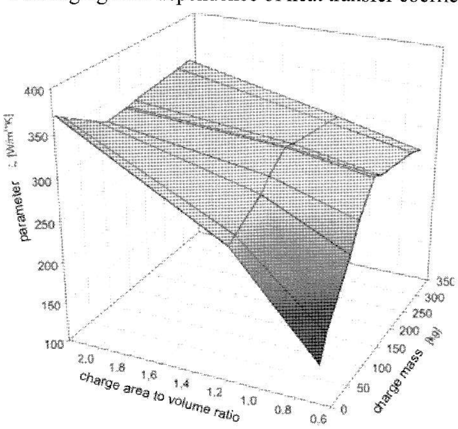

Fig. 3 Dependence between ξ parameter and charge mass and charge area for 9bar pressure.

To determine properties of material after heat treatment such as limiting hardness, surface and core hardness taking into account changes in carbon content in surface layers of elements after carburizing it was necessary to find dependences connecting hardness with cooling speed in given distance from the surface as well as with carbon percentage. [Kim, 2001], [Reti, 1999].

15 sheets were elaborated showing dependences between hardness, carbon content and cooling speed for 24 typical steel grades used in carburizing. Example of such data is presented in figure 4.

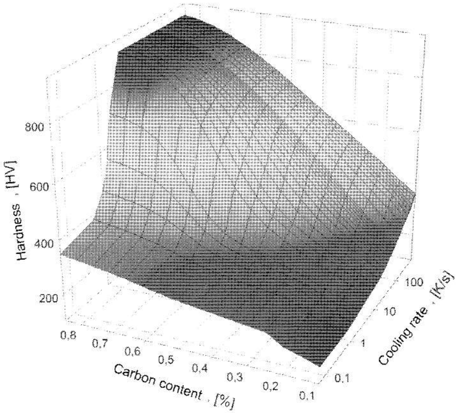

Fig. 4 Dependence between hardness and cooling speed and carbon content for the steel with Cr=0,7-1,0%, P=0,035%, Si=0,0,17-0,37%, Mn=0,5-0,8%, S=0,04%.

3 Computer simulation of carbon profile in surface layer

SimVacPlus Hardness application allows to determine carburizing process followed by quenching in gases under elevated pressures. It gives the user possibility of such design of the process the introduced and desired properties of the material after treatment are achieved. Application allows to define steel grade, geometry of the elements and this base chooses properties of the material such chemical composition, quenching temperature and others used in further calculations of cooling speeds on the base of physical properties of treated elements as well as mass and geometry of the charge.

Designing of the process is possible on two ways: manually – user defines himself the whole procedure, or automatically – program on the base of input parameters calculates all stages of the process and gives ready "recipe".

User, in both cases, can use creators which ease proper defining of the process (fig. 5).

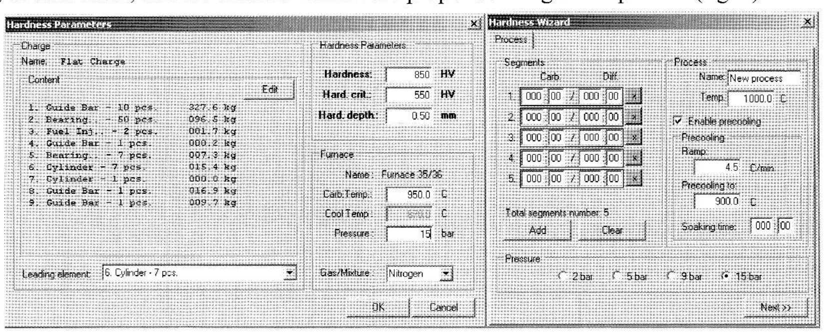

Fig. 5 Automatic and manual designing process windows.

Next step, after introducing requirements for surface layer after the treatment as well as designing the process manually , is defining the treated load. The charge configurator was especially created for this purpose, which in an easy way allows describing details in load and defining so called "leading element" (fig. 6 and 7).

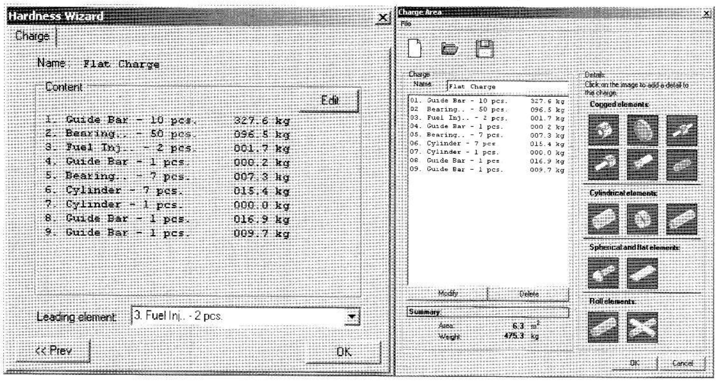

Fig. 6 Windows of configuration and modifying of charge.

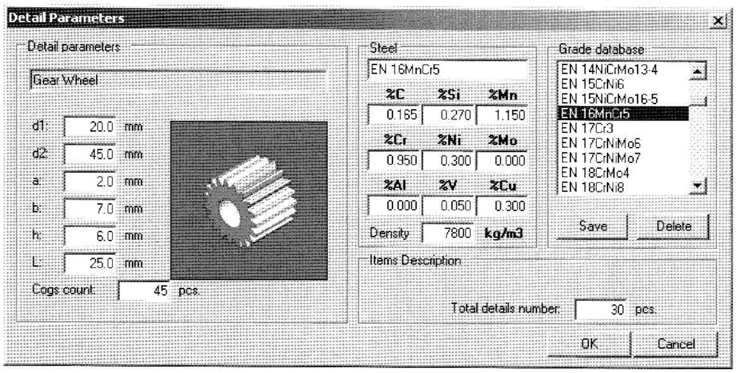

Fig. 7 Simulation window for defining charge elements.

After, mentioned above, parameters are defined , summary is presented to the user, and information about automatic or manual set of treatment (fig. 8).

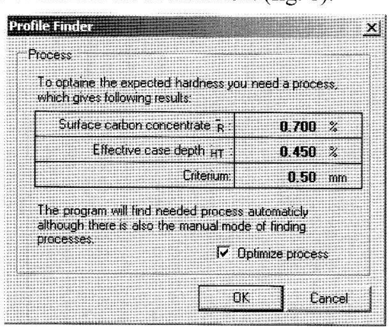

Fig. 8 Creator window with required process parameters.

Acceptance of parameters causes SimVacPlus starts and carbon profile in carburized layer is calculated. On this base program calculates hardness profile and hardness band (fig. 9).

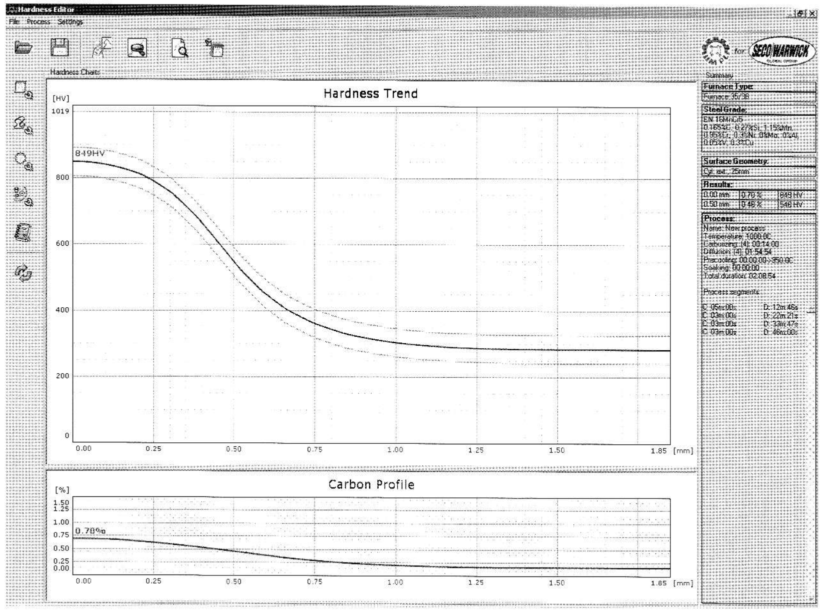

Fig. 9 Application window with carbon and hardness profiles after simulation.

4 Experimental verification

Experimental verification of the results obtained from described hardness calculations method was realized in the single chamber furnace with option of vacuum carburizing type VPT4035/36. Samples of dimensions Ø25x150 made of two types of steel: 16MnCr5 and 18CrMnTi5 underwent different carburizing processes. Each charge contained 270 samples in two layers of total weight 156kg and surface area equal 3,5m^2 . Different thickness of carburized layers and different surface hardness were taken into account to verify calculated by SimVacPlus Hardness program module values.

SimVacPlus Hardness module was used to calculate carbon profiles and process structure (with division into carburizing and diffusion stages). Next these data were imported to logic controller of VPT furnace, and process of vacuum carburizing and quenching in nitrogen at h pressure 9 bars was carried out. Microhardness profiles in treated samples were determined after processes, results are shown in figures 10 and 11. In case of 16MnCr5 steel except varying thickness of carburized layer, different surface hardness were considered; in case of 18CrMnTi5 steel required surface hardness was constant, carburized layer thickness varied.

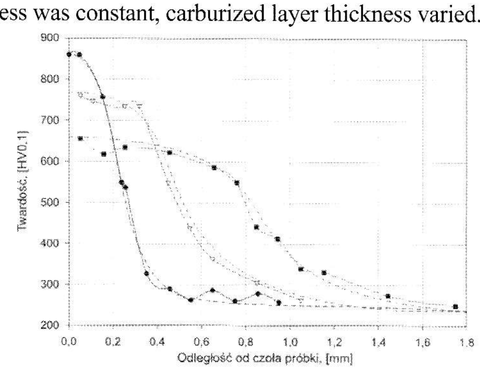

Fig. 10 Hardness profile diagram for 16MnCr5 steel pieces.

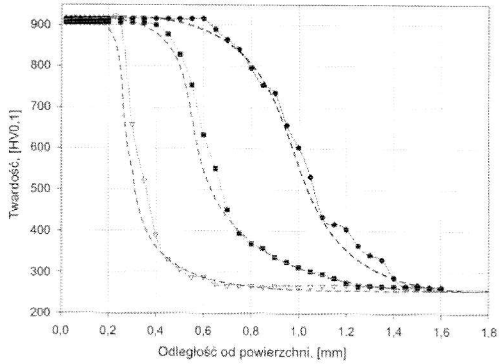

Fig. 11 Hardness profile diagram for 18CrMnTi5 steel pieces.

5 Summary

From engineering point of view, hardness defining criterion after heat treatment is the base of elaborating process parameters, so obtaining of hardness profile for carburized layers is technologically more well-grounded. Simulation proposition of determining hardness profiles presented in this paper meets the need and is new, original solution for engineering processes support with reducing to minimum number of experimental investigations.

SimVaCPlus Hardness is part of FineCarb® technology, compliments it with useful tool for designing heat treatment process on the basis of user defined requirements about limiting hardness, surface hardness and knowledge about installation cooling possibilities used for treatment.

In near future, next steps in development of the application will be: possibility of determining of material structure after heat treatment as well as extending materials database with some modern special carburizing steels.

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