Modern Gas-Quenching Chambers Supported by SimVaCPlus™ Hardness Application

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Vacuum-carburizing field experience has demonstrated the need for a more precise control system that controls case depth and automatically adjusts the furnace cooling rate to achieve a predetermined Vickers hardness. The Institute of Materials Science and Engineering, in cooperation with SECO/WARWICK S.A., has developed the SimVaCPlus™ Hardness software program to determine carburized-layer hardness profiles after gas quenching (cooling).

The SimVaCPlus Hardness program is an essential part of the already commercialized SimVaC™ system that currently provides process advantages. Commercial users of this new program report significant improvements in furnace uptime and fewer errors in the initial heat-treat runs.

Introduction

Vacuum carburizing with high-pressure gas quenching is one of the fastest growing manufacturing processes in both the automotive and aerospace industries. The critical parameters that determine the 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 the treated element
- Transformations during cooling and resulting internal stresses

This paper will introduce and establish the SimVaCPlus Hardness software as a key component to facilitate the correct heat-treatment cycle and to achieve precise metallurgical results in a minimum amount of time.

Model of Gas Cooling Under High Pressure

To analyze the effectiveness of this process, the research group had to address the following design issues:[3]

1. Describe the phenomena accompanying the cooling of the charge-side vacuum-carburizing furnace chamber together with an examination of the model, allowing the characteristic ξ parameter to define the intensity of the cooling. It must be mentioned that with regard to the cooling-chamber geometry, determination of the $\alpha(t)$ parameter involved including both construction parameters and gas-velocity fields inside the chamber.[5]
2. Determine the influence of the material grade (chemical composition, physical properties) on the properties obtained after heat treatment. A database was created to tabulate the results.
3. Describe the relationship between the shape, mass and surface area of the charge on the cooling intensity.
4. Development of a mathematical model to determine the effect of cooling speed on the load – specifically each point of the part geometry.

Determining the cooling speed at a particular distance from the surface of analyzed detail was necessary to calculate the hardness profile in the carburized layer of a particular geometry. To meet this goal, the group decided to use the superposition method.[2, 8, 9] This solution is based on the non-established heat-flow equation.[10, 11]

Working through the controlling equations and making the necessary assumptions, it was necessary to find the relationship between hardness and cooling speed within a given distance from the surface as well as with carbon percentage.[6, 7] As a result, 15 sheets were tested showing the relationship between hardness, carbon content and cooling speed for 24 typical steel grades used in carburizing. Examples of such data are presented in Fig. 1.

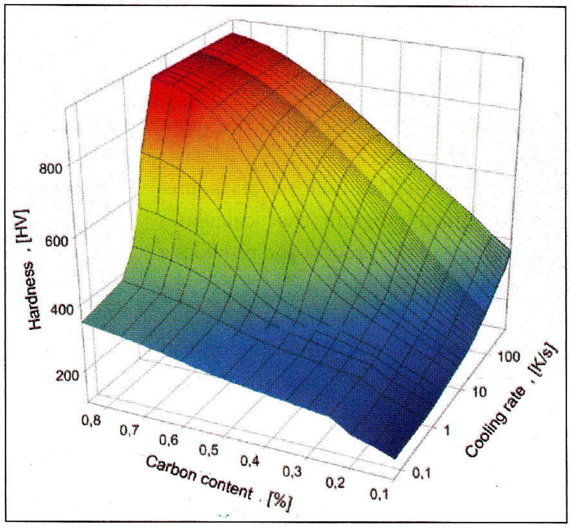

Fig. 1. The relationship between hardness and cooling speed and carbon content for the steel with Cr=0.7-1.0%, P=0.035%, Si=0.17-0.37%, Mn=0.5-0.8%, S=0.04%

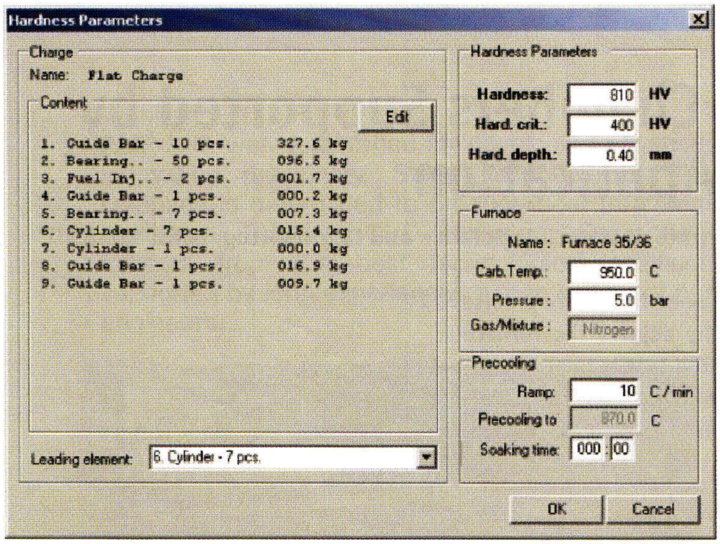

Fig. 2. Automatic process-design window

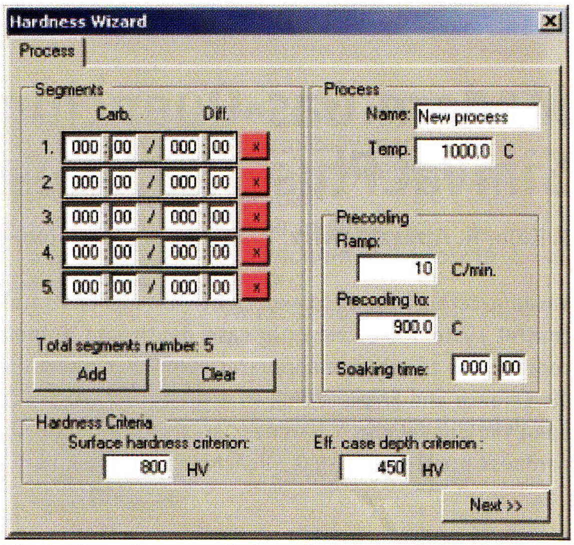

Fig. 3. Manual process-design window

Computer Simulation of the Carbon Profile in the Surface Layer

The SimVaCPlus Hardness application allows the user to select the carburizing and heat-treatment parameters to achieve the desired metallurgical properties. The application allows the user to define the steel grade and part geometry and to select the material or process specifications such as chemical composition and quenching temperature. This criteria is then used for further calculations of cooling speeds based on the physical properties of treated elements as well as the mass and geometry of the charge.

The process may be designed in one of two ways:

- Manual – The user specifies the input data for the cycle.
- Automatic – The user selects a preprogrammed program that calculates each stage of the process and provides a "recipe."

In both cases preloaded information can be used that helps to define the process (Fig. 2, 3).

The next step is defining the load to be heat treated. The menu selections, which quickly describe the physical load properties and the surface area to be carburized (Fig. 4, 5), were created especially for this purpose.

After these steps are completed, a summary is presented to the user with information about the proposed cycle (Fig. 6). Acceptance of these parameters signals the program to start, and the carbon profile in the carburized layer is calculated. The program then calculates the hardness profile and case (Fig. 7). If expected values of hardness cannot be obtained, the application will notify the user (Fig. 8).

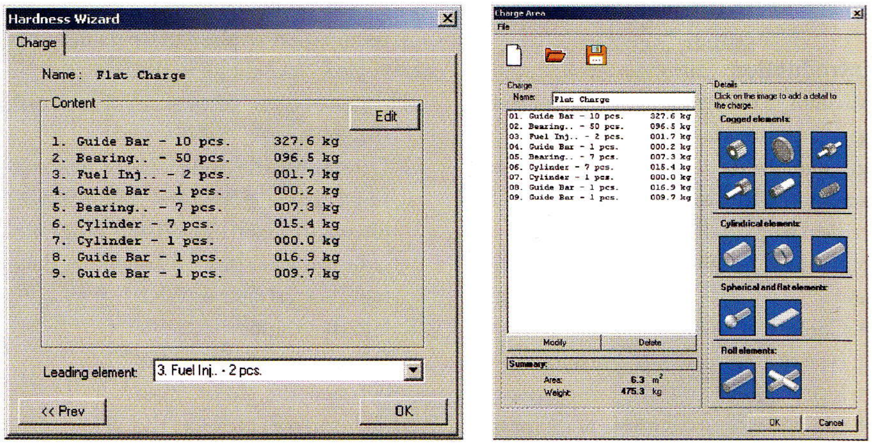

Fig. 4. Windows of configuration and modifying of charge

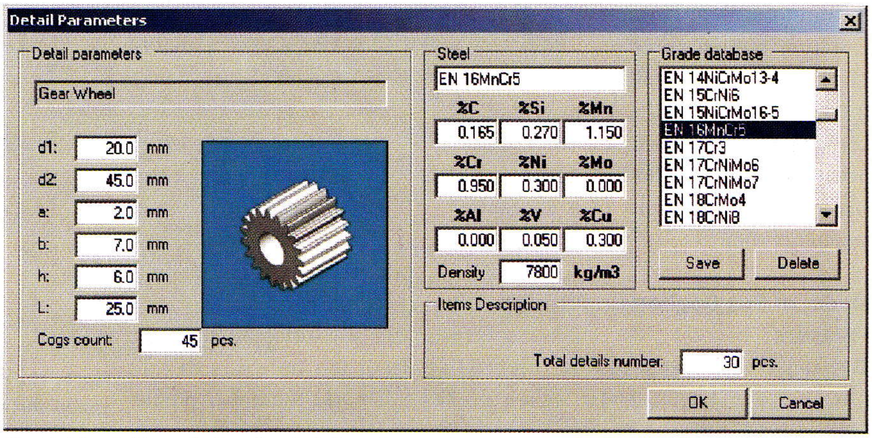

Fig. 5. Simulation window for defining charge elements

Experimental Verification

Experimental verification of the results obtained from the described hardness calculation method was performed in a single-chamber furnace with vacuum carburizing – type VPT4035/36. The samples tested had dimensions of 25mm circumference x 150mm long, were made of two types of steel – 16MnCr5 and 18CrMnTi5 – and underwent different carburizing processes. Each charge contained 270 samples in two layers with a total weight of 156kg and surface area equal 3.5m^2. Different thickness of carburized layers and different surface hardnesses were considered to verify values calculated by the program module.

The SimVaCPlus Hardness module was used to calculate carbon profiles and process structure (with division into carburizing and diffusion stages). Next, the data was imported into the computerized system of the VPT furnace, and the process of vacuum carburizing and quenching in nitrogen at a pressure of 9 bars was carried out. Microhardness profiles in treated samples were determined after the processes, with results shown in Figures 9 and 10. For 16MnCr5 steel, varying carburized-layer thicknesses and different surface hardnesses were considered. The 18CrMnTi5 steel required a constant surface hardness while the carburized-layer thickness varied.

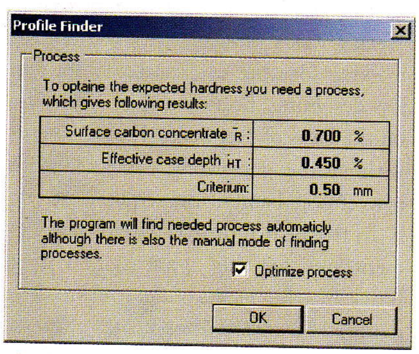

Fig. 6. User menu with process parameters

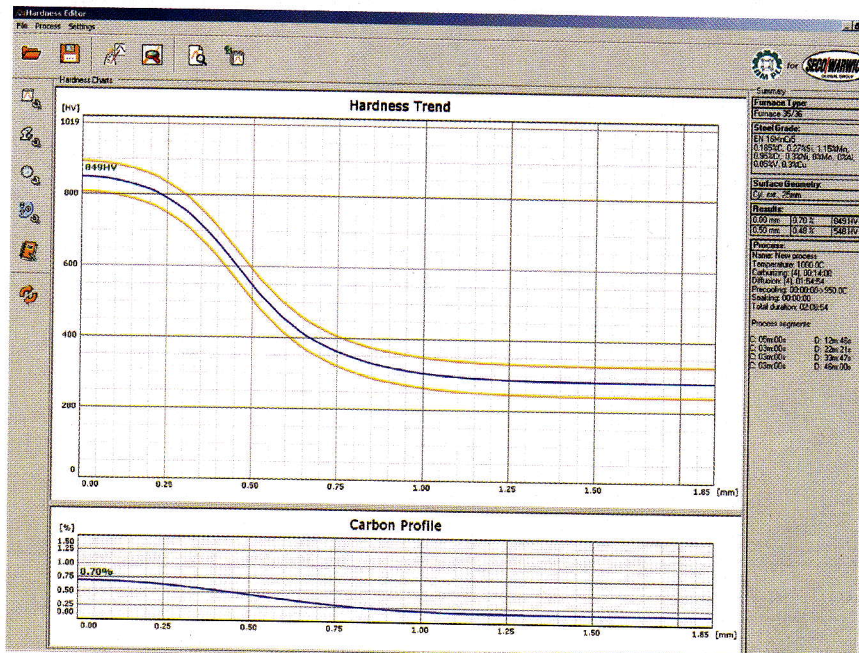

Fig. 7. Application window with carbon and hardness profiles after simulation

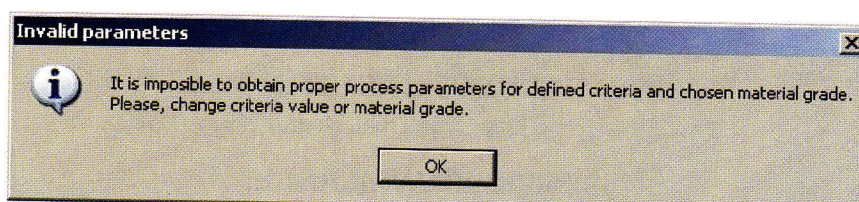

Fig. 8. Warning window for process design

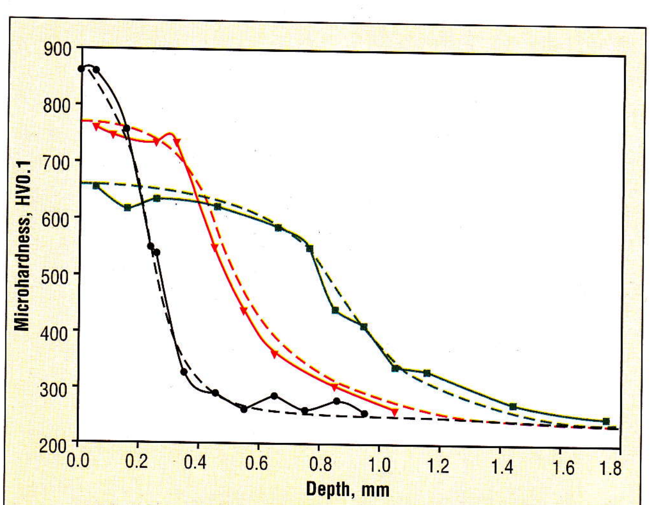

Fig. 9. Hardness-profile diagram for 16MnCr5 steel pieces

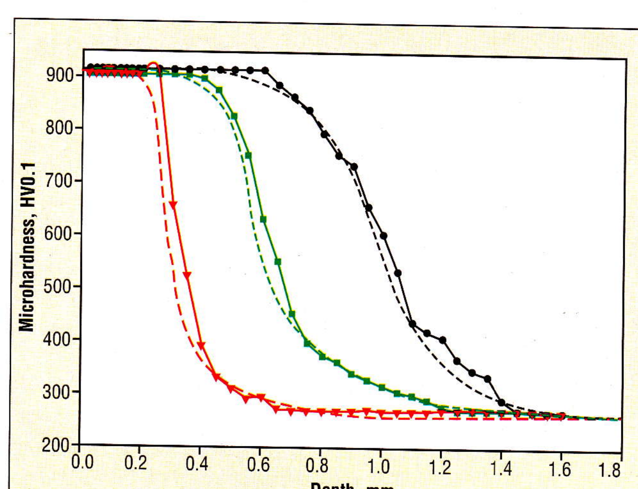

Fig. 10. Hardness-profile diagram for 18CrMnTi5 steel pieces

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Summary

The Institute of Materials Engineering, in cooperation with SECO/WARWICK S.A., developed the SimVaCPlus Hardness software program to determine carburized-layer hardness profiles after gas quenching (cooling). When calculating the cooling-speed requirements (cooling pressure), the program takes into consideration the furnace cooling characteristics, load (charge) configuration, part geometry and carburizing-case profile. This program reduces the heat-treating-process design time and limits or even eliminates trial cycles. To design the cycle, the user can specify carbon surface concentration and effective case depth, and the software calculates the appropriate cycle.

SimVaCPlus Hardness is part of SECO/WARWICK's FineCarb® technology, working together to create a useful tool for designing heat-treatment processes on the basis of user-defined requirements without the guesswork associated with conventional carburizing equipment.

In the near future, the next development step for this application will be providing the means of determining the material structure after heat treatment as well as extending the materials database with additional special carburizing steels. **IH**

References *(available online)*

For more information: Contact Janusz Kowalewski, vice president, Vacuum Group, SECO/WARWICK Corporation, P.O. Box 908, 180 Mercer St., Meadville, PA 16335; tel: 814-332- 8491; fax: 814-724-1407; e-mail: jkowalew@secowarwick.com; web: www.secowarwick.com

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