NEW TECHNOLOGICAL PATHWAYS FOR UNIVERSAL VACUUM FURNACES[1]

Piotr Kula[2]
Robert Pietrasik[2]
Konrad Dybowski[2]
Radomir Atraszkiewicz[2]
Emilia Stanczyk-Wolowiec[2]
Maciej Korecki[3]
Józef Olejnik[3]

Abstract

In this paper we discuss the conventional treatments such as high pressure gas quenching (HPGQ), low pressure carburizing (LPC) and presently applied technology – high temperature low pressure carburizing with prenitriding (PreNitLPC®). The most important issue refers to the new technological option – low pressure nitriding. This technology is very useful in a case of high alloy steels treatment. That new approach of universal vacuum furnaces allows broadening the applications for industry, especially in the hardening shops. FineLPN allows the complex processes to be done only with single furnace, i.e. quenching, tempering, and nitriding of die block, pressure casting die and injection mould for elements made of tool steels.

Keywords: Low pressure carburizing; Low pressure nitriding; Universal vacuum furnaces.

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2 *Technical University of Lodz, Institute of Materials Science and Engineering, 90-924 Lodz, Stefanowskiego 1/15, Poland.*
3 *SECO/WARWICK S.A., 66-200 Swiebodzin, Sobieskiego 8, Poland.*

INTRODUCTION

Modern manufacturing of parts and subassemblies for mechanical devices is headed towards dispersed cooperation services provided by small businesses under conditions of intense market competition. An important position in this manufacturing cycle is occupied by commercial heat treatment plants that provide advanced technological services under varying conditions and process rather small batches of products. On the other hand, owing to the rising requirements in terms of the quality and repeatability of treatment results as well as significant restrictions that arise from work safety practices and environmental protection, these processes need to be conducted with the aid of advanced technological equipment such as, for example, vacuum furnaces. The high cost of purchase and installation of vacuum furnaces is justified only when these furnaces are used to their full potential and if the processes are brought to perfection. In this paper, the authors would like to briefly outline the present and future areas where vacuum furnaces can potentially be used, and the possibilities of retrofitting these furnaces to meet the current and expected demands of the technological services market in terms of heat treatment and surface engineering.

The catalogue of typical heat treatment technological processes, where vacuum is used as a protective atmosphere or a factor that controls the treatment atmosphere, includes hardening and tempering, solution heat treatment and annealing, vacuum carburization, soldering and sintering. A machine which could execute the majority of the processes listed above could be deemed *universal*.

The technological capabilities of a furnace with standard equipment are significantly limited by the hardening capacity of the processed steel. This problem becomes especially important during the hardening of large-size dies and moulds, large cross-section parts made of low-alloy steel for upgrading and vacuum-carburized components.

The design and the basic parameters of universal vacuum furnaces are ideal for expanding their technological capabilities by adding vacuum diffusion treatment, mainly carburization, carbonitriding and nitriding.

Vacuum Carburization

The technology of vacuum carburization is more and more widely used, especially in the automotive industry, and the idea of its expansion into the aviation industry is becoming increasingly popular. This is connected with a number of advantages that this technology has in comparison with the hitherto widespread conventional gas carburization.

Due to the structural limitations of the furnaces used in gas carburizing, the temperature of the process practically does not exceed 930°C, while in the case of vacuum carburization the temperature used equals 1050°C,[1] and it is thought that the maximum temperature will eventually be raised to 1100°C.[2]

Vacuum carburizing is conducted in pressures from a few to several dozen mbar in a coal-bearing gas environment. Out of the many variants of this technology, the best optional system for a universal vacuum furnace appears to be the FineCarb® system.[3] It makes it possible to ensure the optimum composition of the multi-component mixture for carburization, to control the intensity of gas flow depending on the process stage and the surface of the treated charge, and to have continuous control of process parameters with the help of an exhaust gas monitoring system. In order to ensure high quality and repeatability of treatment results as well as easy adaptation to the changing requirements concerning the treated elements and surface layer properties, the FineCarb® system has been equipped with software for simulation of process parameters, SimVacPlus and SimHardPlus, which can determine the surface of the charge and predict hardness distribution in the treated elements.

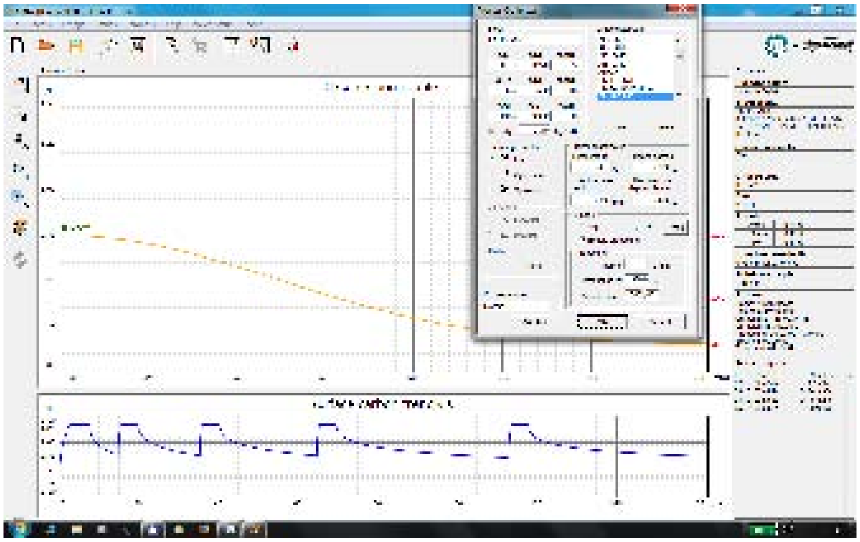

Figure 1. The main dialogue screen of SimVacPlus software.

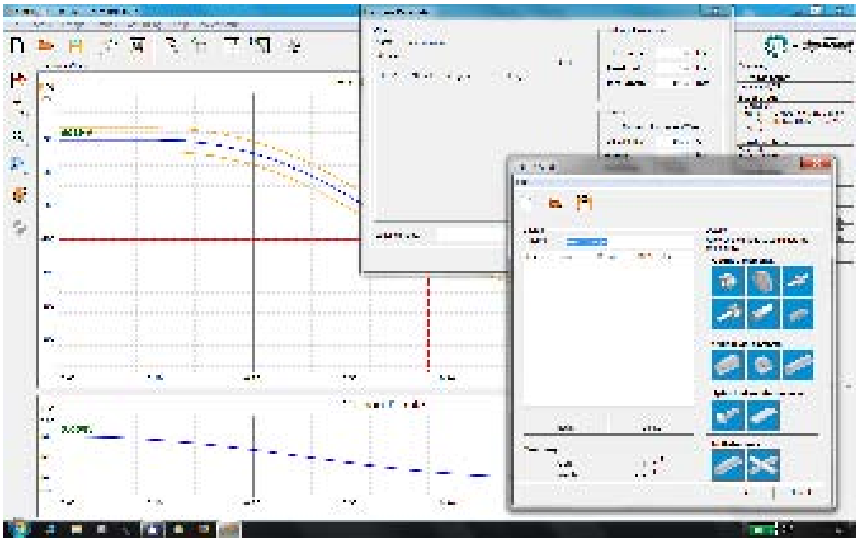

Figure 2. The main dialogue screen of SimHardPlus software.

High Temperature Vacuum Carburization with Pre-Nitriding Treatment

The next stage in developing the technological capabilities of the FineCarb® system was creating a carburization technology supported with nitriding – PreNitLPC®. Research conducted at the Technical University of Łódź made it possible to develop the basics of the technology and prepare it for implementation in industry. This technology is protected by international patents.[4]

This treatment involves introducing ammonia at the initial stage of the process – during the stage of heating for carburizing (Fig. 3). Owing to this, the layers

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carburized in higher than usual process temperatures do not reveal grain growth. This makes it possible to shorten the carburization time by rising the temperature even to 1100°C. Moreover, the layers created in higher temperatures with pre-nitriding exhibit similar strength properties as those carburized in lower temperatures. PreNitLPC® is a modern, economical variation of carburizing in lower pressure; a method that ensures significant intensification of this process.

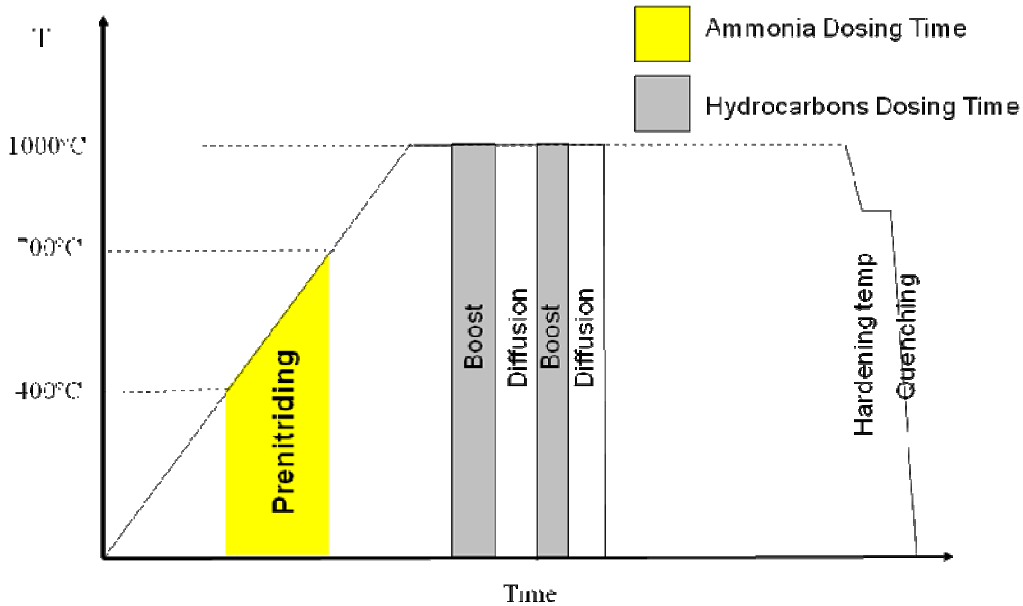

Figure 3. The vacuum carburization process with the PreNitLPC® method.

In the case of oversized products with high functional requirements e.g. related to restricting residue austenite content in the structure of the carburized layer, oil hardening is also used instead of the most widespread cooling in gas. This is especially important for automotive and aircraft parts.

Introducing nitrogen during the charge heating stage leads to release of nitrides and/or carbonitrides, which are heterogenic nucleation sources for austenite grains and block their growth during the carburization stage (Fig. 4). This leads to significant size reduction of the grains in comparison with conventional technologies as well as with vacuum carburization, thus making it possible to intensify the process by raising the treatment temperature without causing the loss of resistance properties (Fig. 5). Whereas in case of fatigue strength, the hardened surface layers exhibit even better properties (Fig. 6). Below are sample results obtained for 16MnCr5 steel.

Figure 4. Nitride release in surface layer.

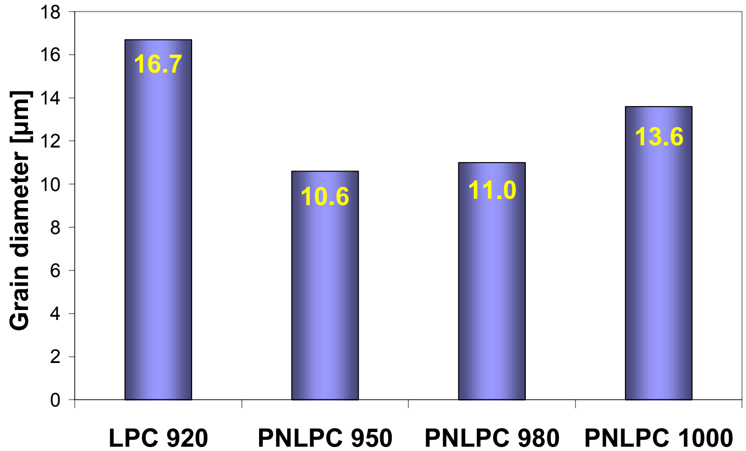

Figure 5. Comparison of grain size in surface layer.

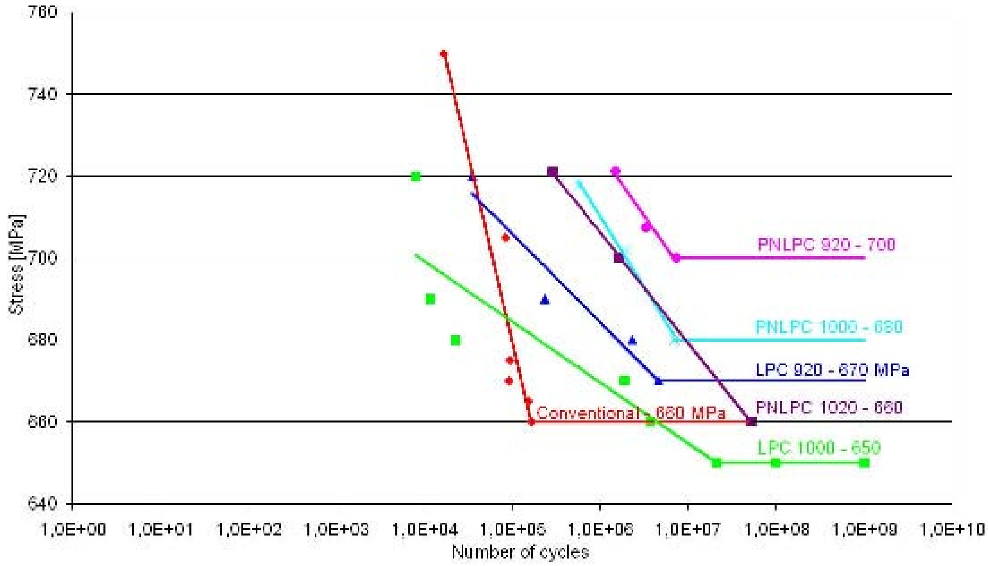

Figure 6. Comparison of fatigue strength.

Low-pressure Nitriding

Another technology that can expand the application possibilities for universal vacuum furnaces is low-pressure nitriding. The processes of gas nitriding are widely used in soaking furnaces; however, for tool steel, placing the treatment in chamber furnaces seems an interesting alternative. For this type of steel, usually relatively thin hardened layers are used and thus comprehensive treatment (hardening + tempering + nitriding) at one workstation is beneficial both in technological and economic terms. However, it is important to ensure full control of both the resistance properties as well as of the structural composition of the nitrided layer. It is also important to ensure full repeatability of the results both with subsequent charges as well as in the entire work chamber.

In order to ensure the above requirements, at the Institute of Materials Science and Engineering of Technical University of Łódź research continues on developing a SimLPN (Simulation Low Pressure Nitriding) software system for designing, simulating and optimising the processes of multi-segment, low-pressure nitriding for elements made of tool steel. Based on advanced artificial intelligence methods, this system enables the use of multi-stage, vacuum nitriding technology, FineLPN (Fine Low Pressure Nitriding) as a technological option for universal vacuum furnaces, and by the same token significantly improves their competitive position in the market.

Using artificial intelligence methods (including neural networks, genetic and evolutionary algorithms) is a modern approach to simulating phenomena which are hard to describe using mathematical methods.[5-7] Thus, it is possible to skip the stage where the mathematical and physical model for the phenomenon is created and to move straight to the stage of simulating material properties on the basis of process parameters. A correctly constructed artificial neural network is capable of reproducing even very complex functions[8] and it is very easy to use (in practice, the network creates the model for the user, using the examples supplied).[9,10] The network can be applied with high likelihood of success in situations where it is difficult to generate mathematical models, which offers the possibility to create models for phenomena and processes which are not well known. Hence the growing interest in this concept in the field of tools supporting the design and control of processes.[11-13]

The purpose of the SimLPN system is to select optimum parameters for the technological process for a selected type of steel in order to obtain the desired modification of the surface layer while maintaining the lowest possible cost of treatment. Before the system was developed, an extensive data base on vacuum nitriding processes was collected, which was necessary for examining and describing the kinetics of these processes, especially for the purpose of generating a mathematical and neural model of growth of a homogenous nitrided layer in tool steel, with the desired hardness profile and structure – the most suitable in terms of the conditions in which the tool is used.

The software functions are based on a modular structure. The calculation modules work independently, exchanging the necessary information, while the core of the system which serves as the calculating kernel is the module which implements advanced artificial intelligence methods, and in particular the functions of artificial neural networks. This module generates a physical model and a functional solution for multi-segment low-pressure nitriding, with the *boost-diffusion* structure (Fig. 7).

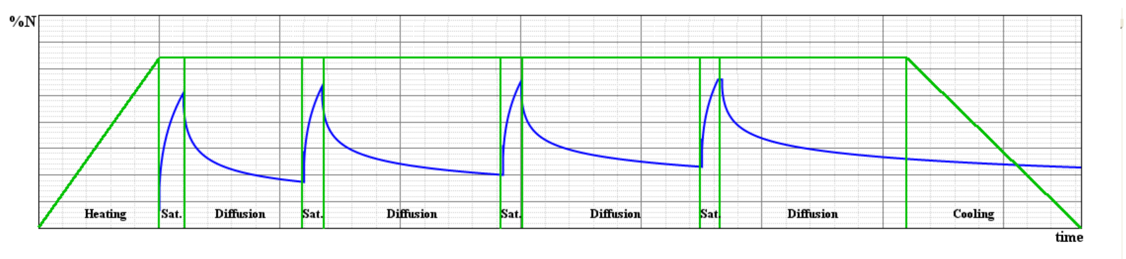

Figure 7. The low-pressure nitriding process using the FineLPN method.

The software can operate in one of the two modes. It can simulate the properties of the surface layer after a process is designed by the user (Fig. 8) or it can suggest process parameters, if the user defines the desired resistance properties of the component after treatment (Fig. 9).

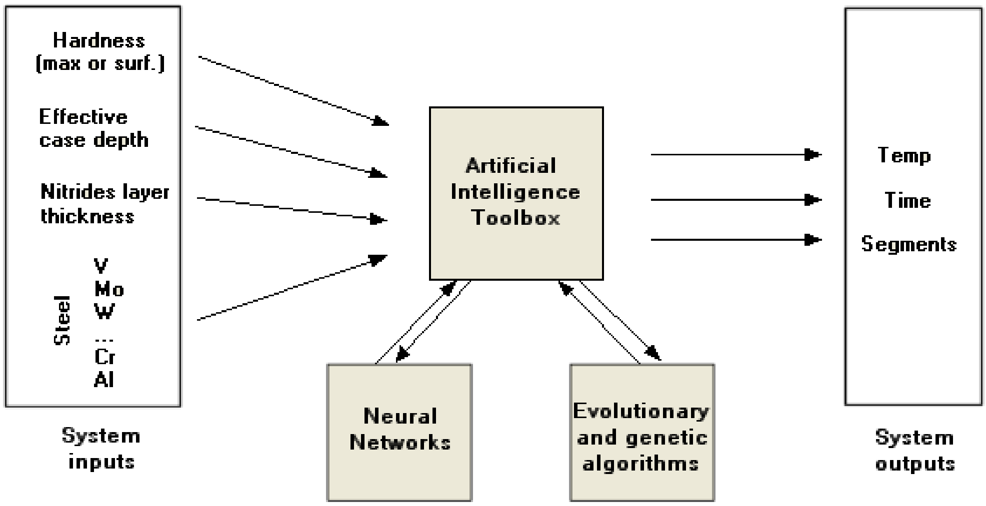

Figure 8. Diagram of SimLPN system operation.

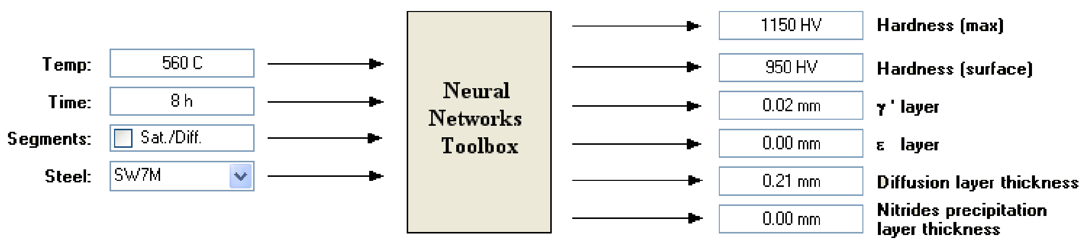

Figure 9. An example of forecasting nitriding results using the SimLPN module.

From the practical viewpoint, the second option is more interesting. During the first step, the system acquires input data from users concerning the properties of the component after the process. After the data is converted into a universal units system, the software activates the artificial intelligence module. The data concerning the component (steel type, the desired hardness, the expected layer thickness) is fed to the neural network. The algorithm searches for a process which would generate the desired properties in the surface layer in the shortest possible time. The next step is the simulation of the vacuum nitriding process using parameters suggested by the network and a presentation of all the characteristics of the material after the process (hardness profile, total layer thickness, white layer area, dark layer, the possible release grid following grain edges). The user can accept the suggested technological parameters for the process or request a new search.

The main advantage of systems based on this solution is the possibility to focus, at the same time, on selecting the resistance properties of the treated machine parts, on determining the technological process (including its economic cost), as well as on selecting the most suitable materials that can best meet the requirements while maintaining the lowest possible cost.

The results obtained in research on tool steel confirm the possibility to use universal vacuum furnaces for low-pressure nitriding (Fig. 10).

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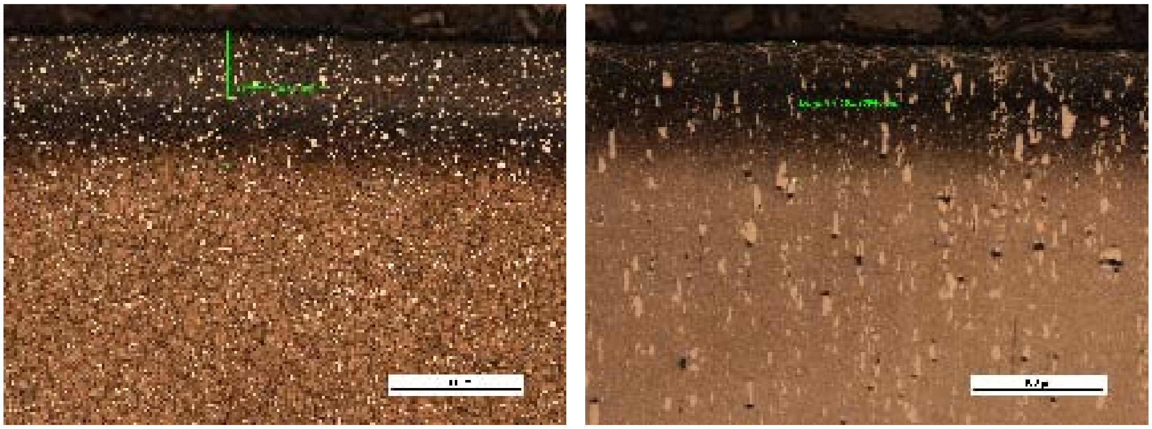

Figure 10. Structures on SW7M and WCL steel, obtained as a result of nitriding at 540oC for 4 hours.

CONCLUSIONS

The modern technologies presented here: FineCarb® vacuum carburization, PreNitLPC® high-temperature vacuum carburization with pre-nitriding and FineLPN low-pressure nitriding constitute a perfect complement to technologies used in universal vacuum furnaces. Thus, they can be applied widely in the commercial thermal and thermochemical treatment industry, with a special focus on commercial heat treatment plants that need to be adaptable and modify the range of products they process. If the capabilities of the universal vacuum furnaces are used to their full potential, it should be possible to reduce investment costs, and therefore offer competitive prices in the tough market, with special regard to the automotive and aircraft applications.

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