The Avac® Process

Optimizing Case-Depth Uniformity

Over the past few decades, the vacuum carburizing process has proven time-and-time again to produce superior part quality. In addition, the use of vacuum technology for carburizing has always shown the most potential for improving the manufacturing process by reducing both processing time and the number of manufacturing steps required to produce a part.[1] These savings are achieved by increased productivity, resulting in lower part cost and reduced total cost of ownership.

Lower part costs can also be achieved by optimizing the case-depth uniformity of parts during the vacuum carburizing process. For this, the carburizing process and influencing parameters, such as positioning of the parts within the load, uniformity of heating and quality of thermal processing equipment utilized, need to be analyzed and optimized. The first step in doing so, however, is to understand the emergence of vacuum carburizing and the advantages it offers for producing high-quality gears.

The Evolution of Low-Pressure Vacuum Carburizing

In the 1960s, development work began to provide a low-pressure carburizing technology that was fully competitive with gas carburizing. While, at the time, low-pressure carburizing offered a myriad of benefits with respect to process time, component quality and minimized fluid burnoff and heat emissions, it still had a high amount of soot forming in the furnace. In addition, there were high maintenance requirements when propane was used as a carburizing gas with relatively high partial pressures. However, in the mid-nineties, acetylene was discovered to have superior qualities as a reactive gas in vacuum carburizing (AvaC®).[2,3] This historical development of vacuum carburizing technology can be seen in Table 1.

Overall, what the history of vacuum carburizing demonstrates is that for the technology to succeed, an effective combination of process development (AvaC) and equipment design – such as Ipsen's Turbo^{2}Treater® vacuum furnace – had to be found.

The Role of Low-Pressure Vacuum Carburizing

When it comes to low-pressure carburizing in vacuum furnaces, the goal is clear: to carburize all workpiece components within a load uniformly, to the same surface carbon content and to the same case depth. Overall, low-pressure vacuum carburizing is marked by its ability to provide precise process control which, in turn, helps result in uniform part microstructures, process repeatability and a reduction in manufacturing and maintenance costs.

It is important to note that the vacuum heat-treating equipment utilized plays a significant role in the ability of vacuum carburizing to achieve such precise process control. An example of such equipment is Ipsen's Turbo^{2}Treater vacuum furnace, which features high quench speeds and uniform cooling and heating of the parts – all essential components for consistently achieving enhanced part quality and repeatability.

One of several processes that this heat-treating vacuum furnace offers is Ipsen's patented AvaC process (acetylene vacuum carburizing), which lends itself extremely well to utilization in combination with high-pressure gas quenching and is ideally suited for integration into production lines.

1960s →	1970s →	1980s →	1990s →	2000 & beyond
Process Development Begins	**Process Introduction to Industry**	**Process Limitations Uncovered**	**Process Solutions Found**	**AvaC® Production Carburizing**
R&D activities focus on finding alternatives to atmosphere gas carburizing.	Ultra-high-pressure carburizing techniques developed using natural gas, 100-percent methane and propane.	R&D activities focus on methods to reduce carburizing pressure, as well as investigating gas pressure quenching as an alternative to oil quenching.	R&D activities focus on finding a solution to excessive soot and tar formation by using acetylene and equipment designed specifically for low-pressure carburizing.	Combination of low-pressure carburizing equipment designs using acetylene achieve production vacuum carburizing with 95+ percent up-time reliability.
First vacuum carburizing patents issued.	Various vacuum carburizing method patents issued.	High maintenance and low up-time due to excessive soot from propane use halts commercialization.	Patents issued on use of low-pressure carburizing with acetylene.	Production loads are heavy, dense and include all types of part geometry in all industries.
Production loads are light, open and simple geometry.	Production loads are heavier, denser and include both simple and complex geometries.	Lower carburizing pressures and various gas introduction methods are adopted to attempt to reduce soot formation.	Combination of low-pressure carburizing with acetylene as the carburizing gas eliminates soot and tar formation (a concern in vacuum carburizing).	Modular-designed batch, semi-continuous and continuous vacuum carburizing furnaces become integrated into manufacturing and become a viable alternative to the use of atmosphere furnaces.
Limitations of existing vacuum equipment identified.	Equipment limitations improve with the introduction of new vacuum integral oil quench batch equipment.	Plasma carburizing becomes a popular alternative to vacuum carburizing.	Industry confidence and process credibility concerns addressed.	Changes in material chemistry make gas quenching an economical alternative to oil quenching.

Table 1: Historical development of vacuum carburizing.

Why AvaC? A Process Overview

It has been found that the AvaC process produces twice the carbon availability as compared to traditional carburizing agents, resulting in excellent carbon transfer into the parts. AvaC also has the advantage of producing an oxidation-free surface microstructure while allowing complex-geometry components to be evenly carburized. Wherever possible, it is used in combination with dry, high-pressure gas quenching as the hardening step. This provides the industry with a safe, environmentally friendly, clean and flexible case hardening process, which – when compared with oil quenching – also has a potential for reducing distortion and improving case-depth uniformity.

Turbo²Treater® – Efficiency in Power

Ipsen's Turbo²Treater® furnace continues to set new standards in quality, versatility and efficiency. Re-engineered for ease of installation and global operation, the Turbo²Treater offers the latest technology and technical solutions (Figure 1). With more than 200 furnaces sold worldwide, its reliable, cost-effective design and standardized production process allow Ipsen to provide quick delivery times and pass on savings directly to you.

Figure 1: Ipsen's Turbo²Treater vacuum furnace.

Offering quench pressures of up to 12 bar and convection-assisted heating that speeds up cycle times and increases temperature uniformity, the Turbo²Treater is ideal for hardening low-alloyed materials. In addition, its alternating directional flow (i.e., top to bottom; bottom to top) helps increase quench uniformity and minimize part distortion. The Turbo²Treater furnace also features an isothermal hold operation build-in with software that assists with distortion control and provides automatic temperature regulation.

Industry-Focused Solutions

Ipsen's Turbo²Treater furnace is ideal for multiple industries, including:

- Aerospace
- Automotive
- Commercial Heat Treating
- Medical
- Tools

Component Versatility

The Turbo²Treater furnace's versatile nature makes it the perfect heat-treating choice for a range of processes and components, including:

- Long and thin parts
- Multi-layer loads
- Tools and small dies
- Gears, drills and saw blades

Understanding the AvaC Process

The AvaC process involves alternate injections of acetylene (boost) and a neutral gas, such as nitrogen, for diffusion. During the boost injection, acetylene will only dissociate when in contact with metallic surfaces, thus allowing for uniform carburizing. At the same time, it almost completely eliminates the soot and tar formation problem known to occur from earlier propane carburizers.

One of the most important advantages of this process, though, is the high carbon availability. This helps ensure extremely homogenous carburizing – even for complex geometries and very high load densities. Overall, AvaC is a fairly diverse process, capable of processing parts with simple and complex geometries; wrought and powder metal materials; dense loading arrangements; variations in section size; and shallow, medium and deep case-depth requirements.

As shown in Figure 2, once the carburizing temperature is reached, the first carburizing step is initiated by injecting acetylene into the furnace to pressures between 3 and 5 Torr.

The carbon transfer is so effective that the limit of carbon solubility in austenite is reached after only a few minutes. As a result, the first carburizing step must be stopped after a relatively short time by interrupting the gas supply and evacuating the furnace chamber.

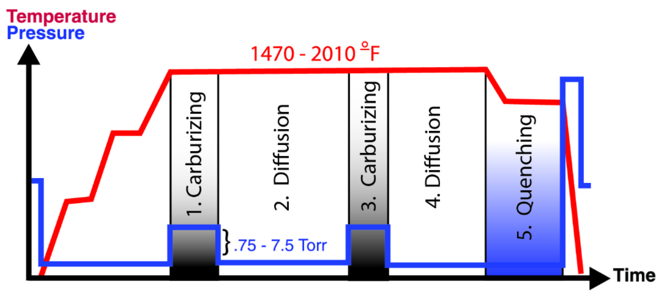

Figure 2: Typical cycle with temperature and pressure curve.

Deactivation of the boost event and evacuating the furnace chamber initiates the first diffusion step. During this segment, the carbon transferred into the material, as well as the surface carbon content, decrease until the desired surface carbon content is reached. Depending on the specified material case depth, further carburizing and diffusion steps may need to follow. Once the specified case depth has been obtained, the next step applied is quenching. This typically involves reducing the load temperature and quenching the load in the same chamber.

In the end, control of the AvaC process for low-pressure carburizing involves an understanding of the variables that influence carbon transfer and diffusion. These include time (total boost or carburizing time, total diffusion time and the number/duration of carburization and diffusion steps); temperature; and gas parameters (type, pressure and flow rate). Depending on the part surface area and geometry, the parameters listed above are determined as constants resulting in homogeneous carburization.

Investigating the AvaC Process and Its Effect on Case-Depth Uniformity

The most remarkable benefit of the AvaC process can be found when the different hydrocarbon gases for low-pressure carburizing are compared for their penetration power into small-diameter, long blind holes. This test was conducted for samples with blind holes of 0.11 inches (.28 mm) in diameter and 3.55 inches (90 mm) in length, as shown in Figure 3.

Figure 3: Example of blind hole.

The test cycle used in this case was carburizing at 1,650 °F (899 °C) (3 Torr pressure) and fast cooling in 2-bar nitrogen, followed by re-hardening from 1,580 °F (860 °C) using a nitrogen quench at 5 bar. After sectioning the round bar sample of 5115 steel, the surface hardness was measured inside the blind hole at various distances from the opening.

The results of these surface hardness measurements are shown in Figure 4, and they clearly indicate that the carburizing power of propane and ethylene is only sufficient to carburize the initial 0.23 inches (5.8 mm) of the blind hole. It was determined that the carburizing fell off rather significantly up to a 1-inch (25.4 mm) hole depth. After 1 inch of hole depth (25.4 mm), the hole's surface was completely uncarburized.

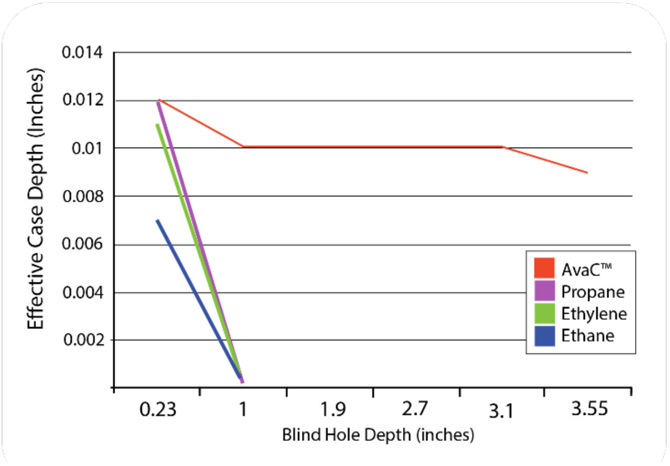

Figure 4: Surface hardness results.

In contrast, vacuum carburizing with acetylene results in a complete carburizing effect along the whole length of the bore, all the way to the bottom of the 3.55-inch (90 mm) blind hole. Since the only atmosphere that comes into contact with the parts during the carburizing process is the hydrocarbon acetylene, the structure of the carburized case is completely free of any intergranular (internal) oxidation. In the end, as one can see, the acetylene has a completely different carburizing capability than that of propane or ethylene.

Integration of the AvaC Process and Cutting-Edge Technology

As previously discussed, the AvaC process is ideally suited for integration into production lines. As a result, this Ipsen-developed process is able to offer several advantages to furnace users, including:

- High carbon transfer rate
- Even carburizing process, even for difficult geometries
- No intergranular oxidation (IGO), thermal radiation, flames or conditioning of the furnace (for the AvaC process)
- Improved part quality with part-to-part and load-to-load repeatability
- Decreased cycle times due to higher carburizing temperatures and increased carbon diffusion rates
- Highly efficient due to low gas consumption
- Higher temperatures
- Advanced Vacuum Furnace Design: Advantages for AvaC Applications

While the AvaC process offers numerous advantages, it is also important that the vacuum furnace used in combination with the AvaC process has the capabilities for delivering optimum efficiency and optimizing case-depth uniformity during the carburizing process (e.g., Ipsen's Turbo²Treater furnace, which features a mass flow controller that is designed to be compatible with acetylene gas).

In addition, to ensure a fully optimized vacuum carburizing process, the thermal processing equipment should be able to provide a precise, uniform gas flow. The Turbo²Treater vacuum furnace is able to achieve this thanks to its vessel housing, which includes a vacuum penetration point (i.e., a multi-point fuel injection delivery system) that is located between the cold wall tank and the hot zone. With injector nozzles penetrating the hot zone, this manifold system is able to precisely meter and deliver a continuous flow of process gas, such as acetylene, from outside the hot zone to inside, which reduces the risk of hot zone contamination. Overall, this not only prevents the process gas from collecting on the cold wall, but it also provides a uniform gas flow, which helps ensure consistent part quality and case-depth uniformities.

VacuProf® – Expert Controls System for Intuitive User Operation

All treatment processes in the Turbo²Treater furnace are controlled by Ipsen's proprietary software, VacuProf® (Figure 5). Through its use, vacuum furnace users can achieve manufacturing time and cost savings, increased quality consistency and improved operational reliability.

Figure 5: VacuProf control screen.

In addition, all data produced by the process is transported to the computer system where it is then available for specific processing and conversion (e.g., for logging, visualization, archiving and reporting of errors and thresholds).

Proven and dependable, the VacuProf controls system is a powerful tool that provides:

- Easy-to-use interface with consistent user prompts and color menus
- Extensive data collection and the ability to download or print reports
- Sophisticated alarm package that monitors the furnace and suggests preventative maintenance
- Remote diagnostics and monitoring of the cycle
- Built-in online manual, parts list and historical records
- Repeatable results with programmable recipes and optimization of processes

VacuProf Expert Software

Unique to the market, this software allows a user without any special prior knowledge to select the correct process for the type of steel to be treated. The user simply needs to enter the characteristics of the steel, the load geometry and a few other details, such as desired hardness or the heating and quenching characteristics. The VacuProf Expert software will then recommend a possible heat treatment recipe for the entered material.

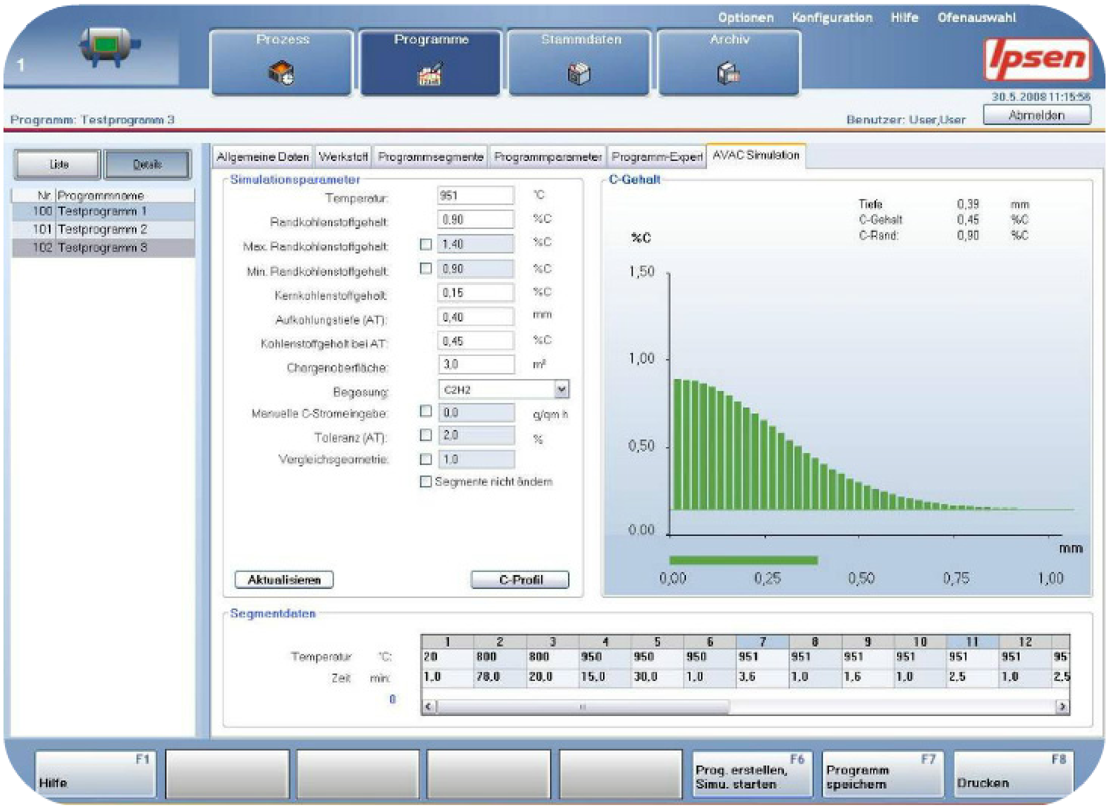

Figure 6: AvaC Simulation software tab.

Advanced Controls Software: Applications of AvaC Simulation Software

Available through the VacuProf® controls system, complete heat treatment cycle programs with heating, treatment and quenching segments are created with the aid of AvaC Simulation software (Figure 6). The program simulates low-pressure vacuum carburizing cycles and calculates carbon profiles that are dependent on the temperature, surface carbon content, and case depth. The calculations are based on the carbon transfer characteristics of acetylene gas.

Development of Superior Quenching Capabilities

Once the specified case depth has been obtained through vacuum carburizing, the next step applied is typically quenching. The goals for quenching with reduced distortion can generally be defined as follows:

- Uniform heat extraction over the whole surface of the part
- Uniform heat extraction on every part within one load
- Material- and part-adapted timing to control the quench intensity

Today's requests of adapting the quenching intensity of quench systems to the needs of different components – specifically hardenability and minimization of distortion – have also led to the increased production of quality components. As such, the Turbo²Treater furnace was also designed with these needs in mind.

Enhanced Gas Flow

Utilizing a high-volume flow with vertical gas quenching, the Turbo²Treater furnace can reach pressures of up to 12 bar when using nitrogen, or 8 bar when using argon. By default, the quench direction is from top to bottom; however, it can be reversed to flow from bottom to top and back. In addition, furnace users can set the interval at which direction changes need to occur based on load temperature and time, thus allowing for a more uniform quench and part quality.

A key feature of the Turbo²Treater that enhances its quenching capabilities, though, is its utilization of the Coanda Effect. This effect describes the flow that follows a curved surface. Integrated into the design of the hot zone's baffle, the Coanda Effect makes it possible for the gas to enter the hot zone in a highly uniform manner, thus ensuring all the parts are hit with the same amount of quench gas, as well as a uniform part quality throughout the load.

Increased Lifespan

The Turbo²Treater furnace's square hot zone is also covered with a special high-performance carbon fiber composite (CFC) – used in the form of either laminated CFC or as CFC with foil coating – that is capable of withstanding temperatures of up to 3,600 °F (2,000 °C). This additional covering of the hot zone is particularly beneficial for high-pressure gas quenching as it protects the hot zone from the high-velocity gas stream. This significantly contributes to extending the hot zone's service life, thus reducing subsequent servicing and maintenance costs.

Overall, experience shows there is significant potential for optimizing, as well as producing, a more uniform quench. The implementation of such features has produced a more uniform hardening of parts – especially gear components – with an improved microstructure and reduced distortion. In addition, using the AvaC process in combination with high-pressure gas quenching can optimize one's manufacturing process by reducing both the processing time and the number of manufacturing steps necessary for heat treating a part.

Conclusion

With the need for the thermal processing industry to heat treat a diverse range of parts in terms of geometries, materials, load sizes and more, it is essential to be able to achieve precise process control. Through the use of vacuum carburizing with acetylene, the industry can continually experience uniform part microstructures, process repeatability and reduced manufacturing costs, as well as control and optimize case-depth uniformity – even for complex geometries and dense loads.

The need for an enhanced carburizing process doesn't stop there, however. As demonstrated by the history of vacuum carburizing, the ability to produce parts with improved case-depth uniformity and reduced distortion required the development of Ipsen's patented AvaC process; it also made it necessary to develop a heat treatment furnace, such as Ipsen's Turbo²Treater vacuum furnace, that meets the industry's diverse process requirements. In the end, by refining the vacuum carburizing process, the end user has the ability to optimize the manufacturing process – which ultimately results in the production of high-quality gears with lower cost per part.

[1] Herring, D. H., Applying Just-In-Time Manufacturing Techniques to Heat Treating, Advanced Materials and Processes, 1994.
[2] EU Patent EP 0 818 555 dated 28 March 1996, JH Corporation, Japan.
[3] EU Patent EP 0 882 811 dated 3 June 1997, Ipsen International GmbH, Kleve, Germany.

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