New ECM Furnace Improves Manufacture Efficiency of PM Components

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The heat treatment processing of powder metal (PM) materials like Astaloy requires four steps—de-waxing, HT sintering, carburizing and surface hardening—which are usually achieved in dedicated, atmospheric furnaces for sintering and heat treat, respectively, leading to intermediate handling operations and repeated heating and cooling cycles. This paper presents the concept of the multi-purpose batch vacuum furnace, one that is able to realize all of these steps in one unique cycle. The multiple benefits brought by this technology are summarized here, the main goal being to use this technology to manufacture high-load transmission gears in PM materials.

Introduction

Today, the usual way to manufacture PM parts like gears is divided into several steps. When the gear is shaped by die compaction, four heat treatment stages must be carried out in order to acquire all the required properties. These four stages are de-waxing, sintering, carburizing treatment, and quenching.

Most of the time, de-waxing and sintering are performed in continuous-belt or walking-beam furnaces. The first operation, de-waxing, is intended to remove the lubricants. This is a critical step because if removal of the lubricant is incomplete, defects like contamination, blistering, etc., might present. Belt or walking-beam furnaces are able to sinter directly after de-waxing in a single run, which presents an advantage compared to the use of two dedicated furnaces. After sintering, the carburizing treatment for tailored, case-hardened profile produces the final, required properties and is generally followed by hardening, using oil quench or high- pressure gas quenching (HPGQ).

Typically, the conventional carburizing treatment is done in batch-type furnaces. This requires intermediate handling between sintering and carburizing, and post washing-and-drying operations after oil quenching.

This article presents the concept of a multi-purpose furnace that performs the mentioned successive steps in one continuous cycle. The discussion will focus on benefits of this furnace and associated cycles, and compare the traditional method of sintering and carburizing to this concept.

Experimental Details

Trials have been carried out with a Höganäs AB industrial furnace (Fig. 1), designed and manufactured by ECM Technologies. The furnace comprises two chambers — one heating cell and one gas quenching cell — separated by an intermediate leak-tight and insulated door.

The front chamber is used as an airlock to load and unload the charge and also as high-pressure gas quenching unit for hardening the parts.

The second chamber — or "heating cell" — is the furnace itself where parts are heated and carburized. It is always maintained under low pressure (1 to 20 mbar) with back-fill of protective atmosphere.

Each chamber is equipped with independent vacuum circuits and can be operated independently. The vacuum circuits are designed to maintain the correct partial pressure inside the heating chamber, and are equipped with a wax trap to collect the lubricant during the de-waxing cycle.

One internal device transfers the load back and forth between the two chambers; a service door facilitates the access to the heating chamber for periodic temperature mapping instrumentation or maintenance. Figure 2 displays the complete treatment cycle in the multipurpose furnace.

The de-waxing step is performed at around 650°C under low pressure. At this temperature the lubricant evaporates and is being pumped out by the vacuum circuit; it is entirely removed from the parts and collected in the wax trap. The temperature is then increased to reach the desired sintering temperature (up to 1,250°C). At this stage, metallic bonds between particles are formed. After sintering is completed, temperature is

Figure 1 Multi-purpose vacuum furnace installed in Höganäs pilot plant.

decreased to reach the desired carburizing temperature (900 to 1,000°C). Then follows the patented (Ref. 1) Infracarb process, where the low-pressure carburizing cycle with alternating injections of acetylene and nitrogen is carried out. The number of injections and cycle time is adjusted, depending on the desired case depth. After final diffusion, the load is transferred back to the front chamber, and is quenched with nitrogen gas (up to 20 bars). Metallurgical transformation occurs during the rapid cooling and enhances the mechanical properties of the parts.

For example, a 300 kg load containing small spur gears has been carburized at 965°C for 74 minutes, and the effective case depth at 550HV obtained is 0.6mm (Fig. 3).

Discussion

For each step, the new concept is compared to the traditionnal way to manufacture PM parts.

De-waxing. When the parts reach a temperature above 400°C, lubricants used during die compaction evaporate. Typical lubricants, such as amide wax, are totally decomposed between 400 and 500°C.

In the pre-heating zone of belt-type furnaces, lubricant vapors are mixed with protective atmosphere and burnt as exhaust. With conventional belt furnaces, the de-waxing time and the sintering time are linked and defined by the belt's length and speed.

In a multi-purpose furnace, a partial pressure of nitrogen (1 to 20 mbar) preserves the parts from oxidation. The vaporized lubricant is condensed and collected in a trap in the vacuum circuit. The de-waxing time can be easily increased or decreased according to the load's weight. The trap reduces the rejects in the atmosphere and keeps the vacuum circuit clean. Vacuum is also well known to be an efficient way to de-wax the part. De-lubrication under vacuum is thus beneficial to the de-waxing rate.

Sintering. Many parameters are crucial during sintering, especially the time and temperature of sintering, the heating rate, and also the design of the fixtures, the arrangement of the parts on the trays, etc.

Sintering temperature (around 1,200°C) is about the maximum limit to be used in traditional furnaces, and reaching it impacts the lifetime of the

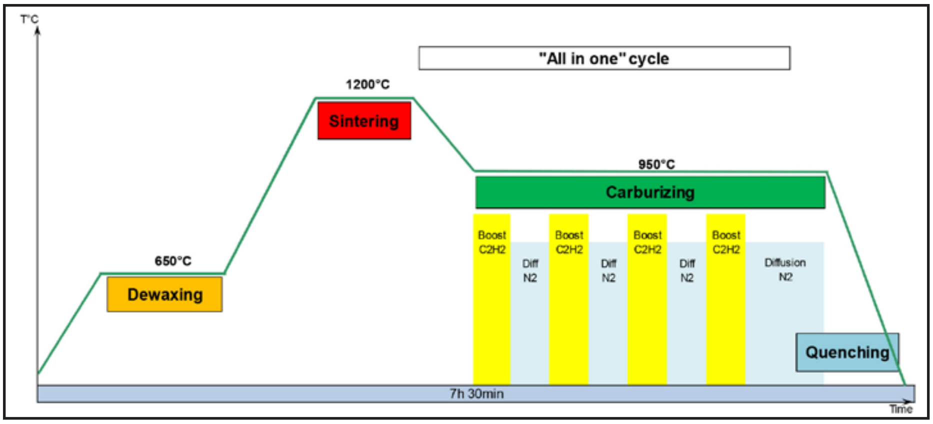

Figure 2 Complete treatment cycle for PM parts.

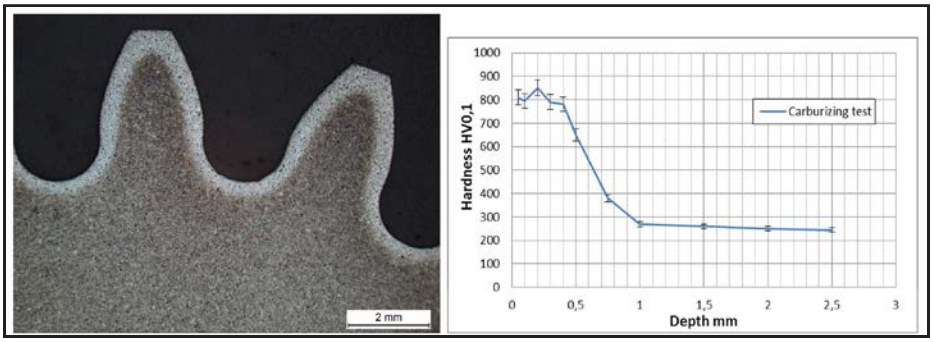

Figure 3 Part etched with nital 2% and hardness profile.

heating elements (radiant tube). In vacuum furnaces, the lack of oxygen permits the use of graphite rods as heating elements. Graphite rods are very stable mechanically (no bending with temperature), and the lifetime is not influenced by the working temperature.

PM compacts, especially chromium alloys, are prone to oxidation and so precise control of atmosphere quality is required. Due to the open pore system, PM compacts are more prone to oxidation than wrought steel. Residual oxidation can introduce defects during sintering. A continuous furnace uses a reducing gas like hydrogen to protect the parts, which is not necessary under vacuum. All the other parameters (heating rate, sintering time, etc.) can be easily adjusted to obtain the best sintering process.

Carburizing. The absence of handling between operations in the multipurpose furnace guarantees that the parts will not be affected by contamination or damaged between sintering and heat treatment.

Frequently, batch furnaces are used for carburizing PM parts. Carbon enrichment is controlled by O_2 sensors or CO/CO_2 ratio.

In the new furnace, the carburizing phase is completely controlled by Infracarb, the patented LPC process with acetylene gas. The case depth and carbon profile are simulated and adapted for porous materials. Low-pressure carburizing processes can be achieved at any temperature up to 1,050°C. The carbon enrichment and diffusion time can be controlled separately to achieve the required microstructure.

The cycle is shortened and diffusion is faster than in an atmospheric carburizing furnace. Moreover, there is no internal oxidation of the parts. The amount of carburizing gas injected in the chamber is optimized to ensure that every part is correctly carburized. Injection is done by short bursts in order to minimize the formation of gas constituent, which leads to volatile organic components and atmospheric rejects are reduced.

Quenching. The high-pressure gas quench allows a range of appropriate cooling speeds (from 1 to 10°C/sec) to be reached; Figure 4 shows the principle of the gas quench chamber. Cold nitrogen gas is pushed down through the load, cooling it, and transfers the heat to the water when passing the heat exchanger. Gas quenching permits high flexibility and more repeatable results than oil quenching, because there is no boiling or

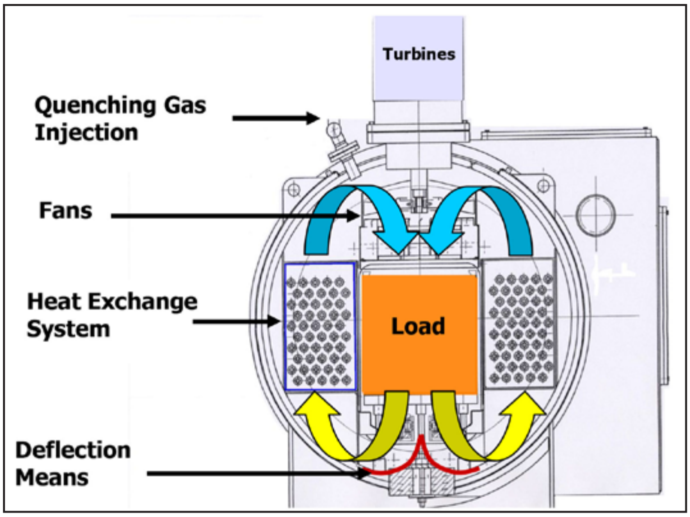

Figure 4 Principle of gas quench chamber.

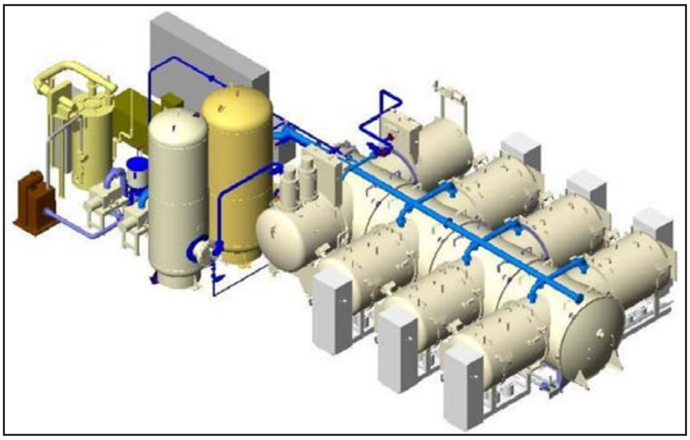

Figure 5 Modular sintering multi-cells line type ICBP.

vapor formation around the parts. With a gas quench, the pressure and also the turbine's speed can be programmed for each cycle in order to adjust the cooling rate for every type of load, thus minimizing parts distortion. The parts exit the furnace clean with no need of washing.

Process Cost Estimation

For typical production of 300 kg net/hour, a modular vacuum installation with multiple heating cells is required (Fig. 5). Based on an engineering cost estimate, the cost of sintering and heat treatment of parts is about 0.5€/kg.

The precise cost depends on the geometry and hardenability of different kinds of parts.

The main saving factor comes from the fact that carburizing and gas quench steps are carried out in situ in the de-waxing/sintering equipment. The maintenance cost per year for an ICBP-type furnace is around 4% of the investment cost, or lower. The high modularity and reduced footprint of the furnace is also an advantage.

The global energy balance cost is positive against the conventional furnace because there is no multiple cool down and reheating of the parts for each step of the process.

The modularity of the heat treatment installation allows for further production extension by the simple addition of heating cells on the mainframe without investment in a second line.

Conclusions

Studies have been carried out in partnership with Höganäs AB on different alloys, including chromium alloys. Positive results have been achieved on:

Control of Case Profiles

Control of core hardness with base carbon content and cooling speed variation

Low-pressure carburizing has been proven very suitable for control of process parameters without oxidation.

The multi-purpose furnace potentially offers an improvement at every stage of the PM production process: It will be the tool for further optimization to improve mechanical properties like fatigue strength, distortion reduction, and validation of the entire process for the production of high-performance PM gears.

References

1. U. S. Patent No. 6,065,964, May 23, 2000.

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Mats Larsson studied mechanical engineering at Lund University (Sweden). He joined Höganäs AB in 1988, working in various positions within the development department, and, in 2009, was appointed manager of PM components/process development. Larsson is also chairman of the ISO standardization committee TC119/SC2: Powder Metallurgy Sampling and Testing Methods of Powders.

Hubert Mulin, PhD engineer and R&D process manager for ECM Technologies, received his undergraduate engineering education at the ECAM School (Catholic school of Arts) in Lyon, France. He then went on to earn a research master's degree in material sciences based on low-pressure carburizing sensors. He subsequently received his doctorate—with a focus on shaping metal powders using MIM (metal injection molding) technology. Mulin joined ECM Technologies in 2012 as an R&D process manager.

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