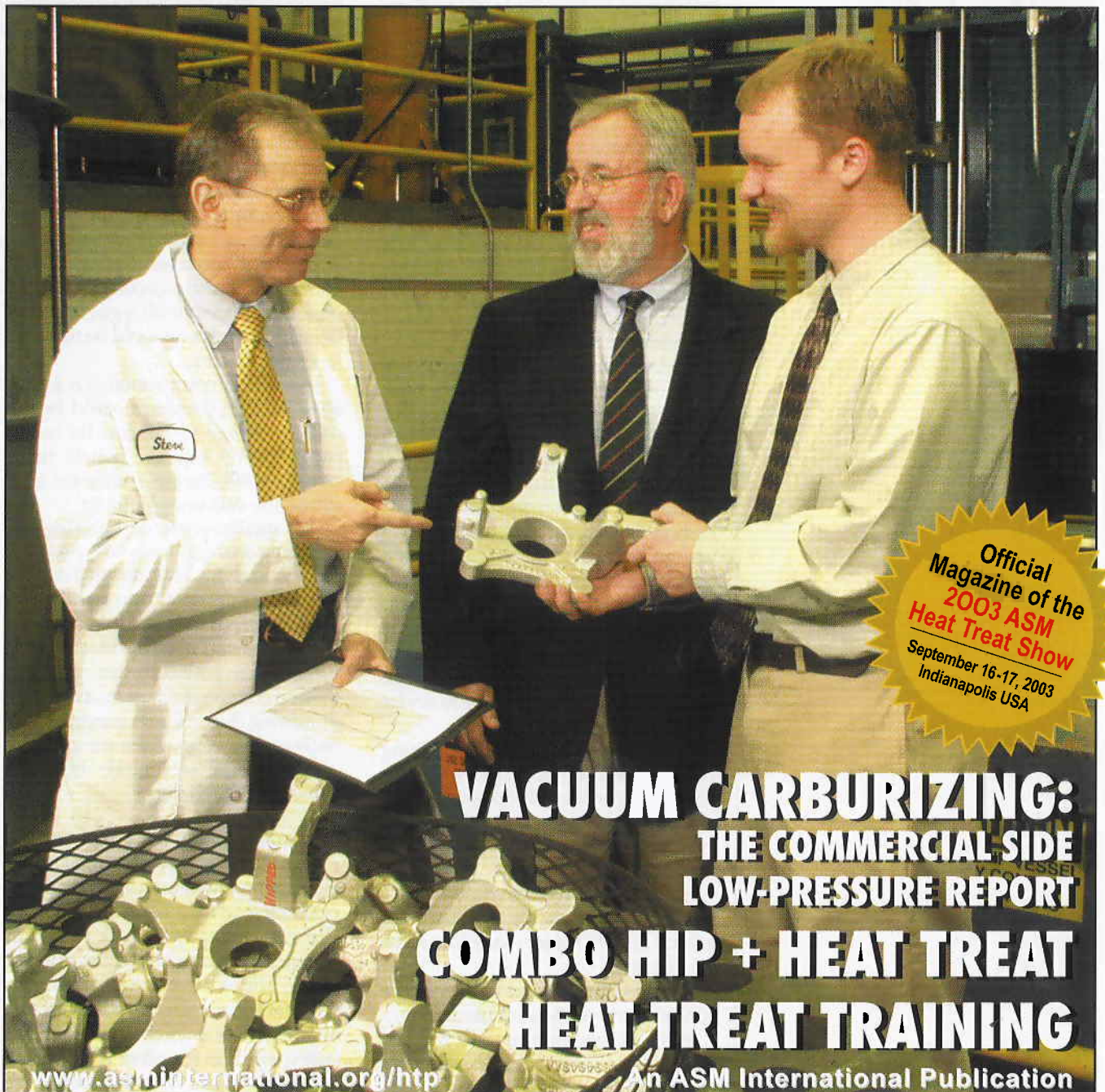


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**VACUUM CARBURIZING:
THE COMMERCIAL SIDE
LOW-PRESSURE REPORT**

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VACUUM CARBURIZING: THE VIEW FROM A

Experimental data show that vacuum carburizing and, especially, its low-pressure variation are viable processes that job shops should consider adopting.

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Vacuum carburizing continues to gain acceptance as an alternative to atmosphere carburizing, particularly in applications where case requirements are demanding. In the United States, vacuum carburizing has predominantly been performed by captive heat treaters, where the equipment was purchased to process fairly narrow ranges of materials, part configurations, and case depths. Less common are commercial heat treaters who offer vacuum carburizing.

However, job shops should take a close look at the process, particularly in light of their customers' increasingly stringent quality demands. As this article demonstrates, former drawbacks have been overcome, resulting in a technology that is versatile, reliable, and consistent.

Advantages summarized

Carburizing in a vacuum furnace is a two-stage boost/diffusion-type process. The boost stage supplies carbon to part surfaces, which is then absorbed. The diffusion stage that follows diffuses the carbon to obtain the required case depth and surface carbon concentration. Parts are preheated in a vacuum to carburizing temperature, and then boost carburized using a hydrocarbon gas under a controlled subatmospheric pressure. The subsequent diffusion step is performed under a rough vacuum. Parts are then quenched in oil or gas under partial or positive pressure.

State-of-the-art vacuum carburizing furnace and process technology offers several important advantages:

- Uniform case microstructure, which is consistent from part to part within a load.
- Furnaces can be equipped for oil, gas, or positive-pressure quenching, which allows many materials to be processed.
- When not carburizing, the furnace can be used for vacuum hardening.
- No oxygen probes or dew-point sensors (or their maintenance) are required.

- Vacuum carburizing can be performed at temperatures from 790 to 1095°C (1450 to 2000°F). Although higher temperatures reduce cycle time, the customer must grant permission.

And, as will be shown, carburizing at lower-than-normal pressures combined with an effective preventive maintenance program can eliminate the excessive downtime that plagued older furnaces.

Sooting problem overcome

In the past, the most common vacuum carburizing problem was excessive soot formation in the furnace. This was directly attributed to the pressure used during the boost stage of carburizing and the quality of the carburizing gas. Early on, pressures as high as 400 torr were being used in combination with a circulating fan. By replacing the fan with a gas injection nozzle, the pressure could be reduced to about 200 torr.

In 1995, a comprehensive study showed that pressure could be reduced further to 100 torr by using pulse/pump injector nozzle technology.¹ Still, the downtime for soot formation was unacceptable.

The quality of the carburizing gas was then changed from 96% propane to 99% propane. This altered the composition of the soot from tar-like to a fine carbon dust that could be more easily removed from the inside of the furnace with air bake-outs.

For a commercial heat treater, better processing due to these changes in furnace carburizing pressure and gas quality translate directly into improved productivity.

Commercial shop benefited

In 1999, Hayes Heat Treating began measuring downtime for unscheduled maintenance for each of its furnaces. Our C.I. Hayes model VBQ vacuum carburizing furnace had the poorest rating. This is a two-chamber furnace, with carburizing in one chamber and an integral oil quench or partial pressure quench in the other (Fig. 1). The most common failure mode was

* Member of the ASM Heat Treating Society

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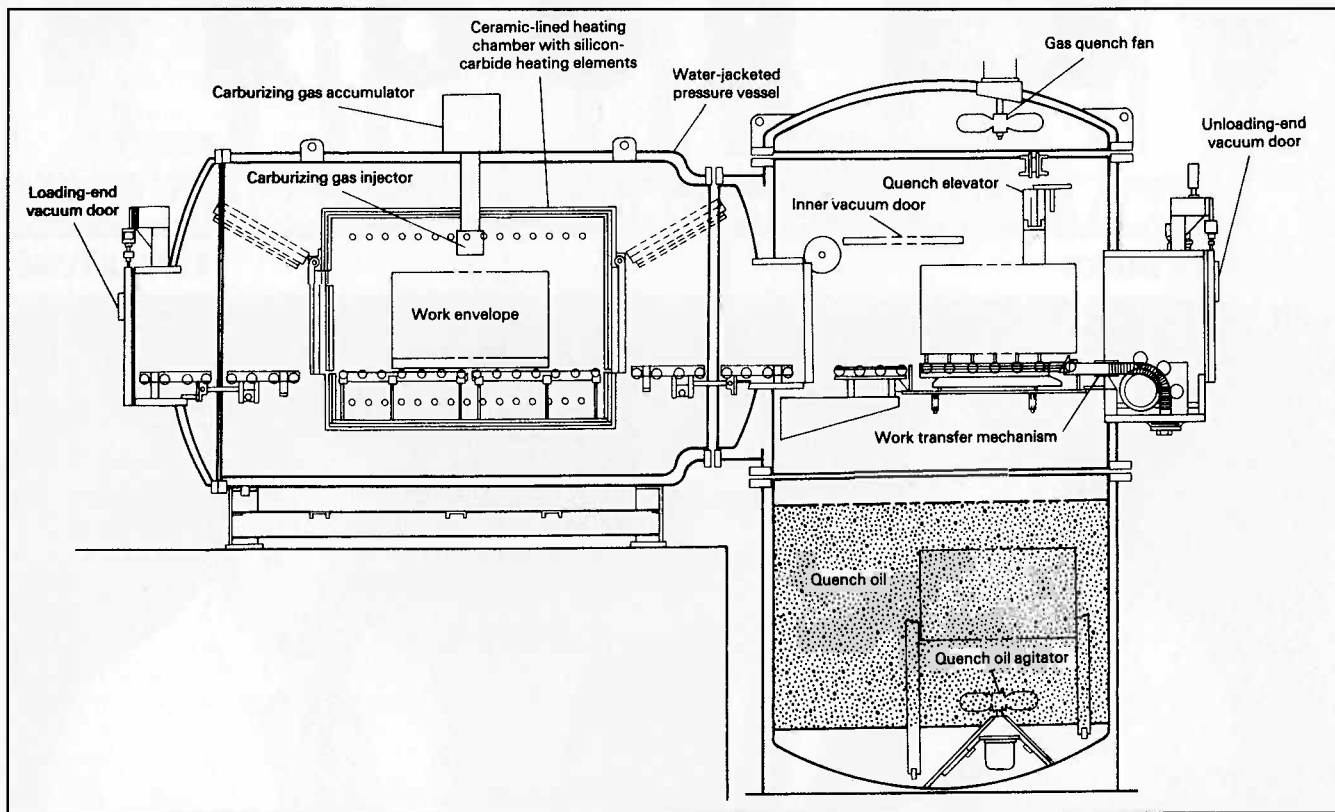


Fig. 1 — Ceramic construction furnaces are well suited for vacuum carburizing because they can be safely operated in air at process temperatures to facilitate soot removal. The Hayes VBQ furnace, for example, features silicon carbide heating elements and ceramic fiber insulation. Ref. 2.

broken heating elements due to "hot spots" caused by soot deposits.

Consequently, a project was launched with the objective of improving the availability of this furnace. As recommended, gas pressure was reduced to 100 torr from 200 torr, and gas quality was upgraded to 99% propane from 96% propane. The improvements measured each year (2000 to 2002) as a result of these two major changes, as well as from other minor enhancements, are shown in the table. These changes had no measurable effect on case hardness or case depth of carburized products.

The model VBQ furnace also is amenable to air bake-out of carbon dust. Its heating chamber features silicon carbide heating elements and ceramic fiber insulation, which can be exposed to air atmosphere at elevated temperatures.

The lesson: By focusing on process improvements and preventive main-

tenance, a vacuum carburizing furnace can be made very productive for a commercial heat treater.

Low-pressure parameters set

Back in 1994-95, experiments were conducted using standard pulse/pump parameters at pressures below 100 torr. A reduction in case depth was observed. In the past year, Hayes Heat Treating revisited this area, but using today's pulse/pump technology, propane gas, and furnace chamber pressures of 15 to 25 torr. A VBQ furnace was used.

A typical cycle for vacuum carburizing AISI 8620 steel (at 100 to 150 torr) to a case depth of 0.76 to 1.02 mm (0.030 to 0.040 in.), followed by a partial-pressure gas quench, is shown in Fig. 2. (The customer requires that parts be hardened by oil quenching in a separate operation.) This cycle for a known, repeatable production process was used as a baseline for comparing

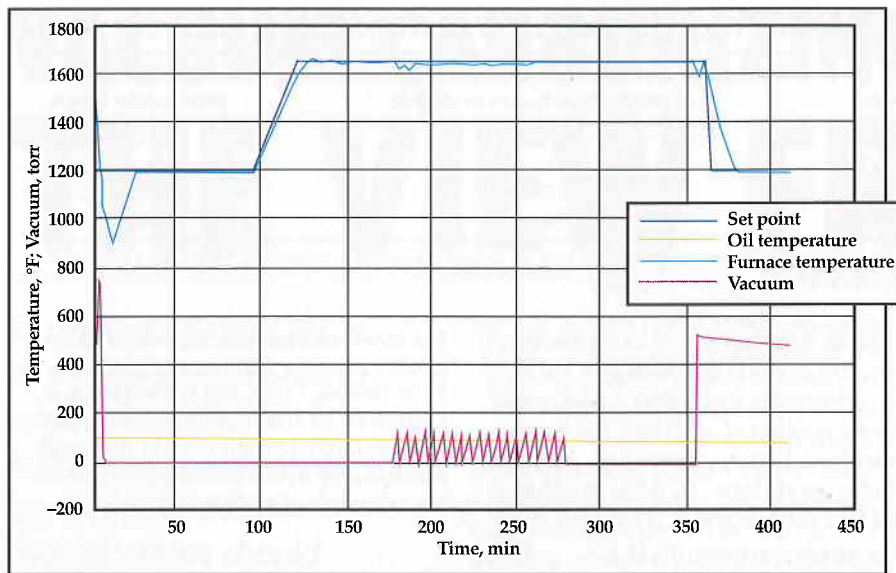


Fig 2 — A typical cycle for vacuum carburizing AISI 8620 steel to a case depth of 0.76 to 1.02 mm (0.030 to 0.040 in.), followed by a partial-pressure gas quench. Furnace pressure: 100 to 150 torr.

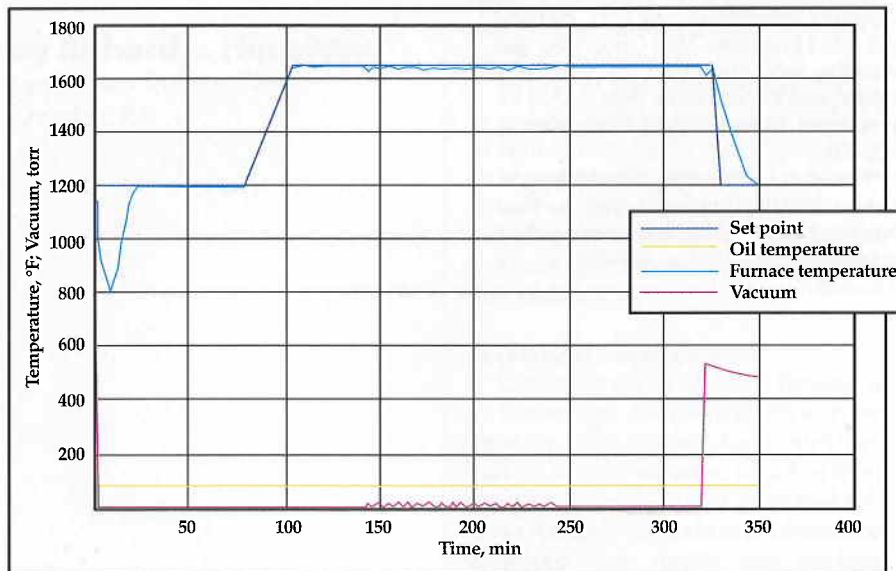


Fig 3 — This low-pressure (15 to 25 torr) carburizing cycle gave case depth and hardness values for AISI 1018 test slugs similar to the baseline values developed at 100 to 150 torr.

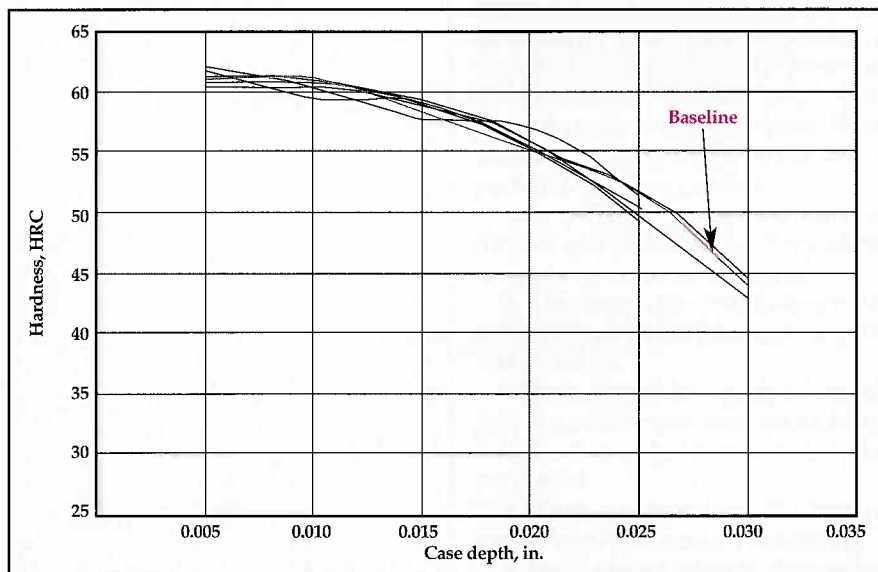


Fig 4 — Hardness profiles for five, low-pressure carburized AISI 1018 test slugs run in a simulated load (four corners and center) compared with the baseline hardness profile.

with the results of low-pressure carburizing tests. Test slugs made from AISI 1018 cold rolled steel were processed with the 8620 production parts to create the baseline data for the testing.

Experiments were then conducted to analyze the effects of varying pulse frequency and pumping parameters. Eventually, low-pressure carburizing conditions were established that gave case depth and hardness values for the AISI 1018 test slugs similar to the baseline values developed at furnace pressures of 100 to 150 torr (Fig. 3). The data plotted in Fig. 4 show the baseline hardness profile and the profiles for five low-pressure carburized slugs run in a simulated load (at the four corners and center).

Low-pressure plusses: Multiple production lots of small gears (Fig. 5) have now been processed using the low-pressure carburizing settings determined experimentally. Case depth and surface hardness have been within acceptable tolerances. Other experiments are now being conducted to confirm these initial results and in so doing, validate a new set of standard processing parameters for low-pressure carburizing.

There are multiple advantages to having a new set of parameters:

- Further increase the “mean time to failure” metric while maintaining the already-low “percent downtime” metric. In other words, the number of failures per year needs to decrease even more. By lowering the carburizing pressure, the furnace should run longer without failing due to soot buildup.

- Improve surface cleanliness of parts after carburizing. This will reduce drag-out of carbon deposits into the degreasing operation that follows the oil quenching. This benefits both the



Fig 5 — Production lots of small gears have now been low-pressure carburized using experimentally determined settings. Case depth and surface hardness have been within acceptable tolerances.

commercial heat treater and customer.

- Maintain the time-temperature parameters used to meet case depth requirements for all parts. Having to increase either the carburizing time or temperature would be an unacceptable tradeoff; and in any event, probably would require the approval of the customer.

- Enhance the carburizing of special alloys such as Pyrowear 675 (AMS 5930), Carpenter Technology Corp.'s carburizing, corrosion-resistant stainless. With vacuum carburizing, it's possible to eliminate the preoxidation step normally required when atmosphere carburizing this steel. And with new low-pressure carburizing parameters, case formation can be controlled by the heat treater to minimize carbide networking.

Furnaces and gases: Several suppliers offer furnaces for low-pressure carburizing (generally below 25 torr). Bear in mind that it is not possible to simply reduce the pressure setting on an older furnace from 200 torr to 20 torr and obtain the same results. Today's furnaces are designed to distribute the carburizing gas around the parts to ensure uniform case formation.

Process improvements extend vacuum carburizing furnace uptime*

Year	Downtime due to unscheduled maintenance, % of production hours available	Mean time to failure, production hours
1999	6.5	—
2000	3.6	213
2001	0.7	558
2002	0.4	1488

* Hayes VBO vacuum carburizing furnace. In 1999, gas pressure was reduced to 100 torr from 200 torr, and gas quality was upgraded to 99% propane from 96% propane.

Note, too, that use of low-pressures also has opened the door to a variety of carburizing gases that could cause severe sooting at ~200 torr, the former standard furnace pressure. Among them: acetylene (C_2H_2), methane (CH_4), cyclohexane (C_6H_{12}), and, as in this article, propane (C_3H_8). **HTP**

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