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Carburizing System Provides
Far-reaching Process Versatility**

New Technology Vacuum Carburizing System Provides Far-Reaching Process Versatility

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Vacuum carburizing, also referred to as "low-pressure carburizing," has become a well-respected and established industrial carburizing process in the United States as well as other regions of the world. Ten years ago in the U.S., Canada and Mexico, the number of vacuum-carburizing systems in day-to-day operation was estimated to be fewer than 40. Today that number has more than tripled and does not appear to be stopping as industry experts cite well over 150 vacuum-carburizing cells presently in North American operation.

Once reserved for aerospace or niche applications in other industries, vacuum carburizing has found its way into general specifications for automotive, gearing, bearing, oil field and heavy-equipment products. Why has this technology taken off at this point in time, whereas earlier interests in vacuum carburizing seemed to die off?

Before looking deeper into the metallurgy of a vacuum-processed component, the bright, clean surface appearance is what is noticed first (Fig. 1). This photo represents an 8620 gear vacuum carburized at 1750°F using cyclohexane at 10-torr pressure. Parts are typically clean, bright and have a silver luster finish.

High-Pressure Gas Quenching

Many customers prefer the associated high-

pressure gas quench technology employed by most vacuum-carburizing systems. Even though capital equipment costs are higher for gas quenching over conventional oil or polymer quenching, the elimination of post washing of parts, bright surface finish and reduced distortion have been the main driving factors in favor of vacuum carburizing. Elimination of quench oil also improves the working environment. In many industries, post heat-treat machining steps have been reduced or even completely eliminated. The reduction in processing steps allows for a reduction in capital equipment required along with factory floor space and labor savings. Even though overall heat-treating capital costs may be higher, the total capital equipment required is often less. Savings are also

reported in the time required to process parts from raw material to final product readiness.

There has also been a move to higher hardenability materials over conventional grades such as 1018 or 8620. This allows larger section parts to be gas quenched. There are also many new alloys available that are earmarked for high-pressure gas quenching and/or higher carburizing temperatures. Many of these new materials have already been introduced to the marketplace and are cost-effective alternatives for many applications.

Process Benefits of Vacuum Carburizing

Vacuum processing allows the heat-treating equipment to be located in clean room



Fig. 1. Vacuum carburized 8620 gear

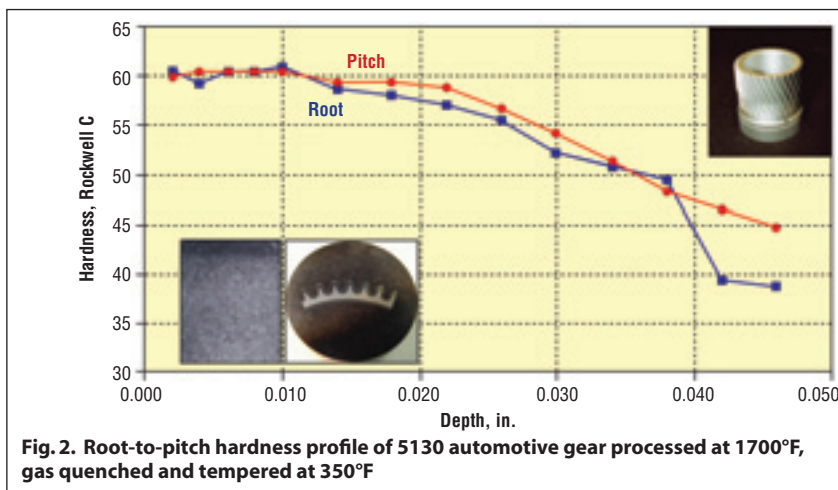
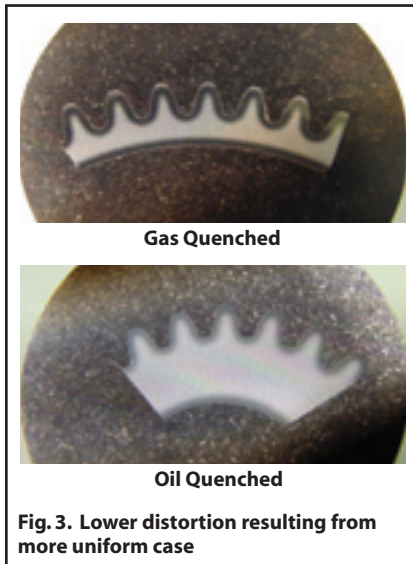


Fig. 2. Root-to-pitch hardness profile of 5130 automotive gear processed at 1700°F, gas quenched and tempered at 350°F



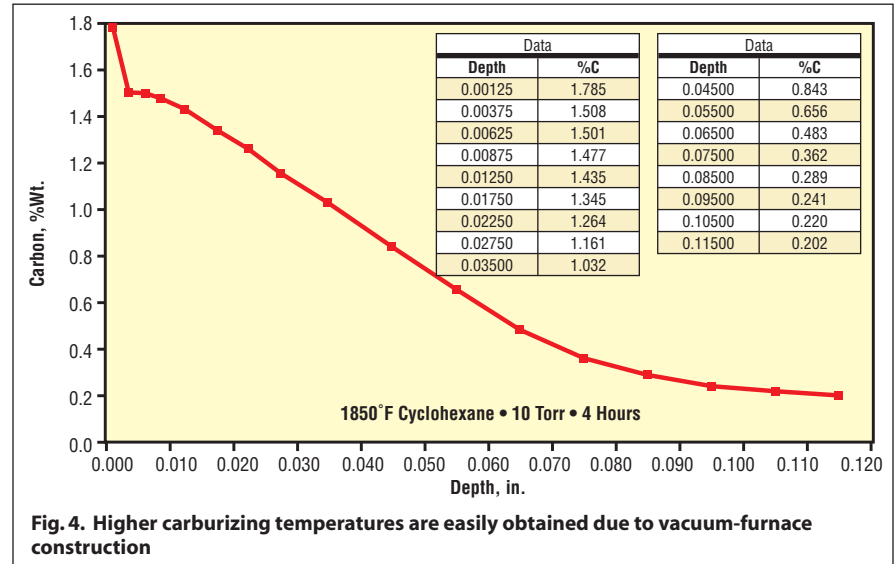
environments or in the area adjacent to production machining equipment. Atmosphere equipment is typically isolated in an area designated strictly for heat treating. With more and more manufacturing areas now being air-conditioned, the cool nature of vacuum equipment fits right in (see sidebar Fig. B).

Vacuum carburizing has also been popular in the gear industry, including those used in high-production automotive and truck transmission gearing as well as final drive gears. Root-to-pitch hardness profiles are typically in the 90-percentile range, whereas atmosphere carburizing typically yields profiles in the 60s to 70s (Fig. 2).

Many industries require low distortion. As seen in Figure 3, vacuum carburizing typically results in a highly uniform case depth throughout the part. This improvement in uniformity can be attributed to the reduced distortion often experienced. Better uniformity of part case depths typically equates to more uniform compressive stresses. Gas quenching can often further reduce distortion since the traditional vapor phase that occurs in liquid quenching is eliminated.

Higher Operating Temperatures

Vacuum carburizing also allows for higher operating temperatures due to the design and construction materials used. Typically, vacuum furnaces do not use conventional nickel-chrome alloys, which experience a



shortened life cycle by operating at high temperatures. Furnaces used in a vacuum environment are built by relying heavily on ceramics, graphite, and refractory metals such as molybdenum or silicon carbide. High-temperature processing can significantly shorten cycle times. Higher temperatures also yield higher carbon potential due to higher saturation levels of carbon in austenite. Vacuum carburizing operating at saturation at low pressures for sustained times does not "rain soot" as atmosphere carburizing normally does. The benefit is faster diffusion, since higher carburizing saturation levels can drive the carbon faster into the case, and carbon diffuses faster at higher temperatures (Fig. 4).

Most applications require carbon levels in the 0.75% to 1.05% range on the part surface. These levels are easily accomplished by boost and diffuse timing relationships. There are, however, some unique applications where extensive carbides are desired in the case. This results in higher surface hardness to stand up to fluid erosion and, in general, to enhance wear properties. For these applications, operating the majority or even the entire cycle at saturation is easy to do with vacuum processing. Most normal applications use a short boost time, running at saturation, followed by a longer diffuse cycle, which allows the surface carbon to fall to the desired final surface-carbon level. The boost and diffuse times are a function of tempera-

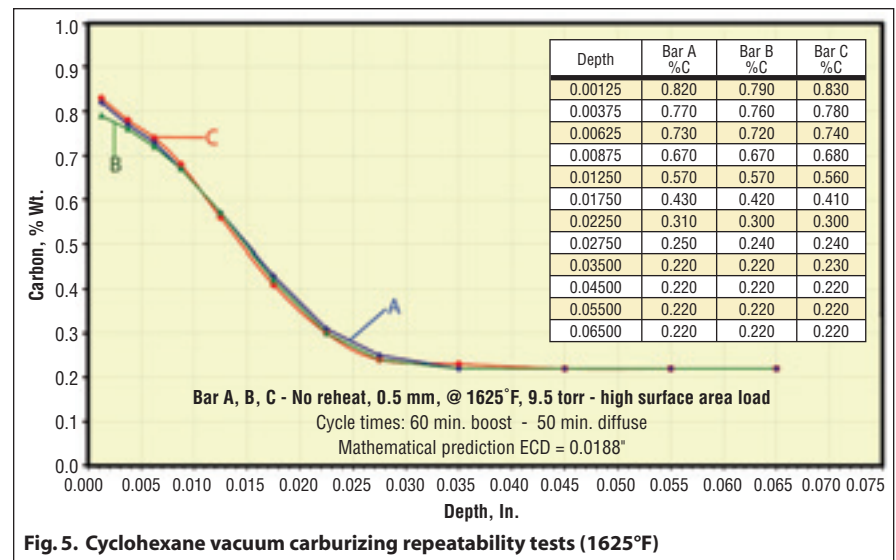




Fig. 6A.
System to sense
hydrocarbon and
ammonia levels

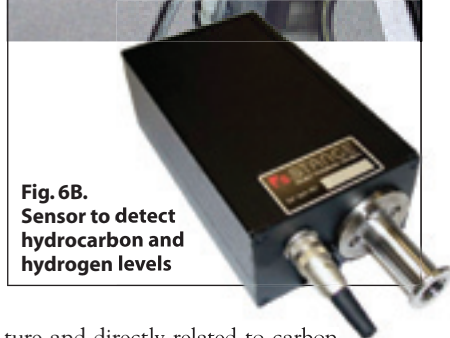


Fig. 6B.
Sensor to detect
hydrocarbon and
hydrogen levels

ture and directly related to carbon saturation but, most importantly, to the final desired surface carbon level (Fig. 5).

Since the process easily obtains carbon saturation directly associated to temperature, vacuum-carburizing cycles are extremely repeatable (Figs. 5, 7 and 8). This demonstrates the repeatability of different runs conducted on different days. All runs were also high surface-area loads. It is important that the carbon-bearing atmosphere have sufficient carbon available to satisfy the demands of these loads. Cyclohexane (C_6H_{12}) atmospheres provide high levels of carbon since each molecule contains six carbon atoms. The hydrogen-to-carbon ratio for cyclohexane is good at two

to one. Abundant levels of hydrogen can lower, or dilute, the potency of a carburizing hydrocarbon. Surface Combustion has also developed several direct-reading sensors for assuring satisfactory hydrocarbon flow rates. This technology assures flow rates are sufficient by actually sensing hydrocarbon levels and/or hydrogen levels in the vacuum chamber (Fig. 6).

Reproducibility

Vacuum carburizing is very predictable. In conventional atmosphere carburizing, both temperature and carbon potential control case depth as well as final surface carbon levels. Both must be strictly controlled, but often carbon potential is harder to maintain.

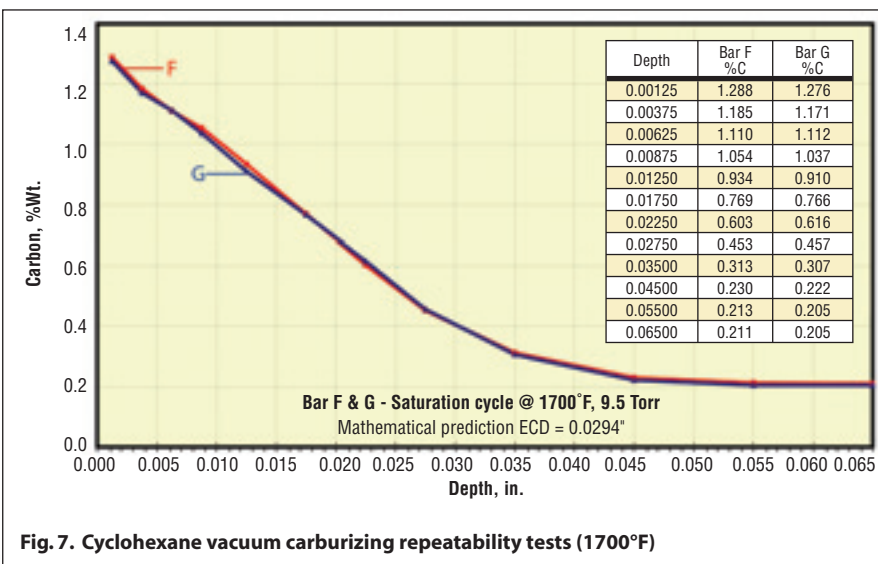


Fig. 7. Cyclohexane vacuum carburizing repeatability tests (1700°F)

In addition, atmosphere carburizing is subject to incoming gas conditions, CO levels, etc. With vacuum carburizing, the temperature is easy to control (as with all furnaces operating in these temperature ranges), but carbon potential automatically goes to saturation (or boost). This inherent process characteristic eliminates carbon control from the vacuum-carburizing process. For this reason, the process is easily repeatable and can be mathematically predicted based on temperature along with the boost and diffusion times involved in the cycle. Another positive aspect of vacuum carburizing is that most cycles allow the load to soak out at carburizing temperature before the carburizing gas is introduced. By doing so, the load is at temperature throughout assuring that parts that may be farther from the radiant tubes or heating source are at temperature before carburizing begins. Load case depth uniformity benefits from this factor.

The predictable nature of the vacuum-carburizing process also applies to different operating temperatures. Comparing the 1750°F and 1625°F carbon-gradient graphs as shown in Figures 8 and 5, we can see that the two cycles are very similar even though saturation levels and diffusion rates are substantially different for the two temperatures used.

System Design Considerations

Surface Combustion has recently sold multiple vacuum-carburizing systems using

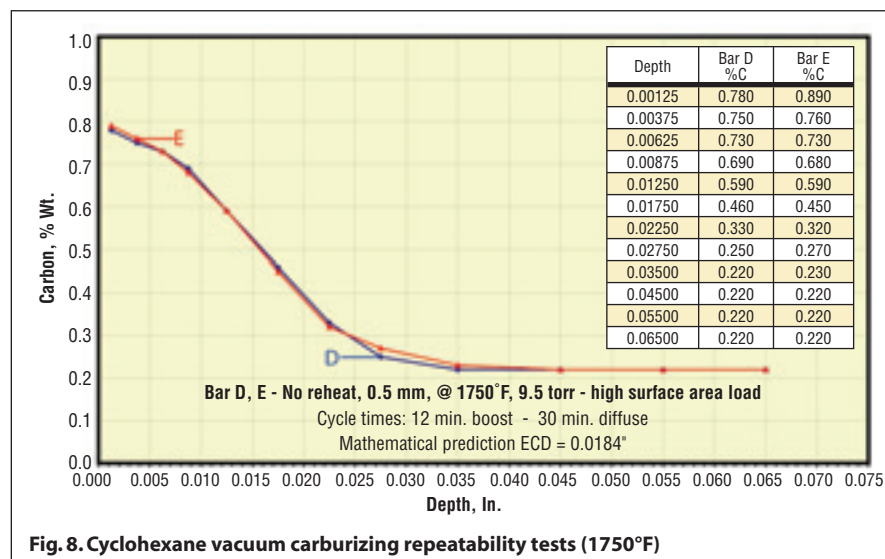


Fig. 8. Cyclohexane vacuum carburizing repeatability tests (1750°F)

the liquid fuel-injector technology built around a readily available, high-density, high-purity, cyclohexane hydrocarbon. One such system (Fig. 9) features individual heating zones that can be isolated from each other via integrated tight-sealing vacuum doors.

The tight-sealing vacuum doors provide process isolation from each cell or chamber. This allows for processing different items at the same time, such as hardening with nitrogen or argon partial pressure in one cell while carburizing under cyclohexane or diffusing under a hard vacuum in another cell. This isolation not only improves processing but also greatly simplifies leak testing or servicing of any given hot zone or cell.

In addition to the tight-sealing vacuum



Fig. 9. VringCARB® vacuum-carburizing technology

doors, each chamber has a service door. The service doors are also provided for the high-pressure gas quench, oil quench and

the transfer mechanism. Any chamber can easily be isolated from production and accessed after it has cooled down and vented

Vacuum Carburizing at MMS

MMS Thermal Processing LLC, located in Davenport, Iowa, is a state-of-the-art commercial vacuum-processing facility that also provides VringCARB® vacuum-carburizing technology. The brand-new 18,000-square-foot facility (Fig. A) is staffed with a full-time metallurgist, bringing MMS' customers over 30 years of vacuum, vacuum-carburizing and atmosphere heat-treating experience. Staffed at 17 full-time personnel, MMS offers conventional vacuum processing for tool steels, stainless steels and conventional oil-quench vacuum grades such as 4140, 52100 and tool steels. The integral vacuum oil-quenching system, in addition to providing both cold oil and warm oil processing, yields a brighter surface finish over conventional atmosphere oil-quenched product.

The MMS vacuum system also has 20-bar nitrogen-gas-quench capability for processing a wide range of carburizing-grade alloy steels, as well as vacuum-carburizing specialty stainless steels such as Pyrowear 675¹, CSS-42L² and other carburizing stainless steels. The 20-bar gas quench, in conjunction with their high-temperature, electrically heated vacuum equipment, provides processing ranging from high-speed M-series tool steels to air-hardening, cold-work tool steels such as A2 or D2 and their associated families (Fig. B).

Air Products worked closely with both Surface Combustion and MMS Heat Treating to meet their nitrogen requirements. MMS needed gaseous nitrogen for their high-pressure gas-quench process and cryogenic-treatment process, requiring -320°F liquid nitrogen. To meet their needs, Air Products installed three house lines – a high-pressure line that will operate at approximately 360 psi, a low-pressure line that will operate at 100 psi and a vacuum-



Fig. A.

jacketed line that will handle the cryogenic liquid. To lower costs as compared to typical mechanical systems, a special high-pressure-supply vaporization system was installed. In addition to the supply system, Air Products installed a PURIFIRE® nitrogen-supply monitoring system that notifies the operator if the nitrogen supply is so low that it would not be able to safely purge the furnaces in the event of an emergency. The nitrogen tanks are equipped with a TELALERT® telemetry system that monitors MMS' nitrogen-use patterns, allowing Air Products to forecast optimized delivery schedules.

Multichamber vacuum equipment also provides the bright processing of stainless steels at low temperatures. By utilizing sealed vacuum chambers in a multichamber arrangement, water vapor or other airborne contaminants are isolated from the heating chamber. This is ideal for processing many materials that may be difficult to keep bright in single-chamber applications.

to atmosphere. Individual vacuum pumps are also provided to improve the overall integrity and reliability of the system.

The system shown has been provided with three vacuum-carburizing chambers and one high-temperature non-carburizing chamber intended for high-temperature processing of tool steels and stainless steels. This chamber can operate under partial pressure or hard vacuum.

Gas-fired radiant tubes utilizing pulsing technology heat the three carburizing chambers. The radiant tubes utilized are silicon carbide, using technology previously supplied by the manufacturer on another gas-fired vacuum furnace at an industrial-tool manufacturer located in Elyria, Ohio. The referenced gas-fired

vacuum furnace has been in operation since 1997, processing at temperatures up to 1975°F.

Gas quenching is accomplished with 20-bar nitrogen-backfill capability, recirculated with an internal 400-horsepower cooling fan. Oil quenching is also provided in a separate chamber using quench oil formulated for vacuum service designed for operation between 160°F to 220°F.

An Allen Bradley PLC and a PC running Iconics Genesis 32 provide control of the total furnace system, storage of recipes, data acquisition and alarm monitoring. **IH**

¹ Pyrowear 675 is a trademark of Carpenter Technology

² CSS42L is a Trademark of Timken Latrobe Steel.

³ Blue Wave is a trademark of Blue Wave Ultrasonic, Inc.

⁴ DMP CryoFurnace is a trademark of DMP CryoSystems

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Fig. B.

For prewashing and postwashing, several units are installed. A Blue Wave³ multistep ultrasonic cleaning system is used to remove all incoming contaminants such as chips, cutting fluids and rust inhibitors. Some surface contaminants can impede vacuum carburizing, and prewashing - often accompanied with air "burn offs" - assures these potential problems are eliminated before entering the vacuum equipment. Also installed is a spray dunk washer for postcleaning oil-quenched product. Gas-quenched product requires no post washing and gas quenching is used whenever possible. For pre-heating or tempering of final product, the facility presently has one Surface Combustion VacuDraw[®] vacuum-tempering furnace and three Uni-DRAW[®] tempering furnaces (Fig. C). Both vacuum- and air-tempering furnaces are capable of processing up to 1400°F.

Quite often tool steels or even high-alloy carburized materials benefit from deep freezing. Many aerospace specifications require



Fig. C.

a deep freeze immediately following quenching. To accommodate this requirement, a DMP CryoFurnace⁴, which is a combination deep freeze and temper, has been installed. The system is capable of reaching -300°F and can immediately raise parts to tempering temperatures up to 1200°F. Some materials may even require multiple tempers or multiple deep freeze/tempering cycles.

For quality assurance, a new complete laboratory is onsite with Buehler technology. Customers will have access to their metallurgical testing data at any time via MMS Thermal's website.

MMS Thermal Processing is one of three facilities within the commercial heat-treating group. In addition to the vacuum-carburizing complex, the organization also has atmosphere processing at Midwest Heat Treat (Havana, Illinois,) and induction-hardening capabilities at Induction Services (Eldridge, Iowa). The three facilities offer customers a complete menu of heat-treating capabilities.