

# GEARSolutions

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## High Temperature Vacuum Carburizing Drives Alloy Development

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With gear surfaces, a growing demand for greater fatigue resistance can only be achieved by specialized heat treatments. Vacuum carburizing — low pressure carburizing — is a process that can be used to apply hardness, wear resistance, and increased fatigue life in specific parts.

Vacuum carburizing (low pressure carburizing, or LPC) is a process used to impart hardness, wear resistance and increased fatigue life in such applications. LPC is a treatment in which the steel component absorbs carbon liberated from a hydrocarbon gas into its surface at a low process pressure of 12 torr or less. New advanced alloys have enabled the use of high temperature vacuum carburizing (HTVC) for high performance parts. Although HTVC requires the use of more costly, special alloys, high temperature processing dramatically lowers the time (and cost) it takes to carburize the part surface to the specified carbon profile and case hardening depth.

## VACUUM CARBURIZING (LOW PRESSURE CARBURIZING)

In many metal part applications, post-production thermal treatments are used to impart desired properties to the parts. Gears are a significant case in point, where increasingly stringent demands for greater fatigue resistance can be achieved only by customized thermal treatments. Heat treating is used impart to gear surfaces their necessary hardness and wear resistance, while leaving the gear's center ductile, but tough. Vacuum carburizing is a thermal treatment in which the steel components absorb carbon, which is dissociated from a hydrocarbon gas at a low process pressure at elevated temperature (Figure 1). This produces a carbon gradient of high concentration (and greater hardness) at the surface of the part and decreasing at depths below the part's surface. The properties of affected areas vary with the time and temperature of the heat treatment.

At the molecular level, vacuum carburizing works via the transfer of carbon atoms into the surface layers of a metal. During the carburizing cycle of the heat treatment, the carbon-containing gas (such as acetylene) is dissociated into its elemental components at the hot surfaces of the steel parts (Figure 2).

The liberated carbon diffuses into the part as a function of time and temperature, to achieve the desired case depth (Figure 3). When the treated component is then cooled rapidly by quenching, the higher carbon content on the outer surface leads microstructural transformation from austenite to martensite, resulting in high hardness. At the same time the core with original carbon content remains a softer but tough microstructure with fractions of ferrite/perlite, bainite and martensite. The magnitude of these volume-fractions in the core depends on part-geometry, cooling rate and the hardenability of the steel. At elevated temperatures the diffusion of carbon into the material is much faster. Thus, more carbon can be transferred and the desired carbon profile is much faster achieved. In addition, the likelihood of carbide-formation is reduced. For most technical applications, the formation of carbides in the components is seen as unfavorable.

The use of vacuum carburizing has gained a great deal of favorable attention in recent years. The process offers a much higher carbon mass-transfer into the part than does conventional atmosphere based gas-carburizing. There are a number of advantages to the use of vacuum carburizing that make the process commercially attractive. The most important among these are:

- Reduced cycle-times (due to high mass transfer)
- Superior carburizing uniformity, even for complex part-geometries
- Components are free of inter-granular oxidation (IGO) and surface oxidation
- Process gases are readily available and moderately priced
- Conditioning of the equipment is not necessary
- High process repeatability
- Environmental friendliness
- Ergonomic comfort; no flames, no smoke, safe to touch

## THE CASE FOR HIGH TEMPERATURE VACUUM CARBURIZING (HTVC)

The primary reason carburizing is commercially used is to enable the use of inexpensive steel grades in applications that might otherwise require the use of more expensive and more highly alloyed grades. The surface hardening achieved through carburizing upgrades the properties of the component so that it can be used in more demanding applications. Vacuum carburizing, which offers a much higher carbon mass-transfer rate than does atmosphere based gas carburizing (and is consequently faster) generally occurs at temperatures ranging from 890 – 980°C (1,635 – 1,800°F), and at pressures of 12 torr or less. When carburizing at temperatures above 980°C, unwanted grain growth may occur when using

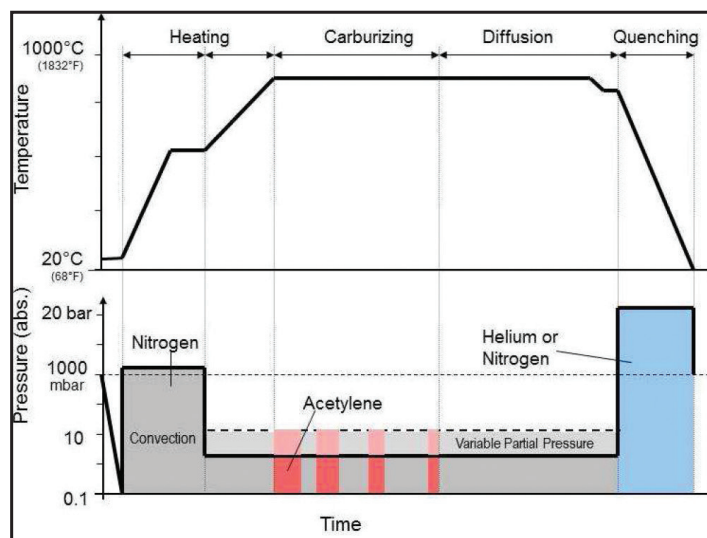


Figure 1. Schematic diagram of the low-pressure carburizing and high-pressure gas quenching process.

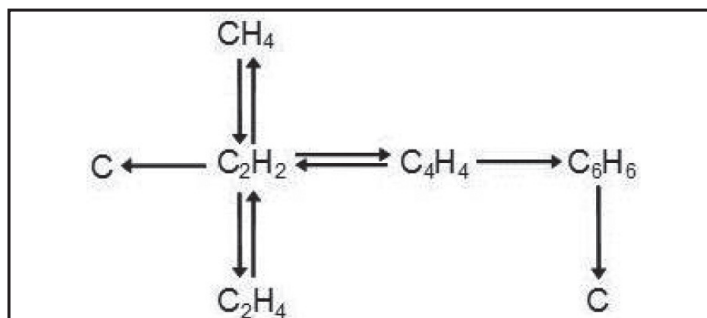


Figure 2. Dissociation reactions during acetylene pyrolysis.



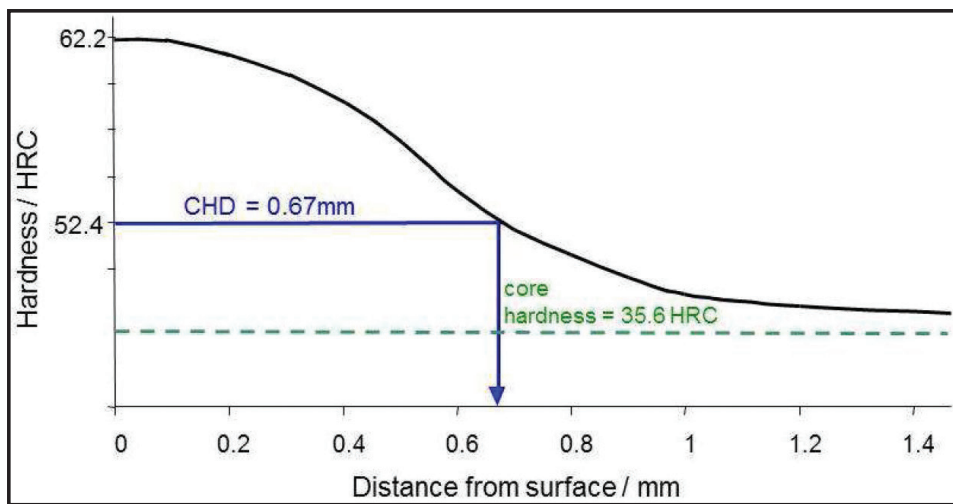


Figure 3. Example of a hardness profile after case hardening.

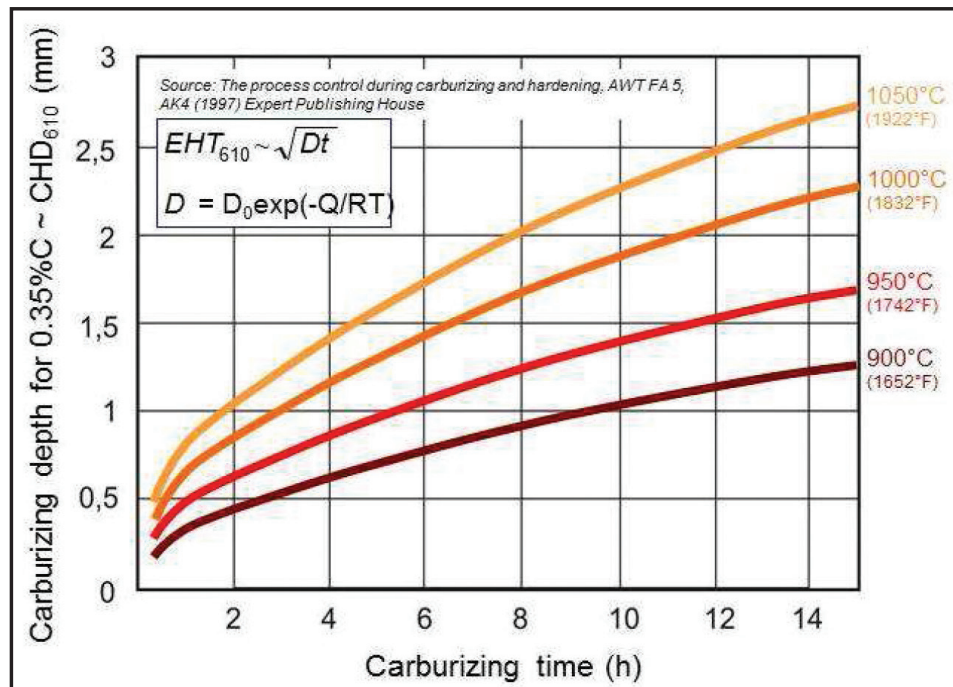


Figure 4. Carburizing depth as a function of carburizing temperature and duration (without heating).

conventional case hardening grades. Such grain growth may have detrimental effects on fatigue properties. But recently, along with the increased use of more advanced alloy materials, it has been proven that higher temperatures during vacuum carburizing can be applied. When using more advanced steel grades, the previous temperature limitation of 980°C (1,800°F) can be exceeded. These new steel grades have been (and are being) developed that enable desirable fine-grain stabilization even at temperatures well above 1,000°C (1,832°F). When combined with modern vacuum furnace technology these advanced alloy grades

have helped establish and promote (HTVC) technology. HTVC alloys have been developed through extensive research efforts to define alloy recipes and test them under actual HTVC cycles. Aside from the ubiquitous carbon found in all these alloys, other alloying elements include manganese, chromium, nickel, molybdenum, boron, etc. In order to establish fine-grain material, tiny amounts of so-called “micro-alloying elements” such as niobium or titanium are added in the ppm-range to the material.

Of critical importance here is that higher temperatures not only accelerate the vacuum carburizing process, but that

they do so exponentially — turning the process into a potential windfall of savings to the part processor or manufacturer (Figure 4). In fact HTVC technology so drastically reduces thermal processing time (and consequently cost) that the use of more expensive alloys becomes more easily justified.

To illustrate, consider the case of parts made of the case hardening steel 18CrNi Mo7-6 that are to be carburized to a case depth of 1.5 mm. If, for example, the carburizing temperature was increased from 930°C (1,706°F) to 980°C (1,796°F), the length of processing time can be reduced by 25 percent. An additional increase to 1,080°C (1,976°F) reduces overall processing time by 40 percent, and if this is compared to standard gas carburizing an approximate reduction in process time of 50 percent can be realized.

In another example, 8620 steel was vacuum (low pressure) carburized with acetylene at 1,700°F (927°C) to a case depth of 0.07-inch and surface carbon concentration of 0.9 percent. This took 5.8 hours (see Figure 5). Achieving the same results at 1,750°F (954°C) took 4.1 hours, a time saving of 29 percent. Finally, at 1,900°F (1,038°C) the same results were achieved in 1.6 hours. In this case, a 200°F increase in processing temperature resulted in an amazing 72 percent total decrease in processing time.

## A NEW GENERATION OF MATERIALS

A number of steel suppliers already offer alloys that can be vacuum carburized at high temperatures while inhibiting unwanted grain growth. These alloys, because they can be vacuum carburized to specified case depths in a fraction of the time required of other alloys at lower temperatures, have drawn a lot of R&D attention and support from various manufacturers, many of which have begun full-fledged programs to develop and offer broader lines of advanced alloys to serve this market. The results of experimental trials on many of these materials verify that grain growth is securely prevented -- even at higher



temperatures. The following companies represent a sample of those that have developed and successfully introduced steel alloys suitable for vacuum carburizing.

Many companies have R&D programs underway to increase the growing list of HTVC-appropriate alloys and to develop alloys capable of being vacuum carburized at increasing temperatures. Below is a list of companies which represent a sample of those that have developed and successfully introduced steel alloys suitable for vacuum carburizing. The advanced alloys listed have been designed specifically for HTVC. Readers are advised to check with the manufacturer before specifying alloys for a certain process or for treatment within a specific temperature range.

- Atlas Specialty Steels — BS970, EN30B
- Aubert & Duval — X13 VDW and XD15NW
- Böhler-Uddeholm — N360 Iso Extra, N695, R250, R350
- Carpenter Technology — Pyrowear® 53 and 675, AF1410, HY180, HP-9-230, HP-9-430 and AerMet 100 and others
- Gerdau Steel — Gerdau offers the technology to produce high temperature carburizing steel to typical carburizing steel grades for forging such as 8620, 4120, and 20MnCrS5 by way of niobium and titanium additions to the melt practice.
- Questek Innovations — Ferrium® C61, CS63, C69, M60S and S53
- Teledyne Corp. — VascoMax C-250, CD-300 and CD-350
- TimkenSteel — VacTec® 200, 250, 275L, 300, 325L, 350, 400, CSS-42L, M50NiL, CBS-600, BG42VIM/VAR, CBS 223 and 16NCD13 VAC-ARC
- VSG Essen — Cronidur 30

(Primary Source: *Vacuum Heat Treatment*, Daniel H. Herring, BNP Media II, © 2012)

## OPENING NEW MARKETS

The materials listed above, designed as they are for HTVC applications, represent more than just a niche market in vacuum thermal processing. They are a growing trend in the vacuum heat treating industry. Often, vacuum carburizing and

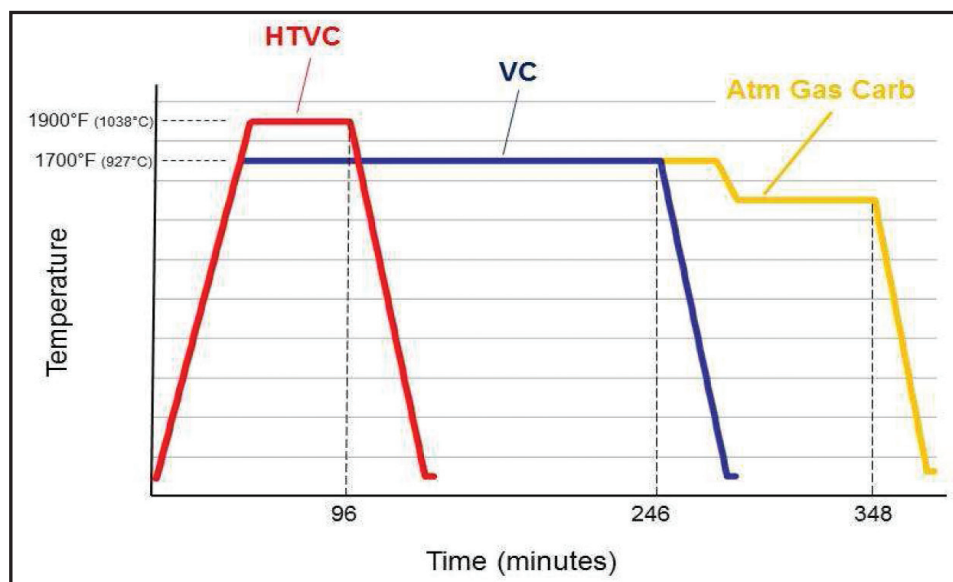


Figure 5. Carburizing Cycle Time Comparisons, Material SAE-8620, .070" total case & .044" ECD @ .9% S.C.


HTVC processes are used in conjunction with high pressure gas quenching (HPGQ) systems (as opposed to oil quenching in traditional gas carburizing techniques) to maintain improved dimensional stability of the parts in process. HPGQ quenches the workload in an inert gas stream. This results in better distortion control and yields cleaner part surfaces, making washing procedures (and the costs associated) after heat treat obsolete.

It is true that the use of HTVC processes usually means the use of more expensive alloys, but the relative speed of HTVC cycle times helps offset the costs of high-performance parts.

The aerospace and high-performance automotive (motorsports) industries are two major beneficiaries of the trend toward the use of advanced alloys in HTVC treatments. Aerospace applications include those for rotorcraft and aircraft, including gearboxes, landing gear systems and numerous other parts. HTVC processes have furthered high performance motorsports by enabling the production of gears and crankshafts rated for highly loaded engine systems.

## SUMMARY

Vacuum Carburizing (Low Pressure Carburizing LPC) is a process used to impart hardness, wear resistance and increased fatigue life to certain types of parts - especially gear surfaces. LPC

is a thermal treatment in which steel absorbs into its surface carbon liberated from a hydrocarbon gas in the furnace chamber at elevated temperature. New advanced alloys have enabled the use of HTVC for high performance parts. HTVC requires the use of more costly, special alloys, but high temperature processing dramatically lowers the time (and cost) it takes to carburize the part surface to the specified carbon potential and case depth. In summary, any application requiring a wear resistant, clean, hard surface and an increase in fatigue life can be considered a candidate for HTVC-processed components. 

## REFERENCES

1. D.H. Herring, *Vacuum Heat Treatment*, BNP Media II, 2012
2. V. Heuer, *Low-Pressure Carburizing* ASM Handbook® Volume 4A; "Steel heat treating fundamentals and processes" 2013, pp. 581-590

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