

# The Advantages of Low Pressure Carburizing in the Heat Treatment Subcontracting Business

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**Abstract:** Low Pressure Carburizing (LPC) was introduced in the 90's in the western Europe Heat Treatment business, mainly for in-house applications where it was especially appreciated for carburizing of transmission parts. However the success of the LPC units installed for gears carburizing in the automotive industry has hindered the development of the process in other fields – like subcontracting business - , where its advantages deserve to be enlightened.

After a brief review of the principle of the process, the interest of its classical application to transmission parts is described, underlining peculiarly the reduction of the distortion observed when LPC is associated with high pressure gas quenching. Then the less-known advantages of the LPC process, like the high accuracy and reproducibility of the results, the modeling possibility and the simulation easiness, the case-depth uniformity and the full flexibility of the units are considered, showing how they can be beneficial to subcontracting business.

**Key words:** carburizing, low pressure, subcontracting.

WHEN VACUUM CARBURIZING (i.e. carburizing in a vacuum furnace) was first introduced in the U.S. in the early 70's, the basic idea was to get a process harmless to the environment using only propane as carburizing gas instead of the toxic and dangerous classical atmospheres made of carbon monoxide and hydrogen mixtures; at that time the pressure range used was just below the atmospheric pressure (some hundreds of millibars) in order to be able to force the carburizing gas throughout the load using a fan. The difficulties experienced with such process were in term of carbon control, case-depth uniformity and sooting.

The development of the modern Low Pressure Carburizing using pressures in the millibars range started in the 80's, when one French car manufacturer pushed forward the idea that using much lower pressures would reduce sooting and improve carburizing penetration through the load, even if not agitating the molecules of the carburizing medium with a fan, but simply because of the longer average free-path of the molecules<sup>1</sup>. However this process evolution had a drawback may be not fully recognized in these early times: there is a very clear and strong limitation regarding the total surface to be carburized related to the dimensions of the working zone of the furnace, depending upon the spread in term of case depth which can be accepted from piece to piece within a load.

The real industrial era of this new process now called "Low Pressure Carburizing" (or LPC) started in 1992 when a furnace manufacturer designed a line made of several carburizing cells (in order to achieve the required throughput) of a limited volume. A new step forward was made in the late 90's when acetylene was introduced as an alternative to propane improving a lot the performances on dense loads made of

numerous pieces of complex geometry.

There are nowadays more than six hundreds LPC cells installed worldwide, most of the lines having four to six cells associated to a gas or oil quench chamber. The way loads are distributed from cell to cell varies regarding the design retained by each furnace manufacturer but always follows the same chain of sequences: enter the load in a separate chamber; evacuate; move the load under vacuum; go to the carburizing cell; carburize; move as quickly as possible to the quench chamber under vacuum; quench; exit through a separate chamber or the quenching one.

Not forgetting its other advantages, the fact that a LPC line is of cold-wall design, with no fumes, outside heat radiation or exhaust gases was a key-point which shortly made this concept very famous within the automotive industry. Most of the references of such lines belong to this heat treatment heavily consuming sector of activity, where the possibility to install directly the LPC facility in the manufacturing line, thus reducing dramatically lead-times and work-in-progress costs was immediately deeply appreciated.



Fig 1 Multi-chamber LPC line (900x600x900mm cells)

This success for sure hindered the development of the technology in the subcontracting business where only few units were installed before the year 2000. However Low Pressure Carburizing can also bring various and heavy advantages to the subcontracting business, as shown hereunder.

## 1. Principle of the modern LPC process

All the hydrocarbon gases having been so far used in LPC are listed in table 1, showing in a very simplified way the products of the dissociation of the molecules at the surface of the steel, under the conditions of temperature and pressure usually encountered in modern applications. Well known is the fact that the methane molecule does not dissociate under these operating conditions, unless we use plasma assistance, the glow discharge breaking then the molecule at the immediate vicinity of the surface. Consequently this gas can be considered as inert in the pure LPC process and active only with plasma assistance, the process being then called PA-LPC for "Plasma Aided Low Pressure Carburizing". However, beside applications where plasma is really needed (like preliminary surface activation, or local protection against carburizing with metallic masking), this process has fallen more or less in disuse, because of the impressive development of the pure LPC process using propane and more recently acetylene (or ethine) without the complexity in the furnace design brought by the plasma assistance. On the other side, ethylene is no longer used because of excessive tendency to produce soot and tar in the cold areas of furnaces.

Table 1 Dissociation of various hydrocarbon molecules (900 °C <  $\theta$  < 1000 °C and  $p < 30$  mbar)

Methane CH <sub>4</sub>	LPC	CH <sub>4</sub> ⇒ CH <sub>4</sub>
	With plasma	CH <sub>4</sub> ⇒ C + 2H <sub>2</sub>
Propane C <sub>3</sub> H <sub>8</sub>	LPC	C <sub>3</sub> H <sub>8</sub> ⇒ C + 2CH <sub>4</sub>
	With plasma	C <sub>3</sub> H <sub>8</sub> ⇒ 3C + 4H <sub>2</sub>
Ethylene C <sub>2</sub> H <sub>4</sub>	LPC	C <sub>2</sub> H <sub>4</sub> ⇒ C + CH <sub>4</sub>
	With plasma	C <sub>2</sub> H <sub>4</sub> ⇒ 2C + 2H <sub>2</sub>
Acetylene C <sub>2</sub> H <sub>2</sub>	LPC	C <sub>2</sub> H <sub>2</sub> ⇒ 2C + H <sub>2</sub>
	With plasma	C <sub>2</sub> H <sub>2</sub> ⇒ 2C + H <sub>2</sub>

Nowadays we can state that applications using either propane or acetylene (without plasma assistance) represent something like 95% of the cycles run worldwide. The proportion of acetylene in the total grows permanently due to the tremendous capacity of this molecule to transfer carbon to large surfaces even if of very complex geometry, like long and/or blind holes. The differences in the carburizing performances of both molecules lay in the fact that contrary to

propane, acetylene (if operating conditions are appropriate), does not produce methane as intermediate product but radicals and molecules (like vinyl acetylene) which at the end break in carbon and hydrogen<sup>2</sup>.

## 2. Application to transmission parts

As explained in the introduction, the success of the LPC in the automotive industry was immediate because of its ability to be operated by the car or component makers in furnaces installed in-house and integrated in the machining lines. As a matter of fact, all these first applications concerned transmission parts like axles, pinions or other gear-boxes components. Beside the operating advantage mentioned above, two other key points have been shortly enlightened by engineering and manufacturing people: the absence of intergranular oxidation and the reduced distortion observed.

The first one has been reported right from the beginning<sup>3,4</sup> as a clear metallurgical difference between gaseous and vacuum processes resulting from the fact LPC only uses molecules free of any oxygen atom, improving surface hardness and fatigue performances of pieces heat treated in (or close to) their final shape and so not ground or only shaved after carburizing. The reduction of distortion may be impressive sometimes on transmission parts as a result of:

- a better temperature uniformity (across the load, or from the root to the tip of a gear tooth for instance) when the carbon transfer starts leading to a case-depth variance only depending on the local geometry of the pieces.
- the use of high pressure gases to cool down the load instead of oil, a quenching mode much easier to implement with furnaces of vacuum design than with standard gaseous carburizing sealed quenches. A proper adjustment of the pressure, the velocity, and the nature of the cooling gas used allows a fine tuning of the cooling speed just (and not in excess) to the value required to achieve the relevant properties of the case or at core of the pieces. The limitation is of course that some massive pieces made of low hardenable materials may not be cooled down quickly enough, or may require to do so the use of expensive gases and equipment (Helium, 20 bars, recuperating and recompressing system).

Although still far below the in-house applications, it is now common to see commercial heat treaters offering LPC to car or component makers for small or mid-sized batches of transmission parts in order to provide them with the same level of quality they have in their own in-house equipment for large series. However, because they cannot influence easily the choice of the material, they often combine oil and gas quench facilities in their lines, using as much as possible gas quench and selecting oil only when the

hardenability of the material is too low regarding the weight and the thickness of the pieces.

Figure 2 shows such a load made of transmission axles, at the preparation stage in a commercial heat treater shop. The micrograph (top left insertion) illustrates the out-standing uniformity of the case-depth, from the root to the tip of the teeth.



Fig 2 Typical LPC application to transmission axles in a commercial heat treater shop (18MnCr5).

The distortion obtained on these pieces quenched in a separate cold chamber under 20 bars of Nitrogen was claimed to be equivalent to the one formerly received when quenching in salt bath; this is obviously quite of interest but has however to be related to the fact that there is no big variances in diameter and no very thin sections in this peculiar axle. Otherwise salt bath quenching after gaseous carburizing may remain the only solution unless we accept straightening pieces after the quench. Indeed, this last route (LPC + 20 bars Nitrogen + straightening) has been retained for other very critical axles, with the benefit of a risk of rejection for cracking during the straightening operation reduced to zero. Other end-user specialist of heavy duty transmission gears reports dramatic savings on ground gears, with finishing costs down from 25% up to 85% if comparing LPC to the former classical process<sup>5</sup>.

### 3. Specific benefits of LPC in subcontracting business

The former example of LPC application to subcontracting business has not underlined any significant advantage touching more commercial heat treaters than in-house users. Though subcontracting business has needs and requirements which may be felt specific (or at least much stronger) if compared to in-house applications of large series of pieces.

#### 3.1 Flexibility

Flexibility is for sure one of the most important

specific requirements of commercial heat treaters: they need not only units able to be switched on and off according to the fluctuation of the customers' needs (obviously with sharper peaks and valleys than in the in-house business) but also units tolerant regarding the change of process between two consecutive loads. As a matter of fact, all a commercial heat treater may dream of in term of flexibility is offered by LPC: first of all, vacuum technology allows switching off and on one cell as soon as the activity drops down or picks up again. But on top, the carbon transfer to the surface of the work load starts and stops with the injection of carburizing gases and is in no way influenced by the state of the insulation (contrary to the classical gaseous furnaces with their bricking works). Consequently one neutral hardening treatment can follow a deep carburizing one, still giving in both cases the expected results in term of metallurgy. This is of special interest if the cell is capable for instance of 1200 °C and thus complies with the carburizing temperature range (900 to 1050 °C) as well as with the one required by most of the tool hardening applications.

#### 3.2 Tolerance towards load and pieces configuration

This is an other key-issue for commercial heat treaters who badly need to put in the same load all compatible (on a material point of view) small batches of pieces they receive in order to match the short delivery all their customers require. This is again no problem with LPC: as it can be seen in Figure 3, such batches of different mechanical parts may be gathered in one load as easily as in gaseous processes.

The only limitation is the total surface to be carburized in a given volume: the higher the surface is, the greater the spread of the case-depth (between pieces at the outside of the load and pieces in the center).

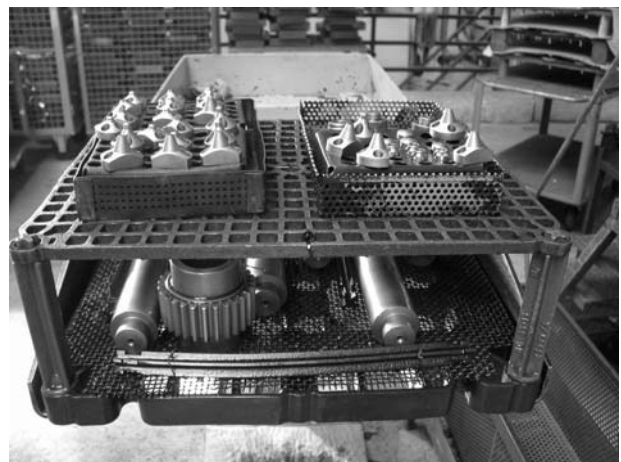


Fig 3 Various batches of pieces in a commercial load

If carburizing transmission parts like the ones in Figure 2, this limitation specific to LPC will not affect

the number of pieces per load, the limiting parameter being in such a case the weight or the dimensions of the pieces. But if carburizing smaller pieces with complex geometry (like spiral pinions for automotive powered steering systems) or with a lot of long holes of small diameter (like components for diesel injection systems), the total surface will be the factor limiting the number of pieces per load. Any attempt to exceed this maximum number of pieces will lead to big disappointments with a significant lack of carbon transferred to the pieces sitting in the middle of the load, or even with no carbon at all on the pieces in the center.

The possibility to treat pieces in bulk is another question often risen when talking about LPC application to commercial jobs. If using acetylene (tremendously efficient to penetrate small voids and carburize them evenly), there is again no problem as illustrated on the Figure 4. When sampling 30 random of these small pieces among the 15000 constituting the load and across the different layers, the spread of the case-depth measured is +/- 0.05 mm (from 0.43 to 0.53 mm), below the +/- 3σ classical spread of the statistical distribution (0.4 – 0.6 mm). It is worthy noting that the total surface carburized is less than three square meters and does not touch the limit for the 600 x 900 x 600 mm useful volume of the furnace. Each piece was found evenly carburized without any soft spot.

An other important point lays in the fact that a commercial heat treater does not have the possibility to run many preliminary trials before delivering the right quality in term of case-depth, surface hardness or surface carbon content. The pieces he is “playing” with belong to his customer, and consequently any unsuccessful trial will raise the question of who has to carry on the cost of the scrapped pieces. On top of that, the timing is of course always squeezed to the minimum.... In other words, the commercial heat treater has to process the pieces immediately, with no preliminary trial and must absolutely be successful at the first shot. Here again, the LPC process is beneficial to the job treater. The accuracy with which the carbon transfer may be predicted and controlled (because it depends only on well-known physical laws) makes possible the realization of modeling software guiding very efficiently and quickly the user to the best set of parameters for the carburizing sequences of the cycle.

An amazing and note-worthy consequence of the outstanding accuracy, predictability and reproducibility of this process is enlightened by Figure 5. This example concerns the acceptance test of a new LPC cell using circular rings as test pieces: the parameters of the cycle were determined using the modeling software; the result after carburizing was followed by the weight increase of each controlled ring, this parameter being very easy to measure and representing perfectly the carbon picked-up by the pieces.

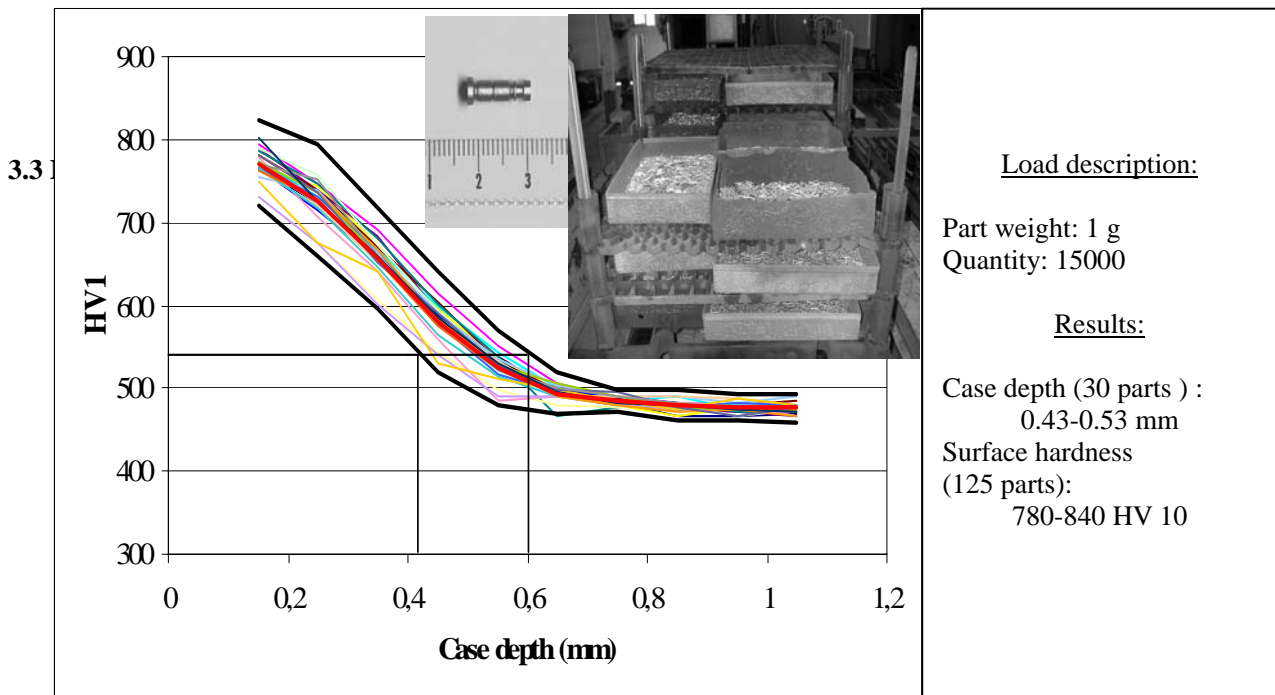


Fig 4 Load made of 15000 small pieces in several baskets containing a thin layer of pieces in bulk.

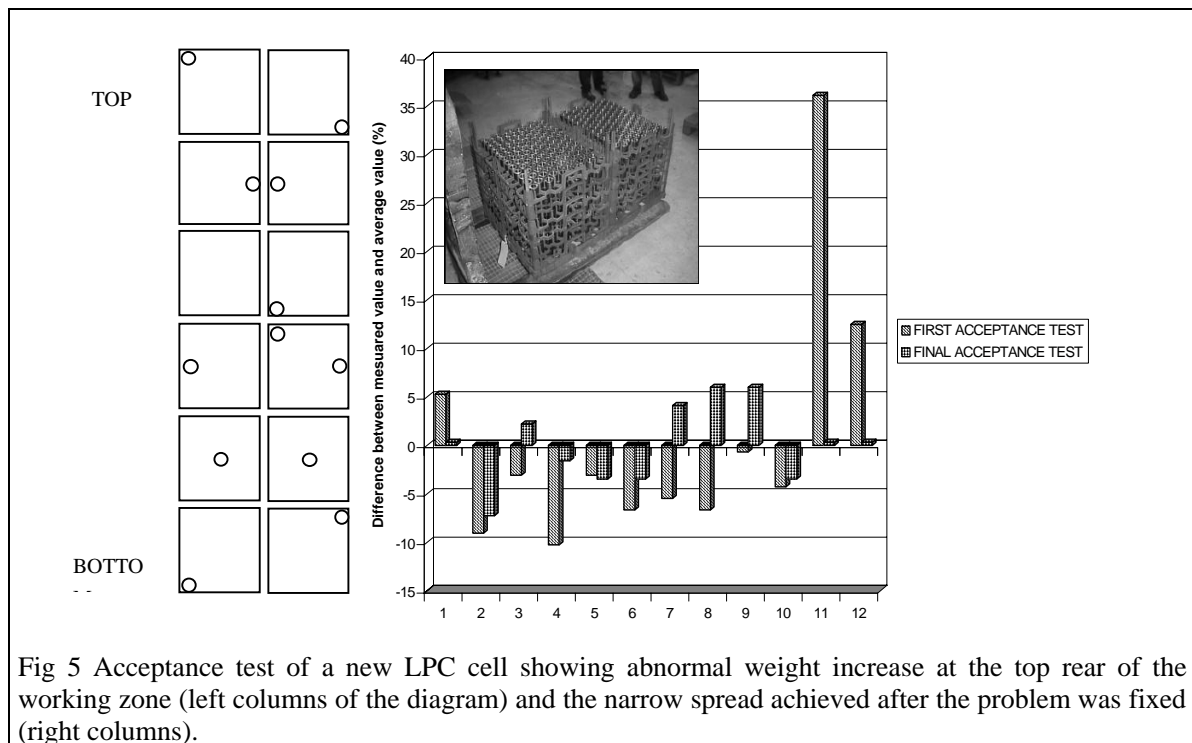


Fig 5 Acceptance test of a new LPC cell showing abnormal weight increase at the top rear of the working zone (left columns of the diagram) and the narrow spread achieved after the problem was fixed (right columns).

The y axis of the graph represents the variation (percentage wise) of the weight increase of every controlled ring versus the average of all measurements, this average being very close to the expected value given by the modeling software. The location where the rings are sampled in the load is given by the scheme on the left. The surprise was that instead of the maximum of +/- 5 to 10% variance around the average, two rings located on the top rear of the working zone (on the graph represented by the two columns at the right of the diagram) were exceeding the limits especially one ring showing weight increase 35% above the goal. Indeed the effect on the case-depth was not so impressive, all the rings staying within the 0,6 – 0,8 mm range specified. If operating a gaseous carburizing furnace, nothing really abnormal would have been reported and the furnace for sure would have been accepted like that.

Here the idea to operate the LPC furnace with no further modifications was rejected and a complementary deep analysis undertaken. At the end, it appears that the space between the casing and the vessel was not evacuated properly after the injection of acetylene (here used as carburizing gas) is stopped and that acetylene molecules were slowly sucked in the chamber during the diffusion phases along the feed-troughs bringing the power to the heating elements. As soon the problem was fixed, a perfect behavior was found, with all weight increases back roughly in the +/- 5% range.

The interest of this experience is to prove that a LPC furnace must deliver outstanding results and that all the software used to predict the results are reliable enough to be very good tools to reveal problems and to guide technicians to the solution.

### 3.3 Cleanliness

Cleanliness is far from being an exclusive requirement of job contracting, but it is a fact that even if cleanliness is not a must written down in the specifications of every piece heat treated by subcontractors, it is always a plus to return pieces as bright after the heat treatment as they were before. Times when carburized pieces had to be black and dirty (at least to prove that they are treated) are gone. Here also, LPC is the right answer: if properly controlled, this process does not spoil at all the surface of pieces or even change its color. If on top we use high pressurized gases as quenching media, the pieces are as bright when exiting the furnace as they were before loading.

Consequently, even if of pure esthetic interest, the perfect cleanliness of Low Pressure Carburized pieces is well appreciated nowadays and set new standards which put pressure on classical processes. If now talking about components for hydraulic devices or diesel injection systems, perfect cleanliness is no longer a cosmetic option but becomes a very strong requirement to which LPC is THE answer, especially if combined with gas quench.

## 4. LPC limits in subcontracting applications

Low Pressure Carburizing, as all processes, has its own limits. We just want to briefly underline these which belong to the preparation of the surface of the pieces before processing, and thus are more critical for commercial heat treaters.

As a matter of fact LPC may be very sensitive to several types of residues as those resulting from alkaline washing agent used for pre-cleaning and not thoroughly eliminated before carburizing. Small particles of rust at the surface of the pieces might also act as catalyst<sup>2</sup> for the dissociation of the acetylene molecules, and so induce soot formation locally. However the consequence is often limited to small dark spots, not always visible to the naked eye, consisting in soot and having no negative local impact on the metallurgy.

Much more dangerous are the boron-containing residues coming from some water-soluble coolants used when machining the parts before heat treatment. If this coolant is not correctly eliminated before heat treatment, the boron acts as a “stop off” during Low Pressure Carburizing and results in soft spots on the pieces. Knowing that this will affect in a random way the parts, yet very often in cavities where the boron containing products are more difficult to wash out and may be dried at the surface of the steel, one can imagine how dangerous this problem may be. Here we touch obviously a critical aspect of the subcontracting business, since the commercial heat treater does not control or very seldom knows the nature of the machining coolants used ahead of the heat treatment. The only thing to do to counter the risk is to have a very efficient pre-cleaning process with up-to-date equipment, plus strong maintenance and survey procedures. This can make the pre-washing process really costly and non insignificant when judging the global economical aspect of the Low Pressure Carburizing process.

The Low Pressure Carburizing process is now well established as an alternative to classical gaseous furnaces; it has proven it could be beneficial to the mass production of transmission parts in the automotive industry, where component makers have installed numerous multi-chamber LPC systems integrated in their machining lines.

The application of this technology to subcontracting business has not been developed that much so far. However the advantages of the LPC process itself, associated to these of the vacuum-based design of the furnaces utilized, can bring outstanding benefits to the commercial heat treater like a total flexibility, a great tolerance towards load configuration and pieces geometry, a high accuracy of the control of the process leading to a remarkable reproducibility and easiness of simulation, and last but not least, a perfect cleanliness.

With all these winning cards on hand, no doubt that Low Pressure Carburizing will now quickly develop in job treaters shops.

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## 5. Summary