# LOW PRESSURE CARBURIZING - PRACTICAL EXPERIENCES

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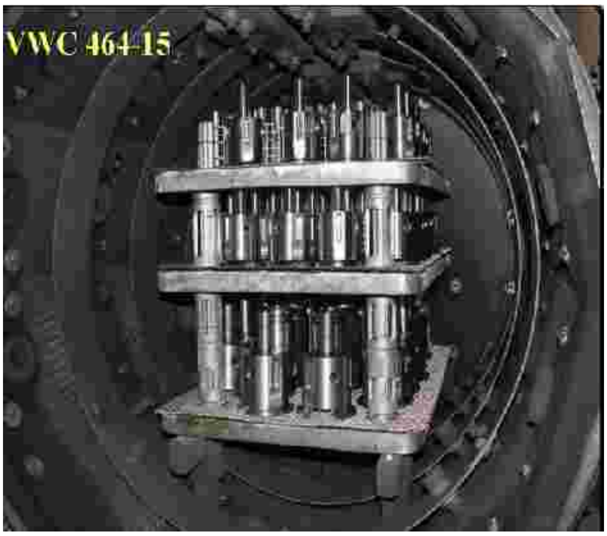
The article shows the examples of LPC in practical heat treatment. The published results of 16MnCr5 steel heat treatment demonstrate very good efficiency of LPC technology, influences of time, temperature, carburizing depth, sub zero treatment, tempering, etc. and comparison LPC with gas carburizing. Besides these the report balances economic savings of this modern technology (time and energy consumption in comparison with conventional carburizing).




***VWC464-15 furnace made by SECO/WARWICK and Systherms***

- 400 x 400 x 600 mm working space
- 200 kg max batch weight
- 15 bar nitrogen cooling

## 1. THE CHARACTERISATION OF THE TESTS

The tests run under full operating conditions according to Table 1 :

| Test Nr. | 3 | 4 | 5 | 6 |
|---|---|---|---|---|
| Technology | LPC + HPGQ* | | | GC+SBQ** |
| Temperature | 950°C | 950°C | 1000°C | 920°C |
| Eht required (mm) | 0.3+0.1 | 0.5+0.1 | 1.0±0.1 | 1.0-0.1 |
| Quenching temperature | 820°C | 820°C | 820°C | 820°C |

Table 1 : The 16MnCr5 tests summary

* low pressure carburizing (LPC) and high pressure gas quenching (HPGQ) : carburizing with acethylene, ethylene and hydrogen, cooling with 15 bar nitrogen

** gas carburizing (GC) and salt bath quenching (SBQ)  carburizing with methanol and propane, cooling to 160°C salt bath AS140

Each test was twice repeated. The samples were evaluated in different grades of heat treatment:

- Quenched
- Frozen
- Quenched and tempered 2x 2 hours / 160°C
- Quenched, frozen and tempered 2x 2 h /160°C

We measured surface hardness HV10, surface microhardness HV1, carburizing depth Eht 550 HV0,5 and core hardness HV30 on the samples. The structure  of carburizing layer, core, residual austenite volume and grain size were evaluated by optical metalography. The surface carbon content was measured on every quenched sample.  construct carbon profile of 0,5 mm carburizing for LPC and for GC as well.

The size of samples was 20x10x7 mm. The checked chemical analysis of testing steel:

| Element | C | Mn | Si | P | S | Cr | Ni | Cu | Mo | Al | Ti | Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16MnCr5 | 0,196 | 1,20 | 0,175 | 0,0065 | 0,0211 | 0,937 | 0,0796 | 0,248 | 0,0212 | 0,0425 | 0,0014 | 0,158 |

Table 2 : The spectral chemical analysis of 16MnCr5 samples measured by GDS 500A

## 2. THE RESULTS AND DISCUSSION

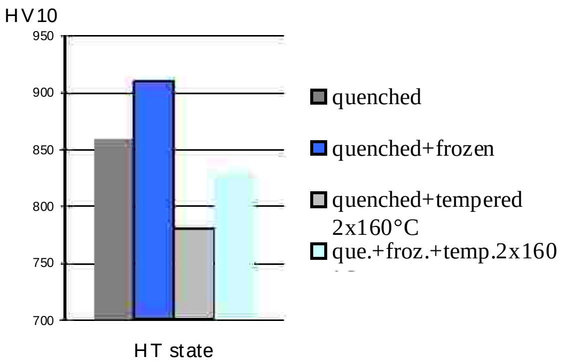
### 2.1 Carburizing up to 1.0 mm

The test samples were carburizing to the depths of 0.3 and 0.5 mm according to Table 1 by LPC technology. The SimVac program simulated carburizing time 20 minutes alternatively 70 minutes using 950°C carb. temperature, required surface carbon concentration 0.7% C and criterion 0.42% C. Cooling pressure 15 bar of nitrogen. One sample set was evaluated after quenching, next sets were evaluated after freezing, tempering and freezing and tempering.

Surface carbon concentration measurement verified 0.7  0.2 % C values in correspondence to simulation.

The core hardness was measured between 264 – 295 HV30. Achieved Eht 0.39 – 0.43 mm or 0.58 – 0.65 mm goes beyond upper limit slightly. The residual austenite volume keeps up to 20 % and it is reduced to less than 5% after freezing. Average grain size was measured 30 µm.

Graph 1 : 16MnCr5 Surface Hardness

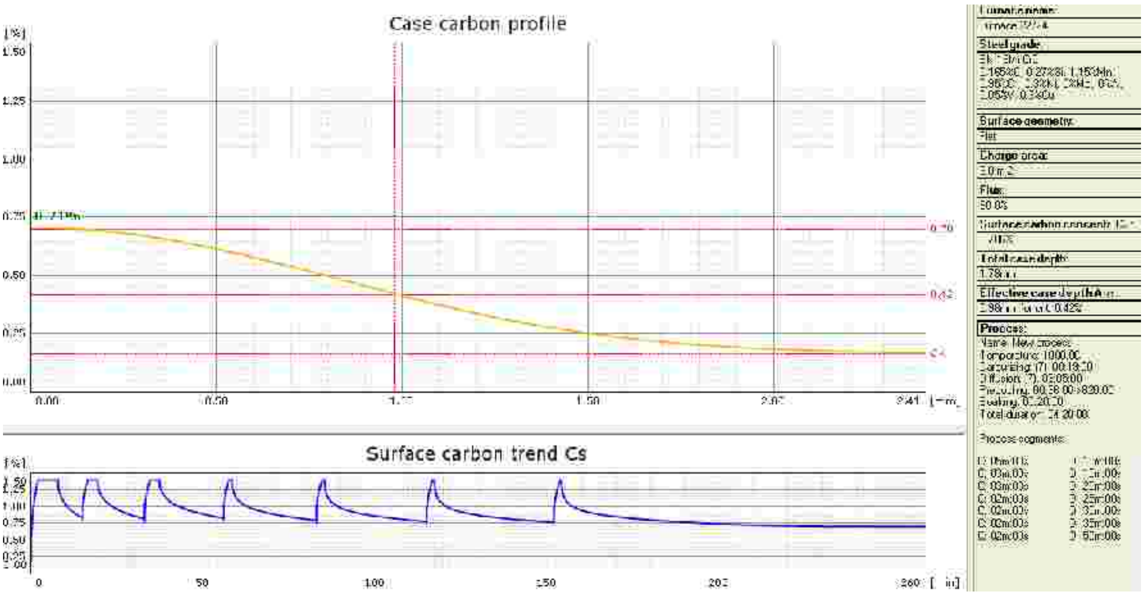


| Carburizing up to 1.0 mm | Requirements | Measured values |
|---|---|---|
| Surface carbon concentration | 0.7 % | 0.7 ± 0.02 % |
| Carb. depth Eht | 0.3 + 0.1 mm<br>0.5 + 0.1 mm | 0.39 – 0.43 mm<br>0.58 – 0.65 mm |
| Core hardness | > 300 HV | 264 – 296 HV30 |
| Residual austenite | Up to 10 % | Up to 20 %,<br>resp. do 5 % |
| Grain size | max 60 µm | 30 µm |

Table 3 : The Summary of the short carburizing dept ults

## 2.2 Carburizing 1.0 – 1.5 mm

The carburizing time is reduced by half using 1000°C carburizing temperature over against 950°C. Pict.1 shows model of 1.0 mm carburizing in SimVac program :




Pict.1 : The 1.0 mm carburizing simulation in SimVac program

We created the carburizing program in accordance with ion. One sample set was evalueted after quenching, next sets were evaluated after freezing, tempering and freezing and tempering once again.

No fewer than 840 HV10 or 920 HV10 after freezing are values achieved on the surface. The hardness of tempered samples returns to 840 HV10. The values around 765 HV10 were measured on the surface of no frozen samples.

The fluctuation of surface microhardness HV1 is connecte with content of residual austenite in carburizing layer. The hardness changes u ore than 100 HV.

| Carburizing depths 1.0 – 1.5 mm | Requirements | Measured values |
|---|---|---|
| Surface carbon concentration | 0.7 % | 0.7 ± 0.03 % |
| Carb. depth Eht | 1.0 ± 0.1 mm | 1.25 – 1.34 mm |
| Core hardness | > 300 HV | 280 - 300 HV30 |
| Residual austenite | Up to 10 % | Up to 20 %, resp. do 5 % |
| Grain size | max 60 µm | 60 µm |

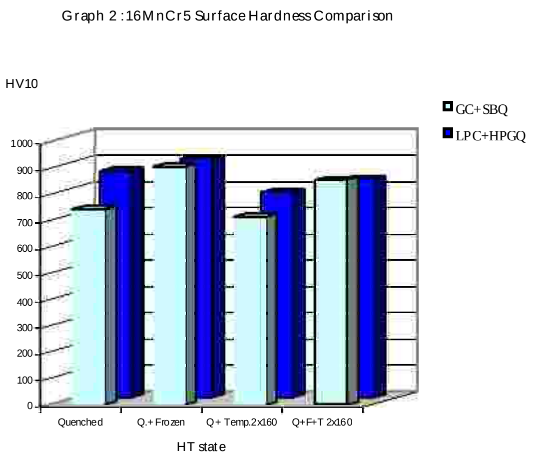
Table 4 : The Summary of more than 1.0 mm carburizing depths results

The microstucture of carburizing layer after LPC is shown on the Puct. 2. The sample was carburized at 1000°C temperature for 3 hours and than quenched by 15 bar nitrogen. There is fully martensitical structure and the residual austenit content is not bigger than 10% on the picture. The Pict.3 shows core structure. The hardness of sample was measured 263 HV10 and it corresponds to feritical and perlitical structure.

Pict.2: 16MnCr5 LPC layer (quenched condition) magn. 500x

Pict.3: 16MnCr5 LPC - the core 263 HV10 magn. 500x

## 2.3 LPC + HPGQ & GC + SBQ comparison



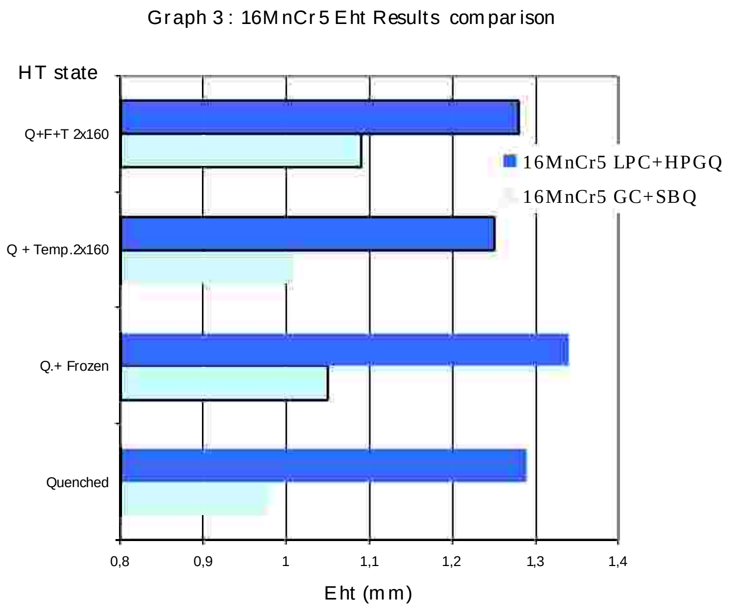

The model carburizing of 1.0 mm depth was chosen to compare low pressure carburizing and high pressure gas quenching results with gas carburizing with salth bath quenching. The LPC conditions were described in 2.2 chapter (see Pict.1). The gas carburizing was provided by 920°C temperature for 290 minutes. The carburizing potential regulated with the oxygen probe was set to 1.05 % C for carburizing period or 0.75% C for diffusion period. Controlled cooling to 820°C was followed by quenching into 160°C warm salth bath AS140.

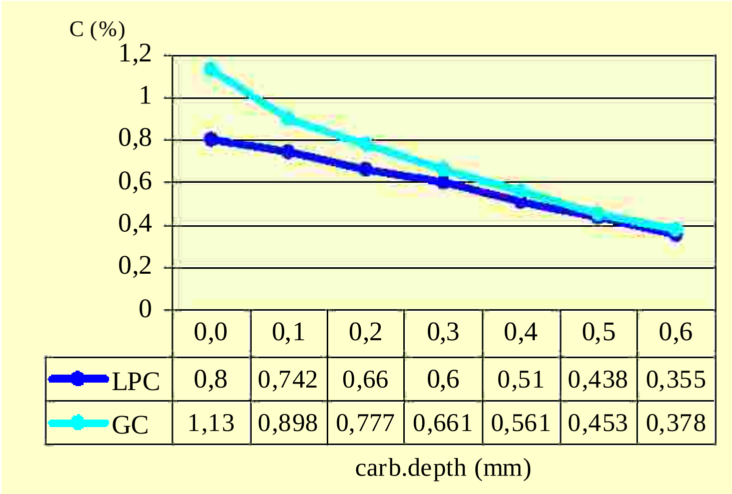
The samples were evaluated as usual. The achieved results and differences are compared in the Table 5. The core hardness as important parameter differs by more than 130 HV. On the other hand the content of residual austenite is much higher in case of salth bath quenching.

| Carburizing depth 1.0 mm - comparison | LPC + HPGQ | GC + SBQ |
|---|---|---|
| Surface carbon concentration | 0.73 % | 0.93 % |
| Carb. depth Eht | 1.25 – 1.34 mm | 0.98 – 1.09 mm |
| Core hardness | 280 – 300 HV30 | 430 - 440 HV30 |
| Residual austenite | Up to 20 %, resp. 5% | Up to 25 %, resp. 5 % |
| Grain size | 60 µm | 22 µm |

Table 5 : The Summary of LPC + HPQC and GC + SBQ comparison results

We can see quite important differences between achieved carburizing depth after GC and SBQ on the Graph 3. We must keep in mind that achievement of good carburizing results is also dependent on the quenching mode. Whereas one chamber furnace with 15 bar nitrogen cooling has heat exchange coefficient a 400-800 W/m2.K while slow cooling oil has a coefficient between 1000 – 1500 W/m2.K. We can carburize very successfully almost all case-hardening steels by LPC but to achieve satisfying results depends significantly on the quenching conditions.






Pict.4 : The carbon profiles comparison for LPC and GC

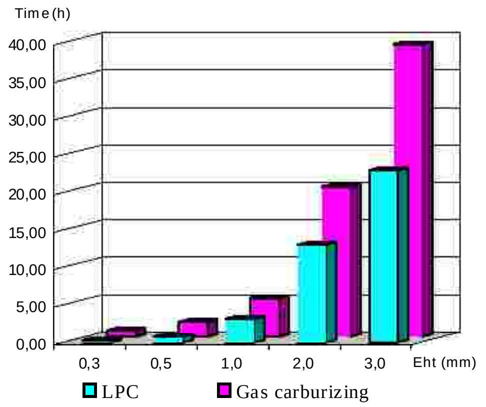
The carbon profile comparison is shown on the Pict.4 for 0.5 mm carburizing depth. The carbon profile created by LPC is linearly decreasing with eutectoid surface concentration 0.8% C. On the other side the carbon profile created by gas carburizing is overcarburized at first and the curve drops very fast.

## 3. ECONOMY OF LPC PROCESSES

The quality of low pressure carburizing processes is only one side of coin. We must evaluate the economic savings. Unfortunately there are too many views how to evaluate LPC processes perfectly in every details. This is why we selected several carburizing depths and compared partly absolute carburizing time and partly total costs.

The absolute carburizing time means the sum of all the carburizing and diffusion periods. We should not be surprised that LPC is more economical in case of time even for low carburizing depths as we can see on the Graph 4. It is possible thanks to faster kinetics by high carburizing temperatures and much better starting conditions.

Graph 4 : Absolute carburizing time comparison



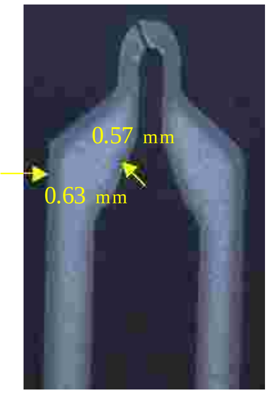

| Eht | Gas | Vacuum | |
|---|---|---|---|
| | 920°C | 950°C | 1000°C |
| (mm) | (%) | (%) | (%) |
| 0,3 | 100 | 90 | 82 |
| 0,5 | 100 | 88 | 81 |
| 1,0 | 100 | 86 | 72 |
| 2,0 | 100 | 87 | 65 |
| 3,0 | 100 | 84 | 60 |

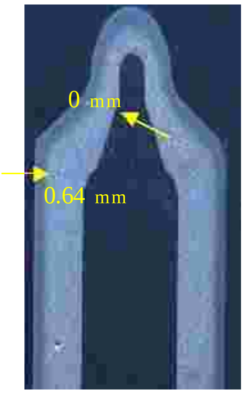
Table 6: The total costs comparison

The total costs of processes include the expenses of all necessary technological steps in accordance with carburizing way. The efficiency of LPC processes increases with carburizing depth and using higher carburizing temperature.

## 4. CONCLUSIONS

- § High quality of carburizing layers with achieved hardnesses over 800 HV
- § High carburizing uniformity. It is advantage especially for pieces of complicated shape or pieces with deep holes:




- § Lower distortions achieved after LPC and HPGQ
- § High quality of heat treated surfaces. It does not require additional processes like washing, cleaning oxides or blasting. The pieces are ready to expedition immediately after tempering.
- § Nothing soots inside the chamber thanks to precise simulation and calculation of carburizing surface area
- § Excellent reproducibility
- § Time savings up to 60%. It is advantageous for deeper than 0.5 mm relative to heating time
- § Cost savings up to 40% depending on using higher carburizing temperature and deeper carburizing depths