CO2-REDUCTION BY ENHANCED ENERGY EFFICIENCY IN LPC-HEAT TREATING PLANTS

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CONTENT

- Introduction
- Technology of LPC and HPGQ
- Measures to reduce energy consumption
  - Heat treat system
  - Process
  - Production
  - Material
  - Specification
- Conclusions

MOTIVATION AND MEASURES TO ACHIEVE THE CLIMATE TARGETS

To limit the global warming to 1,5 – 2°C,

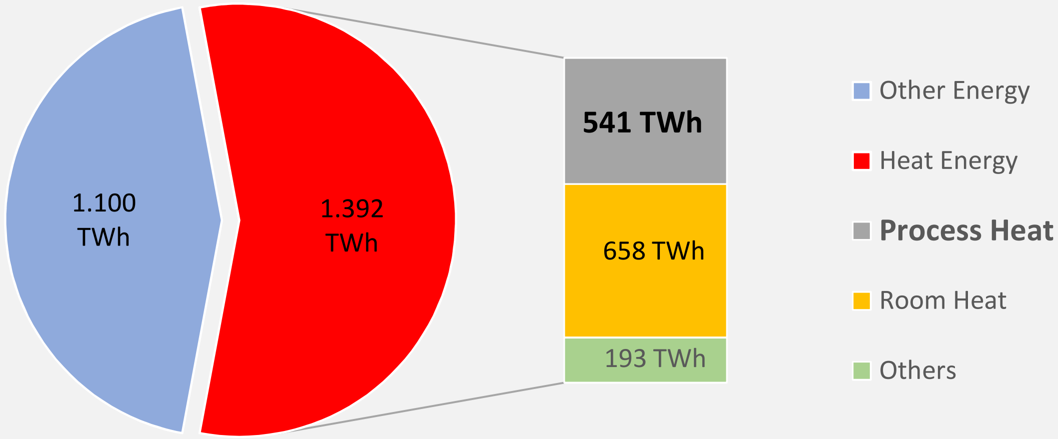
green house gases need to be limited

Climate Targets EU27 (Germany):

55% (65%) reduction of green house gases until 2030

Climate neutrality until 2050 (2045)

End Energy Consumption in Germany 2019 (total ~2.500 TWh)[1)]



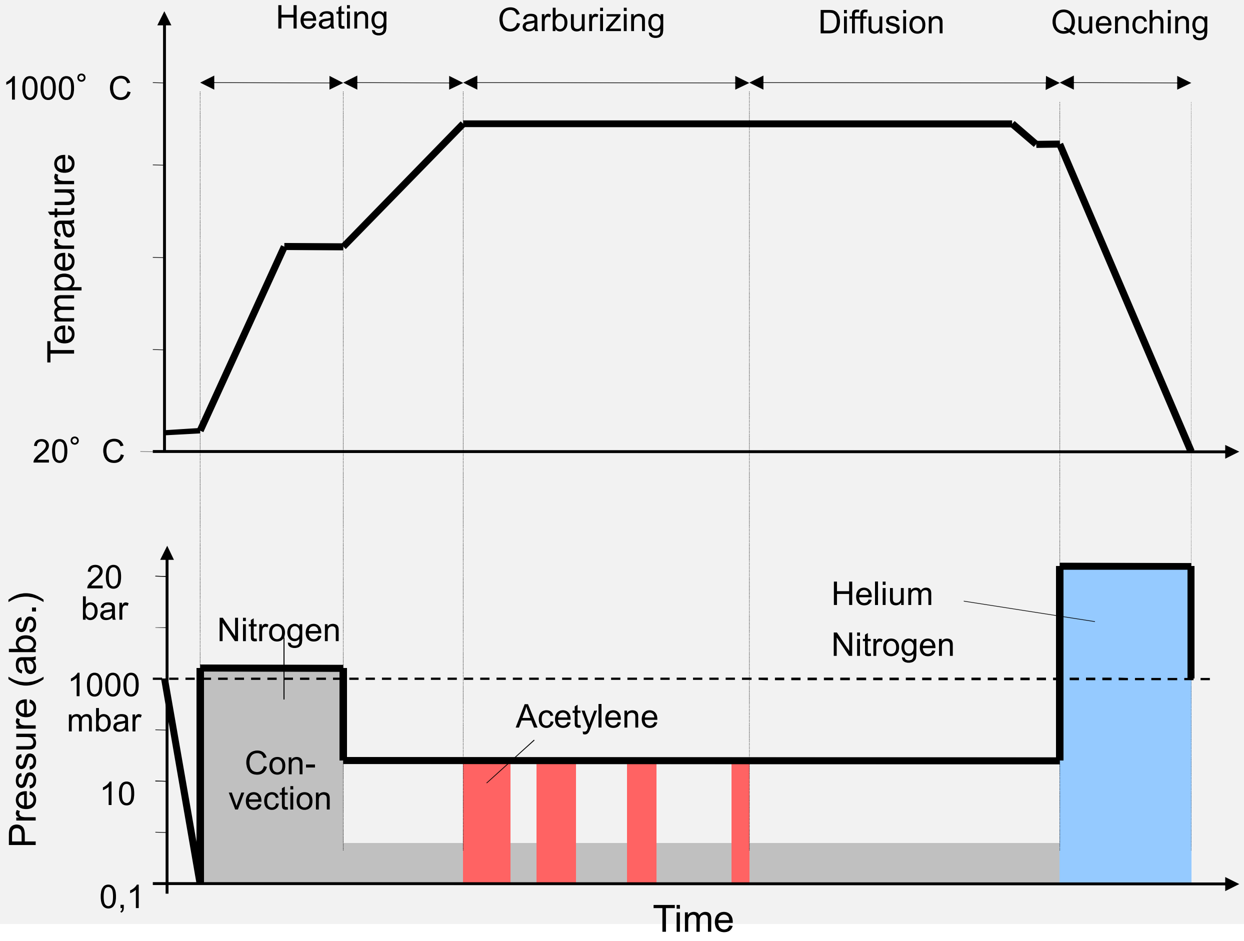
Process heat contributes ~22% to total energy consumption

How can Heat Processing Industry (manufacturers, users) contribute to achieve the climate targets?

- reduce dependence on fossil fuels
- increase use of electrical energy generated from renewable sources
- reduce consumption of energy

[1)] Source: BMWi, 2/2021

HEAT TREATMENT PROCESS CYCLE LPC & HPGQ



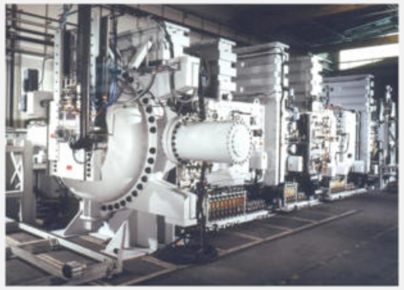
Low Pressure Carburizing (LPC):

Temperature:	900 – 1050° C
Process pressure:	< 20 mbar
Process gas:	Acetylene

High Pressure Gas Quenching (HPGQ):

Gas type:	Nitrogen, Helium
Gas pressure:	max. 20 bar
Gas velocity:	max. 20 m/s

DEVELOPMENT OF LPC-PROCESS IN VACUUM FURNACES

Single-chamber furnace Type MonoTherm®	Continuous multi-chamber furnace Type VMKQ	Modular multi-chamber furnace Type ModulTherm®
		
Year 1990	1995	2002

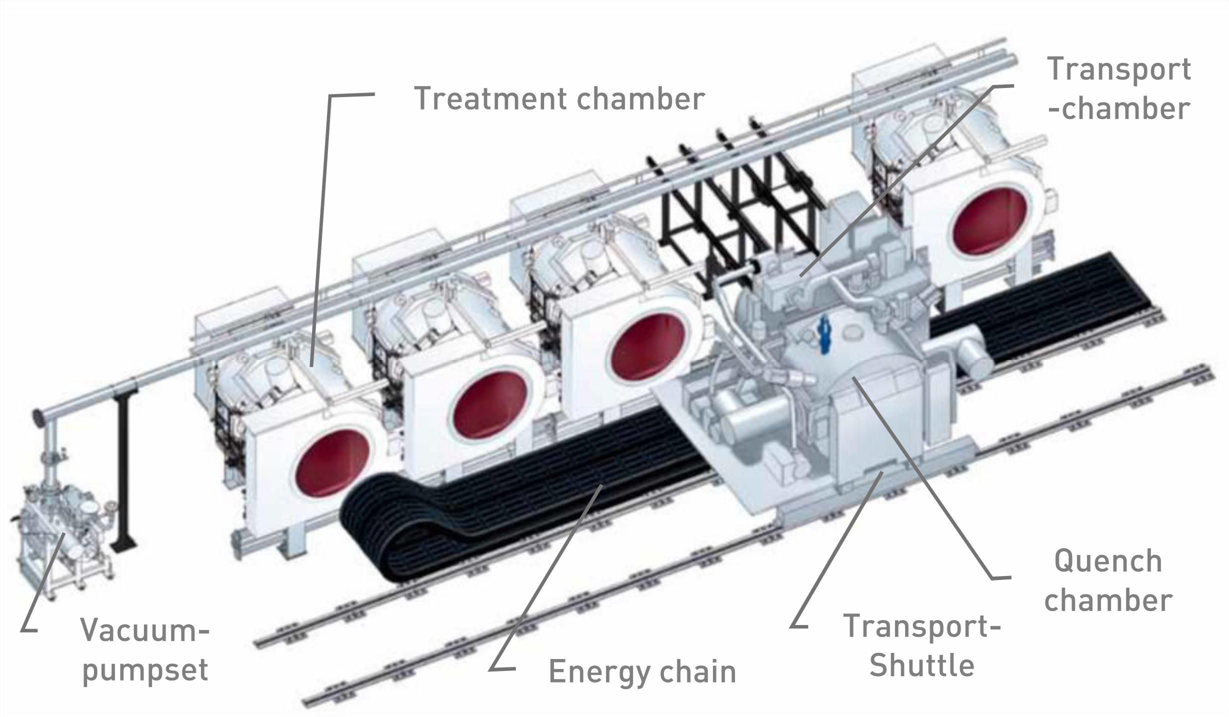
- Load surface: 3-5 m^2
- Low quenching intensity
- High production flexibility
- Low throughput
- Aerospace Applications

- Load surface: 6-8 m^2
- High quenching intensity
- Low production flexibility
- High throughput
- Automotive Applications

- Load surface: 15 - 20 m^2
- High quenching intensity
- High production flexibility
- Highest throughput
- Automotive Applications

MODULAR VACUUM-MULTICHAMBER SYSTEM *MODULTHERM*®

Almost all consumers in the vacuum heat treat system use electrical energy



Treatment chamber
- Graphite heating system
- convective blower

Transport shuttle incl. quench chamber
- Gas blowers
- Transport system
- Vacuum pumps

Auxiliaries
- Vacuum pumpset
- He-Recycling Compressor
- Cooling water sytems (pumps, blower)
- Thermal combustion unit
- Washing machine
- Tempering/Preoxidation furnaces

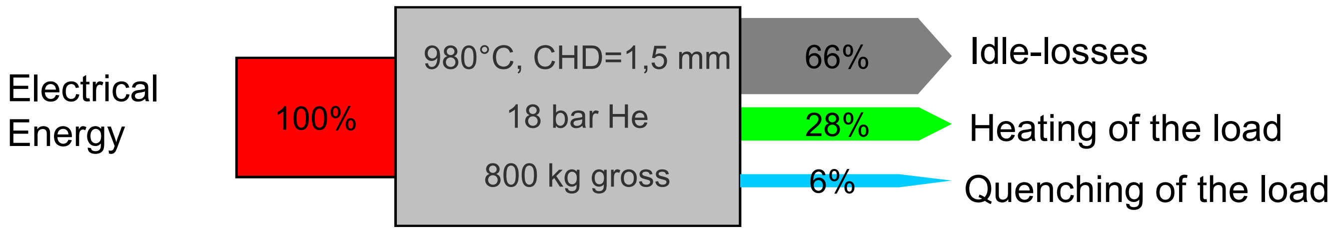
ModulTherm with 8 TC and He-quenching Gears CHD 0,65 mm

Production rate: ~ 950 kg/h
Energy consumption: ~ 750 kWh/h

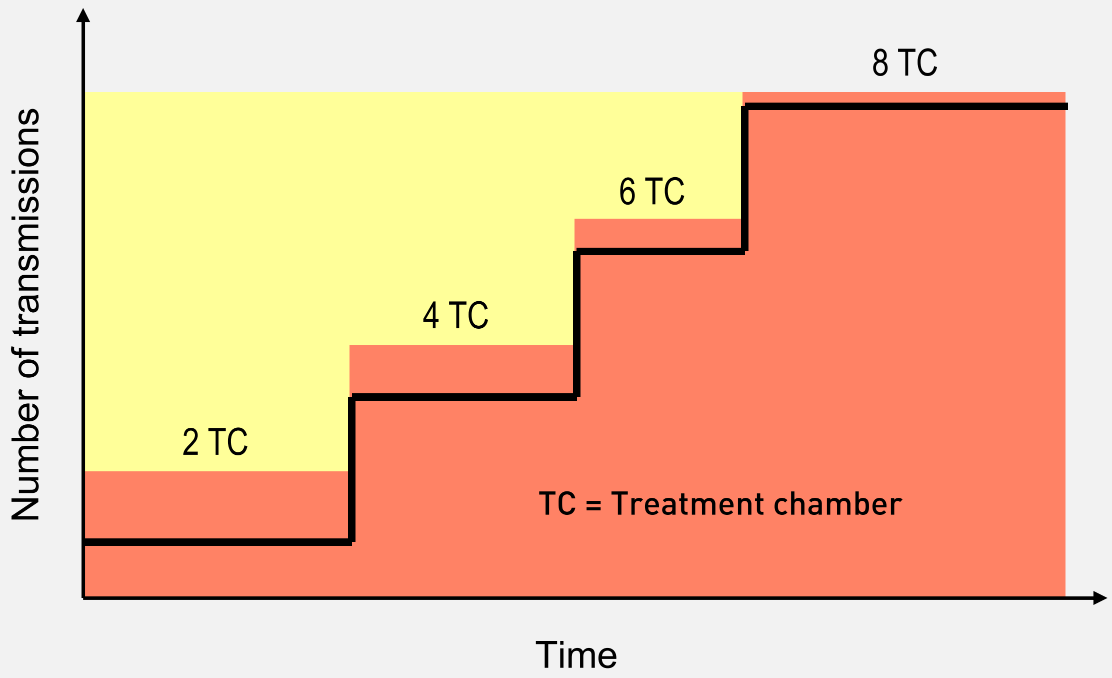
ENERGY FLUXES IN A VACUUM FURNACE PROCESS

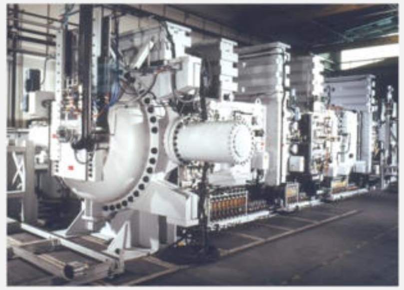
LPC- Heat treatment including high-pressure gasquenching

Sankey-Diagram ModulTherm®-system



ENERGY EFFICIENCY DURING RAMP-UP PHASE / PRODUCTION INCREASE



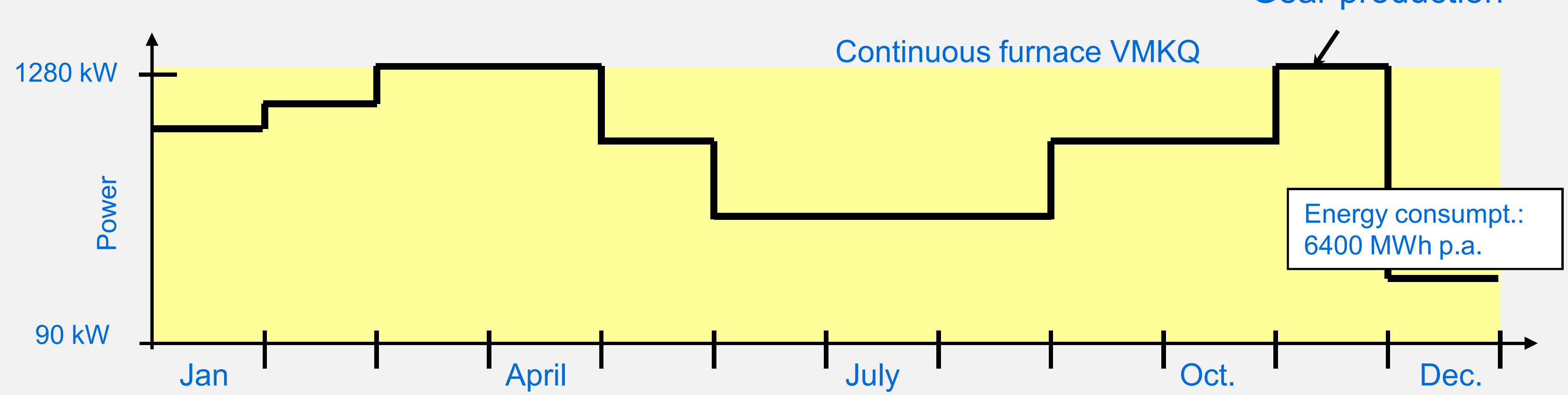


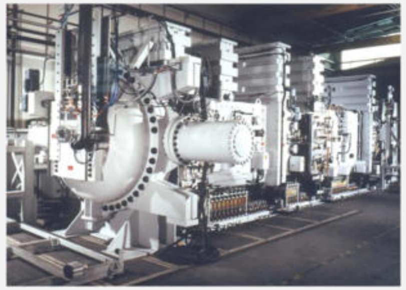
Continuous furnace
Type VMKQ

Modular furnace
Type ModulTherm®

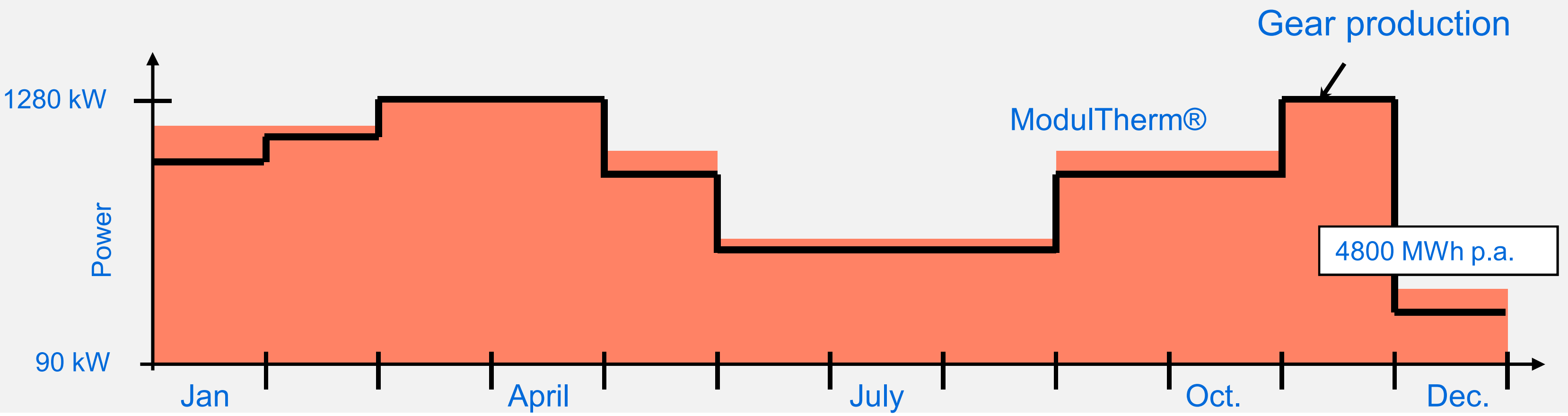
ENERGY CONSUMPTION OVER A PERIOD OF ONE YEAR

Typical annual production-rate



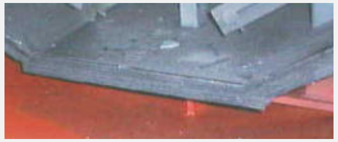


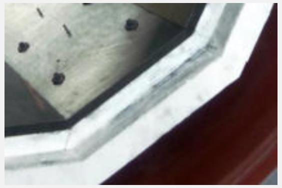
Continuous furnace
Type VMKQ

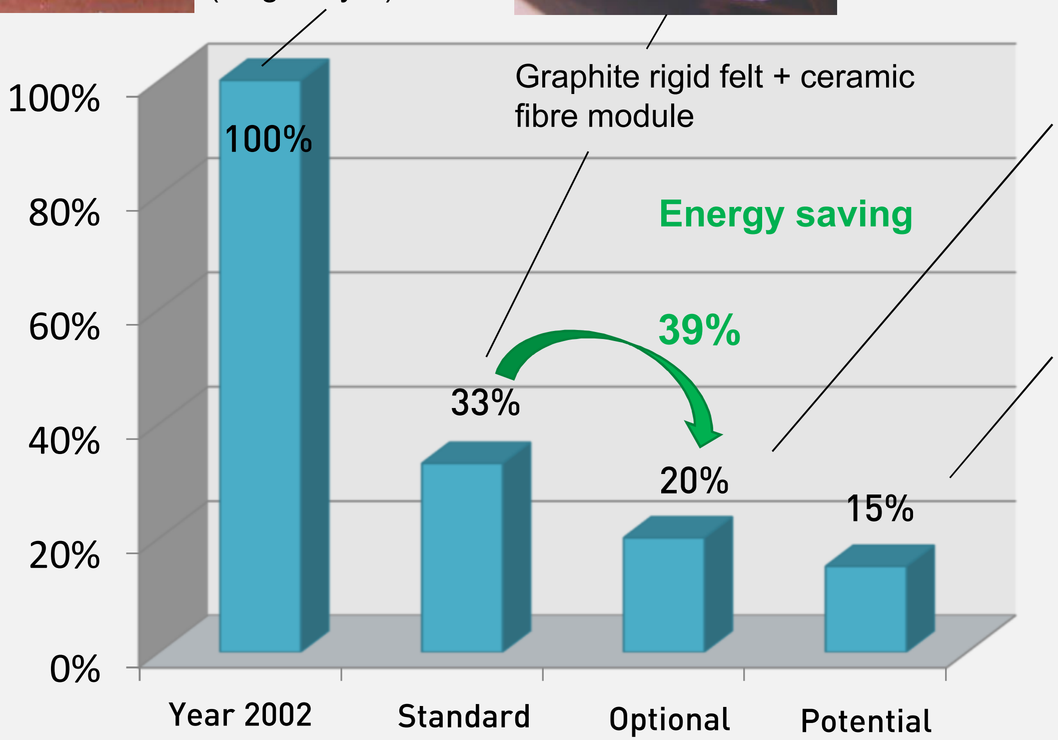


Modular furnace
Type ModulTherm®

RELATIVE IDLE HEAT LOSS OF A TREATMENT CHAMBER AT 950°C AND 5 MBAR NITROGEN



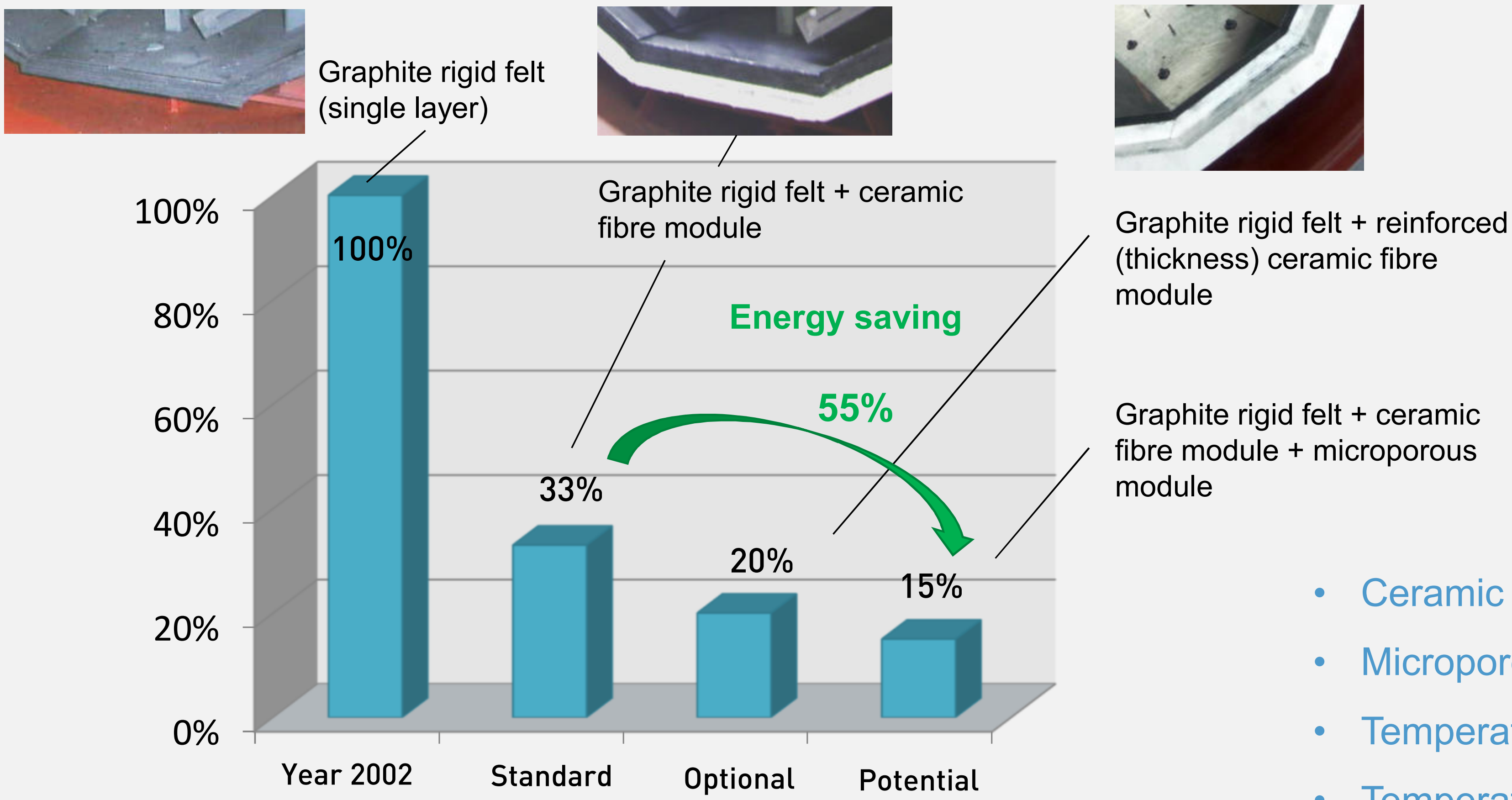




- Ceramic fibre materials
- Microporous insulation materials
- Temperature limits (Cristobalit)
- Temperature flexibility

Not including structural losses (power feed throughs, load support, etc.)

RELATIVE IDLE HEAT LOSS OF A TREATMENT CHAMBER AT 950°C AND 5 MBAR NITROGEN



- Ceramic fibre materials
- Microporous insulation materials
- Temperature limits (Cristobalit)
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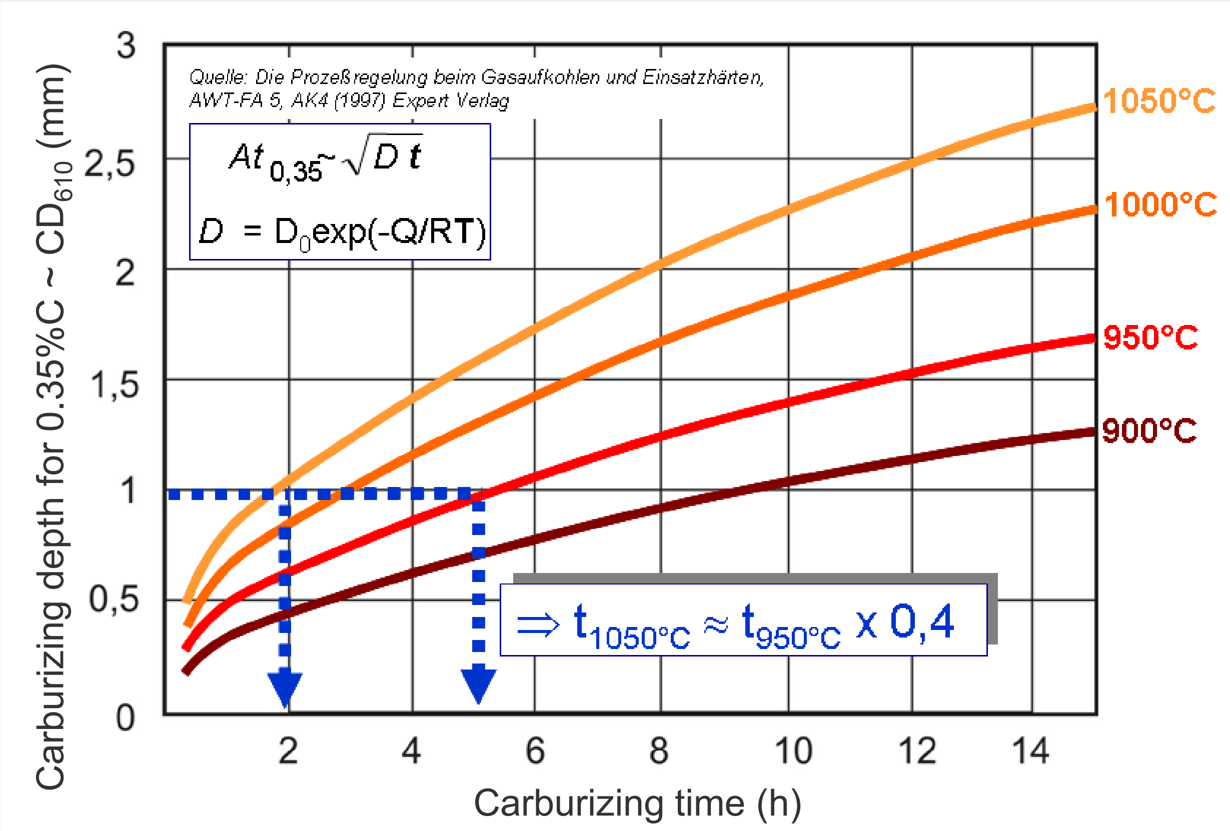
Not including structural losses (power feed throughs, load support, etc.)

HIGH TEMPERATURE CARBURIZING (HTVC)

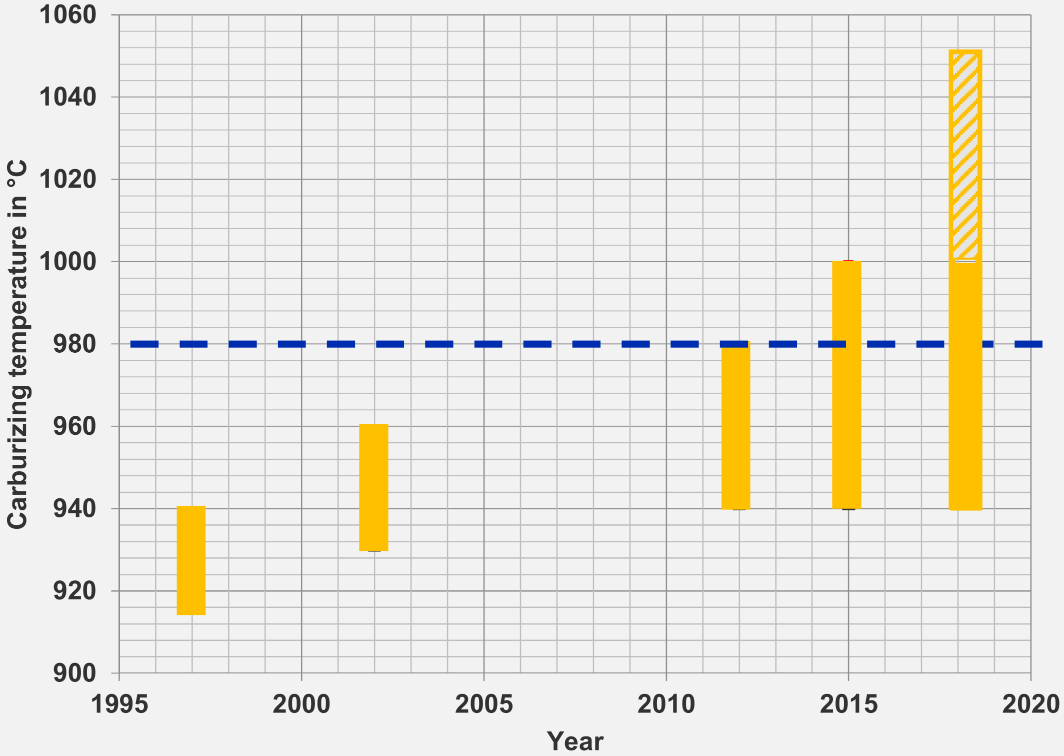


Benefits of HT-Carburizing

- higher C-diffusion rate
- higher C-saturation limit

Faster Carburizing Process

CARBURIZING TEMPERATURES HISTORICALLY



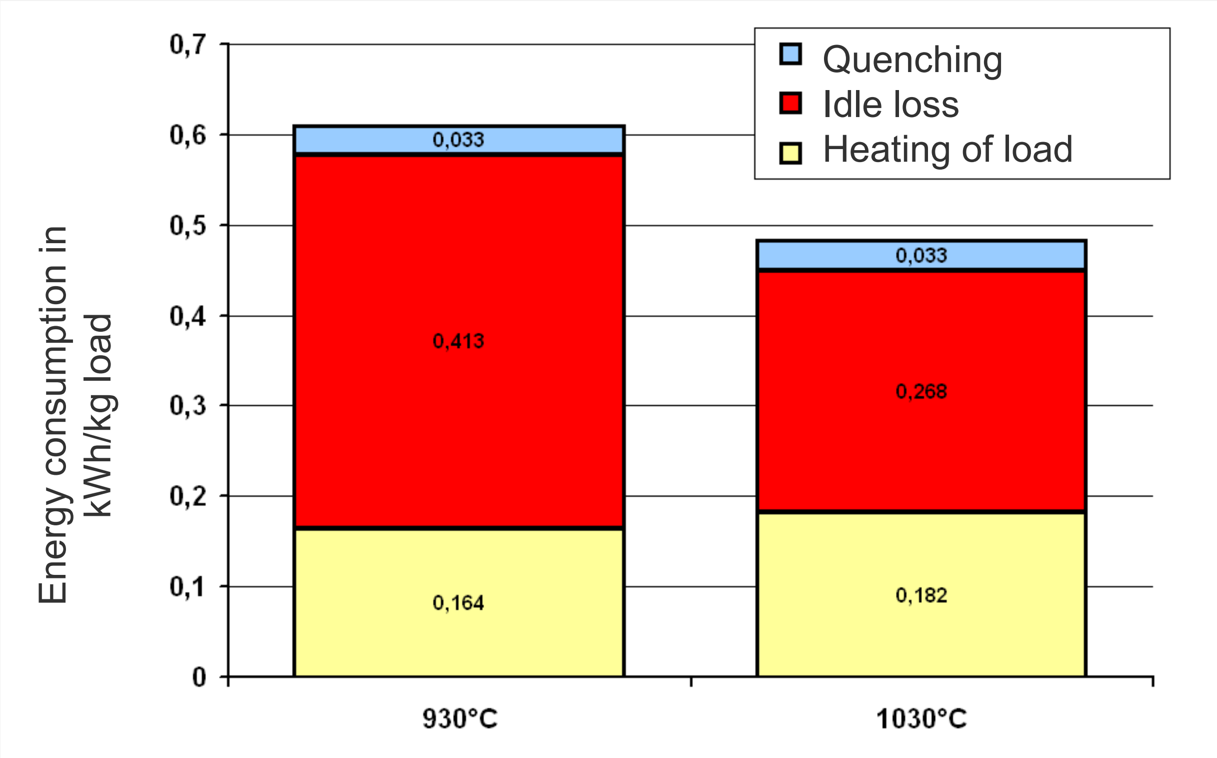
Commonly used carburizing temperatures over the past years when applying Low Pressure Carburizing LPC

HIGHTEMPERATURE-CASE HARDENING

Example: Gears; Gross-load 800 kg; CD=1,5 mm; 12 bar Helium Gasquench

Energy consumption
per 1kg load:

Reduction of process time with high-temperature carburizing leads to significant potential for energy saving (21%)



MICROALLOYED CASE HARDENING STEELS

Case hardening T_{carb} > 960… 980°C:
unwanted grain growth can occur.
Therefore: sufficient grain stability of the steel needed

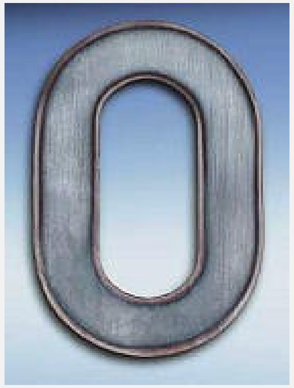
⇨ Necessary to shorten carburizing cycle time:
- Fine grain stability up to 1050°C

Answer of steel-industry: microalloyed case hardening steels e.g. with:
N: 120…170ppm // Al: 250…350ppm // Nb: 320…400ppm.

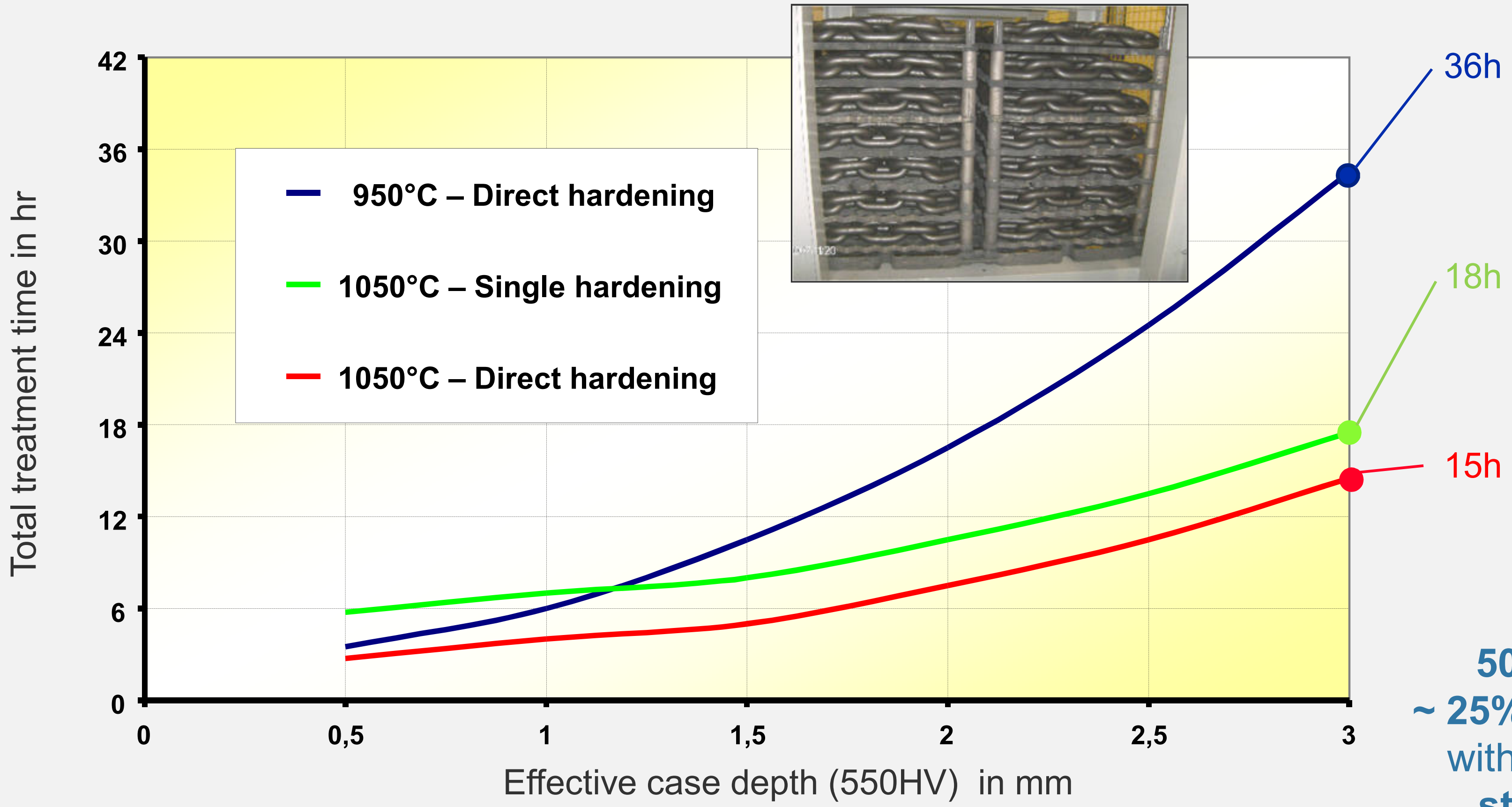
⇨ Industrial “breakthrough” on a large scale was not reached yet

APPLICATION: HIGH-TEMPERATURE VACUUMCARBURIZING OF CHAINS

Parts:	Chain for Conveyors
Material:	21Mn5, 15CrNi6
Spec.:	CHD = up to 3,0 mm
Process:	HT-Vacuum Carburizing: 1050°C
	Gascooling
	Austenitizing: 870°C
	Gasquenching: 20bar He
Load:	600x750x1000 (WxHxL in mm)
	600 - 1000 kg gross
HT-System:	ModulTherm



APPLICATION: HIGH-TEMPERATURE LOW PRESSURE CARBURIZING OF CHAINS



Carburizing at 950°C
(direct hardening)

-50% time

Carburizing at 1050°C
(single hardening),
no grain growth

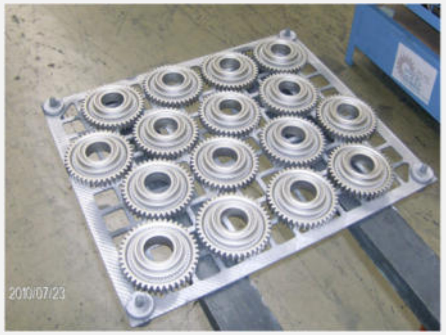
Carburizing at 1050°C
(direct hardening)
but: grain growth

50% Process time reduction
~ 25% (320 kW) energy reduction
with **standard case hardening steels** without grain growth!

OPTIMIZED FIXTURING: COMPARISON CFC- VERSUS ALLOY FIXTURE

Benefits:

- ✓ Less energy consumption
- ✓ Higher strength at temperature
- ✓ Potential for reduction of distortion

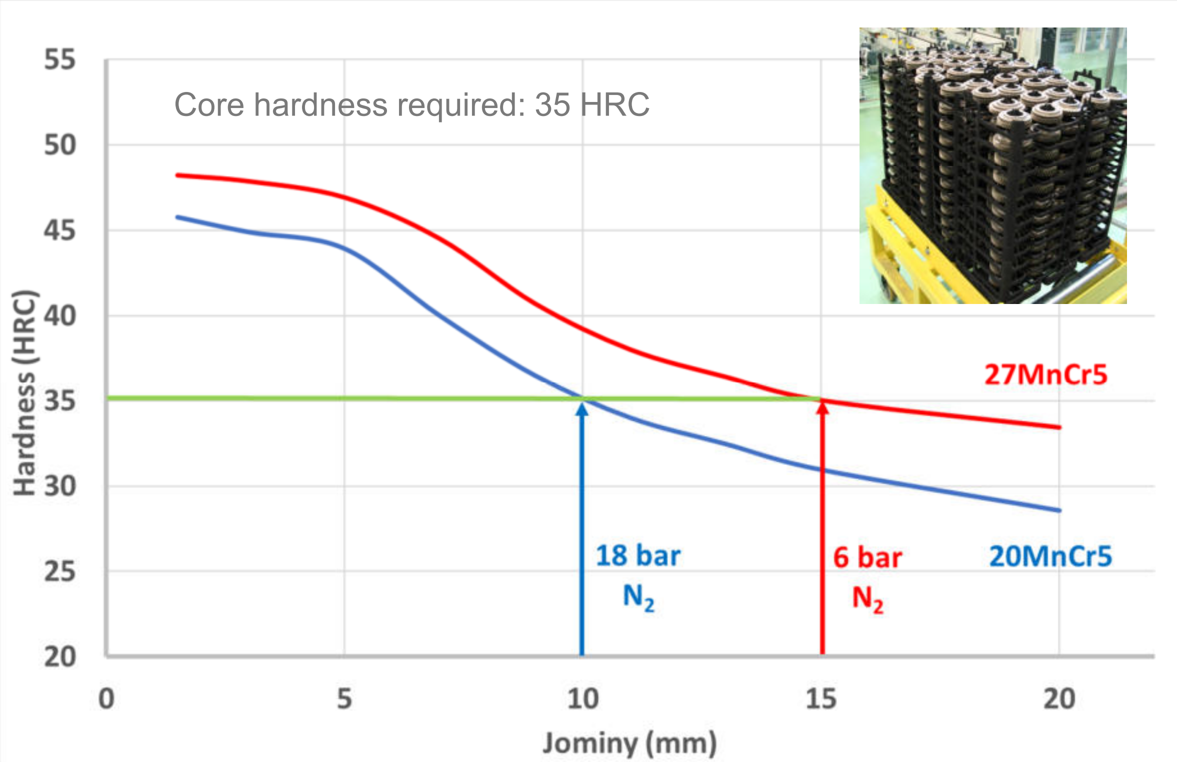


Material	**CFC**	**Cast Alloy (1.4818)**
Density	1,6 kg/dm^3	7,9 kg/dm^3
Weight Fixture	1 kg	12 kg
Spec. Heat Capacity	1,8 kJ/kgK	0,7 kJ/kgK
Energy requirement for heating to 1000°C	**1.764 kJ** **(21%)**	**8.232 kJ** **(100%)**
Bending strength at 1000°C	~ 230 MPa	~ 10 MPa
Thermal expansion coefficient	$5 \times 10^{-6}\ K^{-1}$	$12 \times 10^{-6}\ K^{-1}$

Data: GTD Graphit Technologie GmbH

MATERIAL INFLUENCE ON ENERGY EFFICIENCY

Slightly modified chemical composition in steels has a major impact on required quenching intensity



%	27MnCr5	20MnCr5
C	**0,245**	**0,201**
Si	0,236	0,11
Mn	1,14	1,3
P	0,0119	0,009
S	0,0315	0,026
Cu	0,22	0,016
Al	0,03	0,033
Cr	1,07	1,17
Mo	0,0544	0,025
Ni	0,136	0,074
V	0,006	0,005
Ti	0,00394	0,002
N	0,012	0,007

MATERIAL INFLUENCE ON ENERGY EFFICIENCY

Steels with higher hardenability require lower quenching intensity for same core hardness = 35 HRC

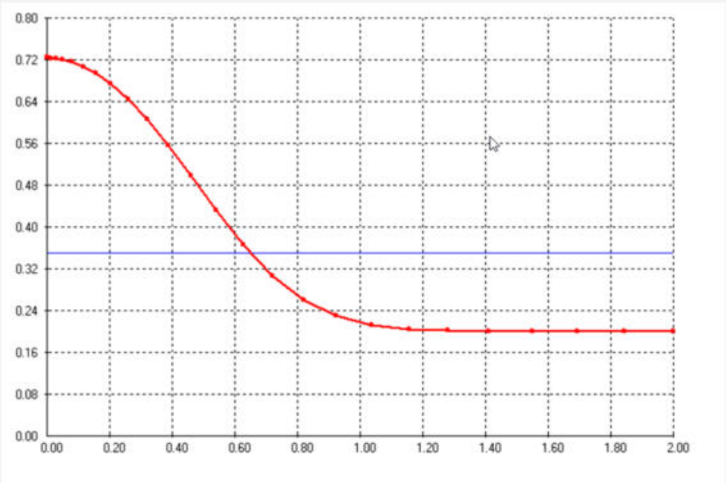
Quenching	Material	
Consumption/Cost	27MnCr5	20MnCr5
Nitrogen	18 Nm^3	54 Nm^3
Cost € [1)]	2,16 €	6,48 €
Electrical energy	16 kWh	28 kWh
Cost € [2)]	3,52 €	6,16 €
Total Cost	5,68 €	12,64 €

43% Energy saving, 55 % Cost savings

[1)] 0,12 €/Nm^3 [2)] 0,22 €/kWh

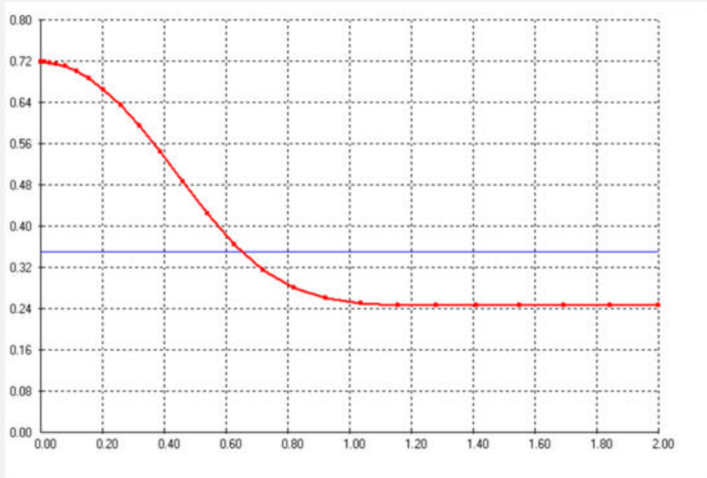
MATERIAL INFLUENCE ON CONSUMPTION

Steels with higher base C-content require less carburizing time for same case depth (CHD=0,65mm)



Steel grade	20MnCr5	
CD actual	0.65	mm
$C_{surf.}$	0.72	%
C_{max} at mm	0.003 = 1.60	%
alloy-factor	1.07	
Mass gain		
Δm_C	22.83	g / m²
Δm_{load}	22.8	g
$\Delta m_{C\text{-}sample}$	49	mg
Duration		
$t_{Carb\text{-}net}$	5.5	min
$t_{Carb\text{-}gross}$	37.0	min
t_{total}	157.0	min

No.	Step	Time	Temp.		Boost	
1	conv. Heating	01:00:00	960.0	°C		
2	Vacuum Heating	00:30:00	960.0	°C		
3	Carburising puls.	00:07:00	960.0	°C	150	s
4	Carburising puls.	00:07:00	960.0	°C	60	s
5	Carburising puls.	00:10:00	960.0	°C	60	s
6	Carburising puls.	00:13:00	960.0	°C	60	s
7	Vacuum Heating	00:30:00	960.0	°C		



Steel grade	27MnCr5	
CD actual	0.65	mm
$C_{surf.}$	0.72	%
C_{max} at mm	0.003 = 1.63	%
alloy-factor	1.09	
Mass gain		
Δm_C	19.13	g / m²
Δm_{load}	19.1	g
$\Delta m_{C\text{-}sample}$	41	mg
Duration		
$t_{Carb\text{-}net}$	4.5	min
$t_{Carb\text{-}gross}$	24.0	min
t_{total}	144.0	min

Saving in Carburizing time: 30%

Total process time saving: 8%

No.	Step	Time	Temp.		Boost	
1	conv. Heating	01:00:00	960.0	°C		
2	Vacuum Heating	00:30:00	960.0	°C		
3	Carburising puls.	00:07:00	960.0	°C	150	s
4	Carburising puls.	00:07:00	960.0	°C	60	s
5	Carburising puls.	00:10:00	960.0	°C	60	s
6	Vacuum Heating	00:30:00	960.0	°C		

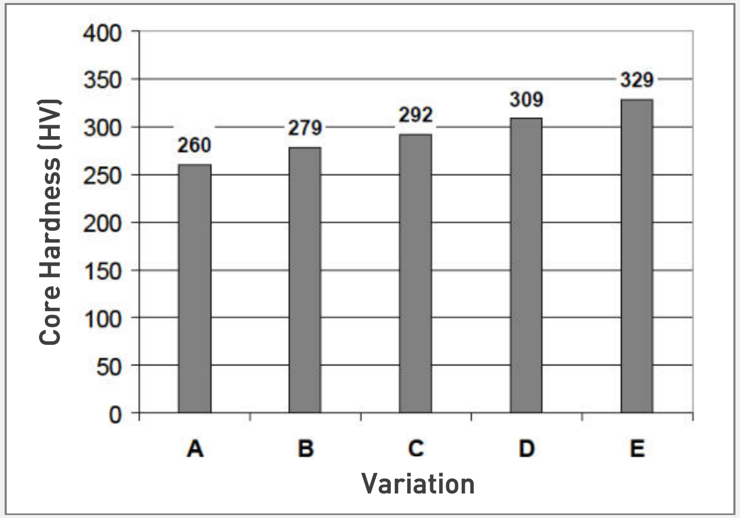
INFLUENCE OF CORE HARDNESS ON THE TOOTH-ROOT FATIGUE-STRENGTH

Typical gear core hardness requirement > 300HV

How does a tooth-root core hardness < 300HV influence the fatigue strength of gears?

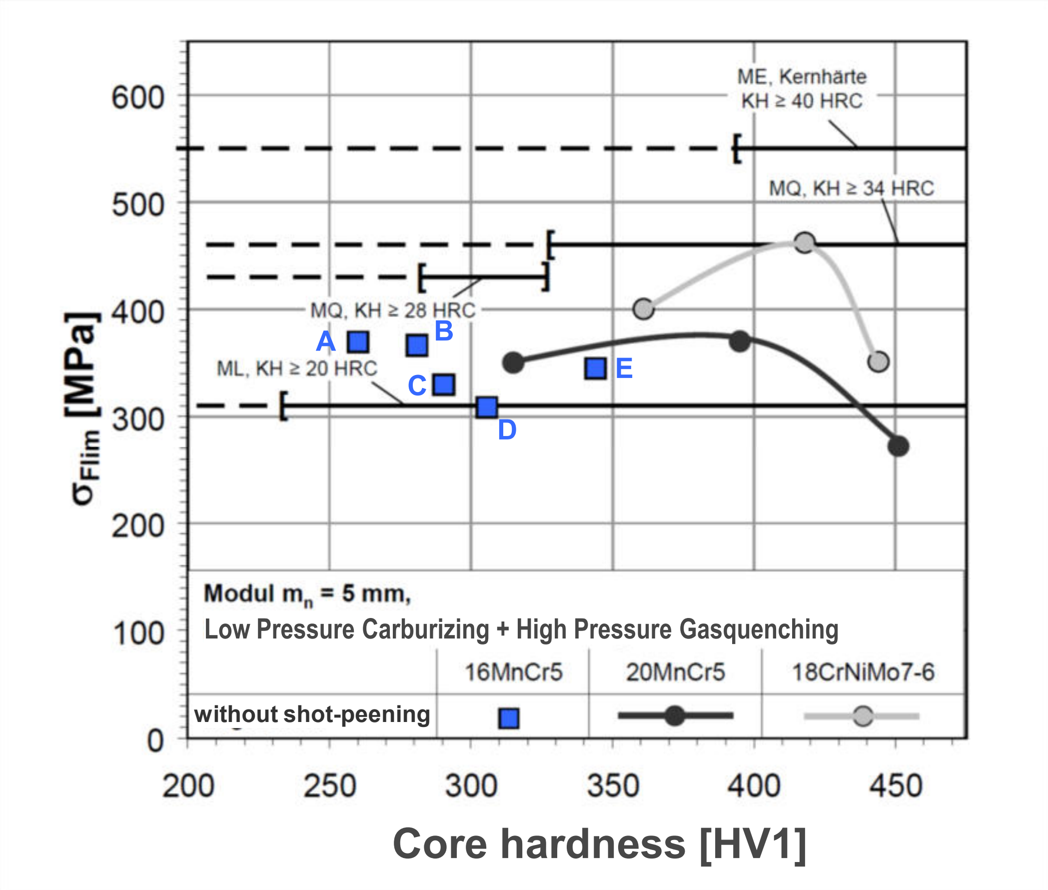
LPC + Gasquenching (v_g = 15 m/s)				
A	B	C	D	E
2 bar N_2	6 bar N_2	10 bar N_2	10 bar He	20 bar He

Material:	16MnCr5 (SAE 5115)
Dia:	134 mm
Thickn.:	30 mm
Modul:	5
CHD:	0.75 + 0.25 mm
$Temp_{carb}$:	940°C



Source: FVA, FV 425 Zahnfußkernfestigkeit II, Heft 893, 2009

INFLUENCE OF CORE HARDNESS ON THE TOOTH-ROOT FATIGUE-STRENGTH



LPC + Gasquenching (v_g = 15 m/s)				
A	**B**	**C**	**D**	**E**
2 bar N_2	6 bar N_2	10 bar N_2	10 bar He	20 bar He

Core hardness values < 300HV do not necessarily reduce the tooth-root fatigue strength

Reduction of core hardness requirement allows to reduce gas quenching parameters (pressure, velocity), thereby:

- saving **electrical energy**
- offer potential for **distortion control**

Source: FVA, FV 425 Zahnfußkernfestigkeit II, Heft 893, 2009

CONCLUSIONS

- In order to achieve the climate targets, the use of fossil fuels will be reduced and instead the use of electricity from renewable sources will be increased
- LPC-heat treatment plants are operated almost exclusively with electrical energy
- The contribution of manufacturers and users of this furnace-technology to the green deal is the reduction of electrical energy consumption
- Measures to reduce energy consumption:
  - Flexible, modular furnace concepts
  - Reduction of idle losses by improved insulation design
  - Use of higher carburizing temperatures
  - Use of C/C-fixtures instead of alloy-fixtures
  - Use of modified gear materials with improved hardenability
  - Adjustment of core-hardness specification

THANK YOU