

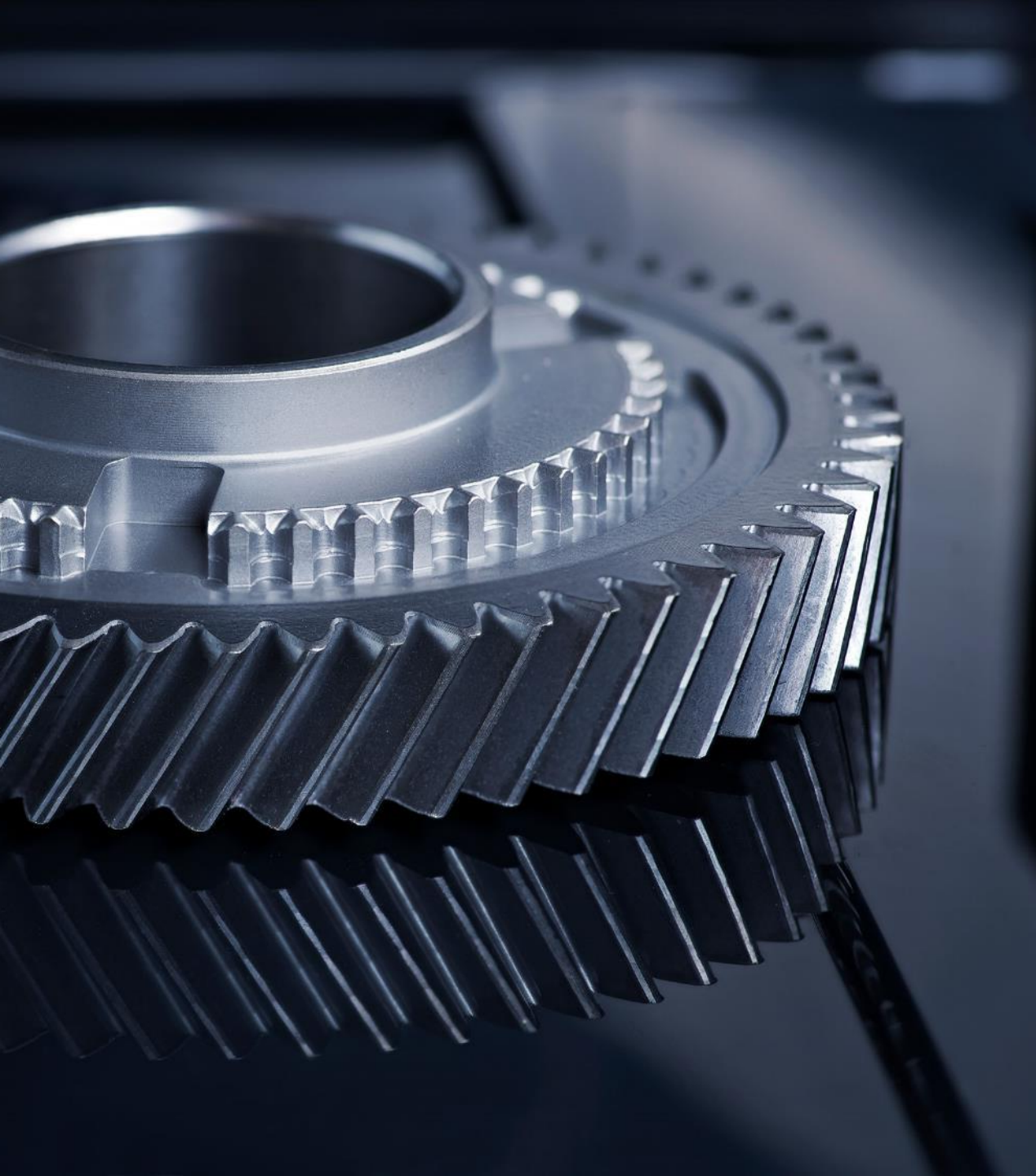
Optimizing Heat Treatment for High-Performance PM Steels



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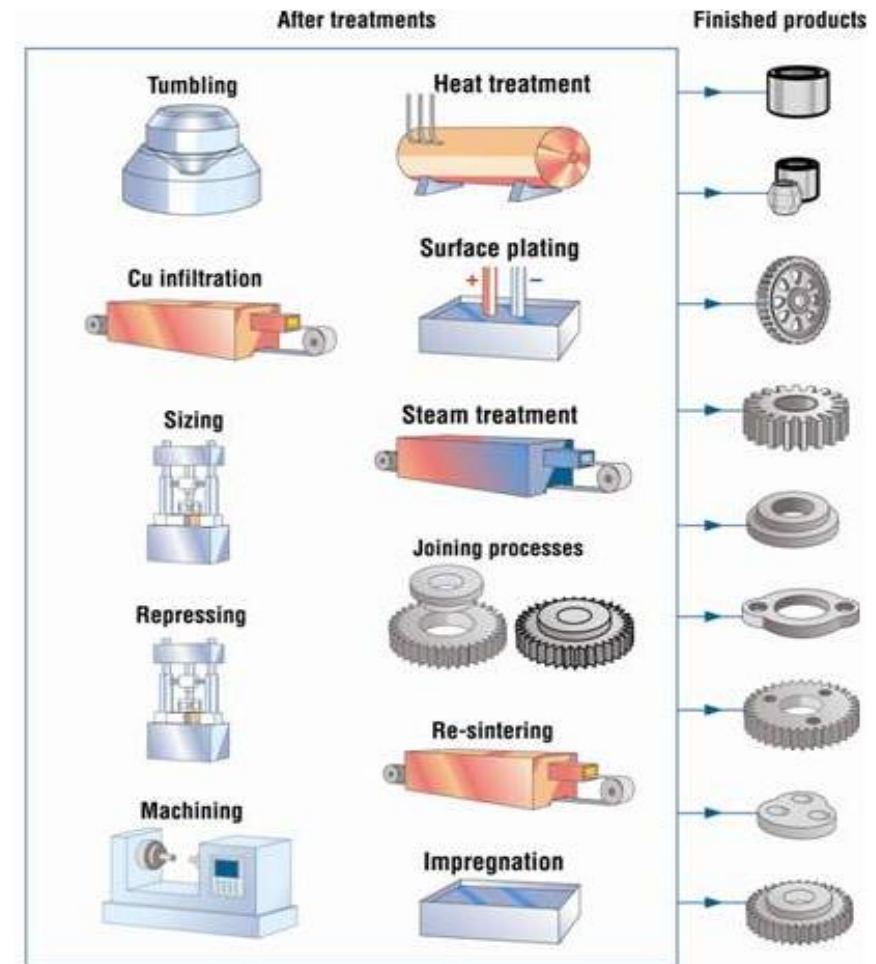
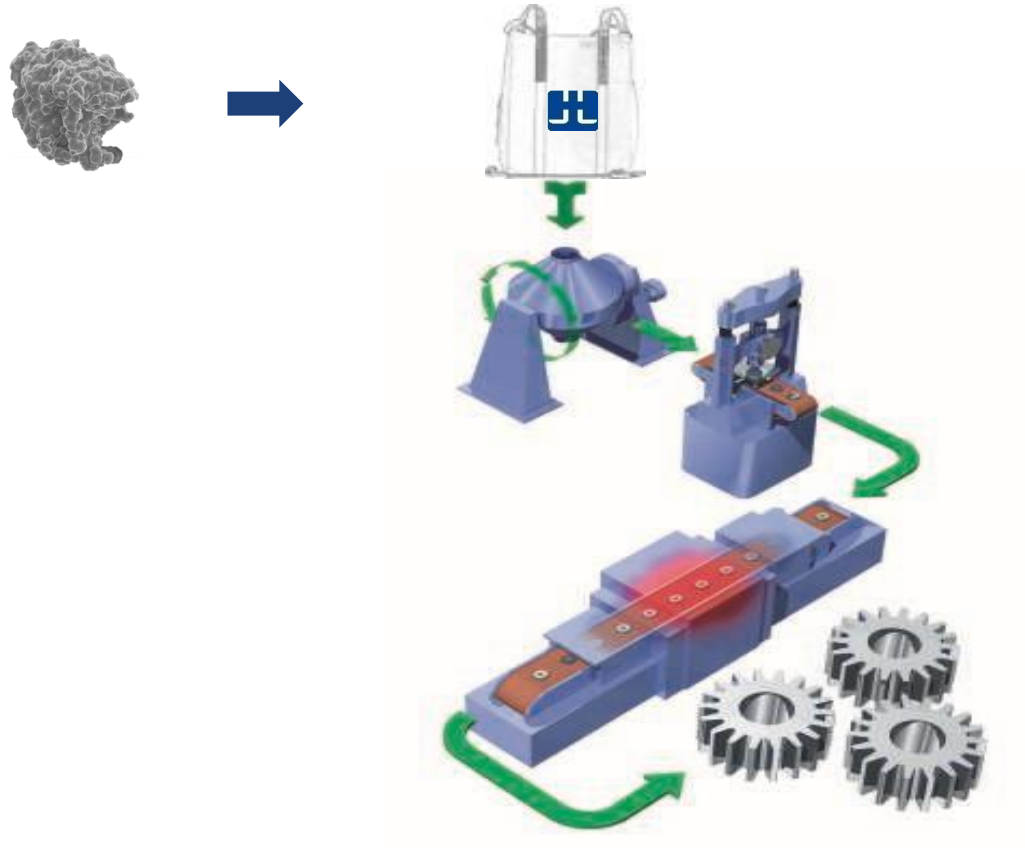
PM, Powder Metallurgy

- » Over 40 million sintered components are produced every day
- » Automotive is the most important industry for PM, such as systems for transmission, engine, chassis and exhaust

Benefits of pressing and sintering:

- » Cost-efficient design solutions
- » Optimal usage of material and energy
- » Design freedom – complex geometries

Press and Sinter



Heat treatment process for PM steels

Case Hardening (850°C – 980°C)

- Gas carburising, oil quenching, and tempering (CQT)
- Low pressure carburising (LPC) + High Pressure Gas quenching and tempering
- Induction hardening

Through Hardening (920°C – 1120°C)

- Quench and tempering (QT)
- Sinterhardening (SH)

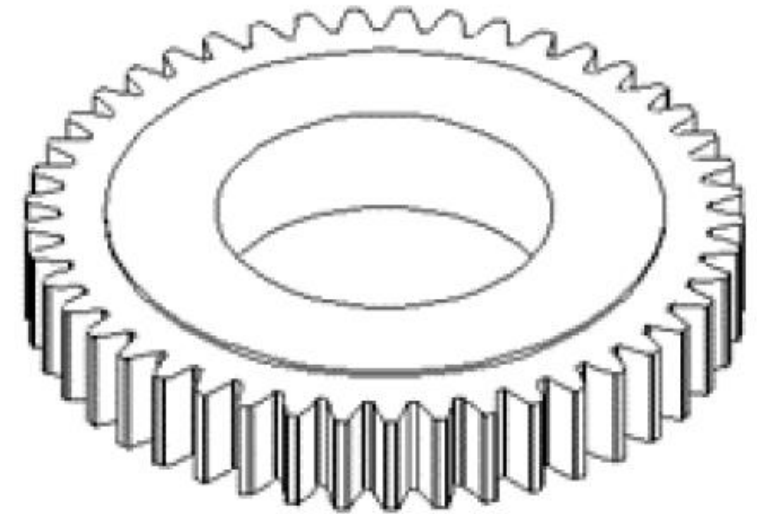
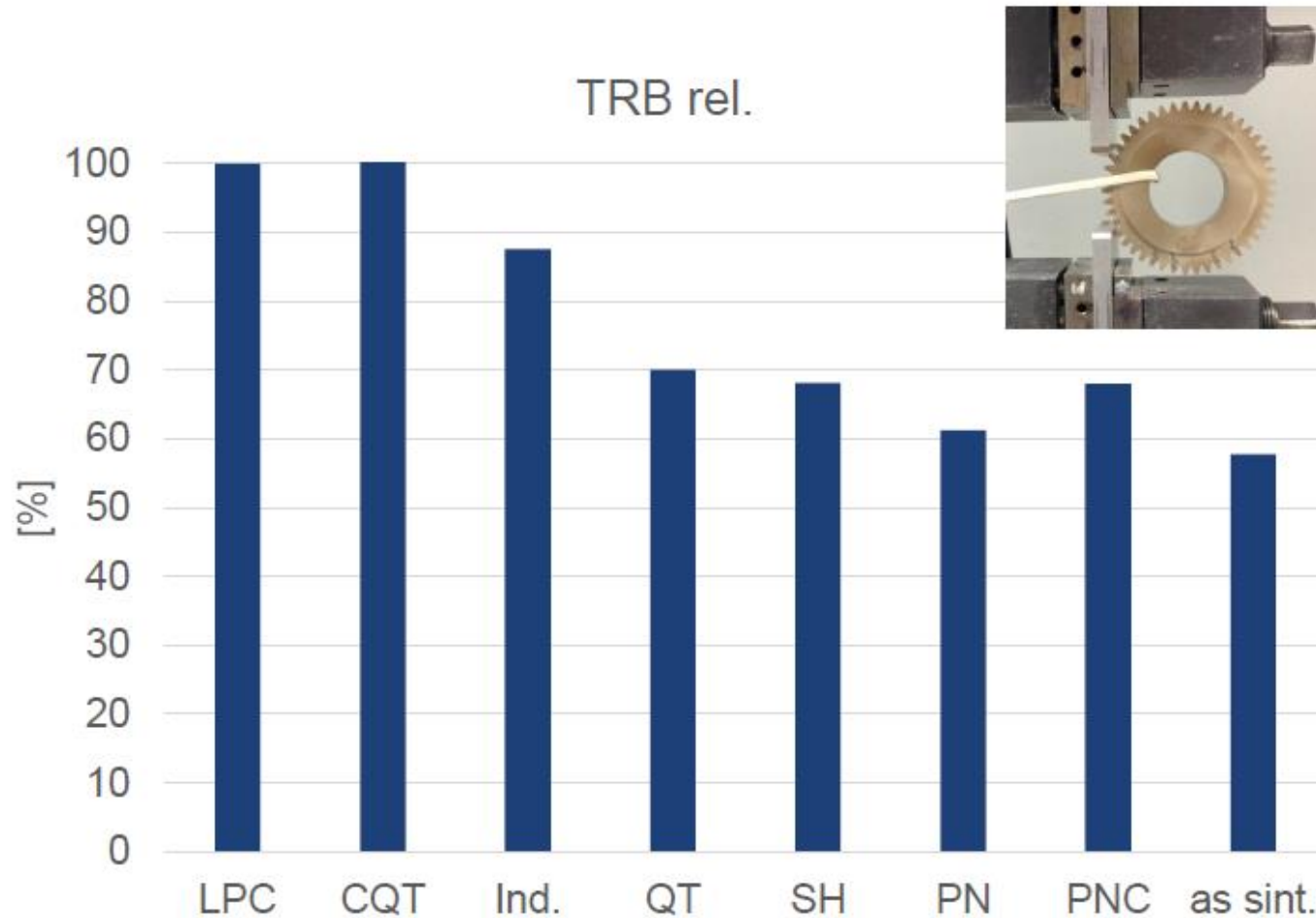
Low temperature diffusion processing (480°C – 580°C)

- Gas Nitriding and Nitrocarburising
- Plasma Nitriding and Plasma Nitrocarburising

Tempering/Annealing (180°C – 500°C)

Steam treatment (450°C – 550°C)

Influence on fatigue performance



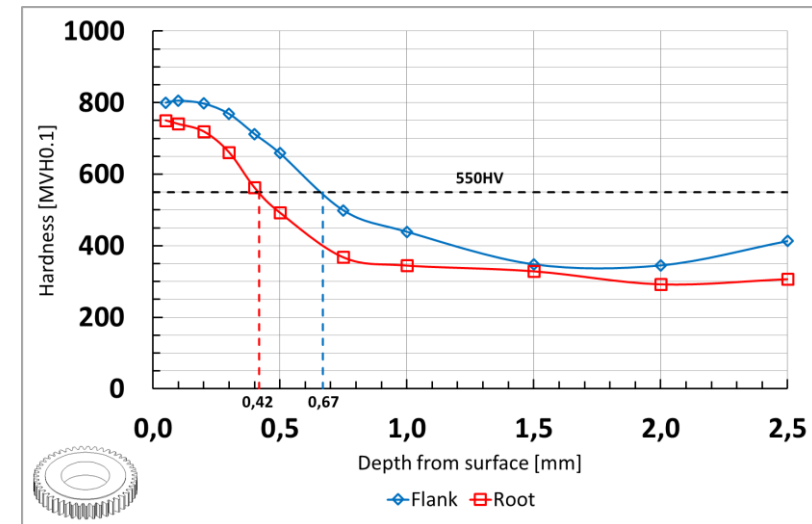
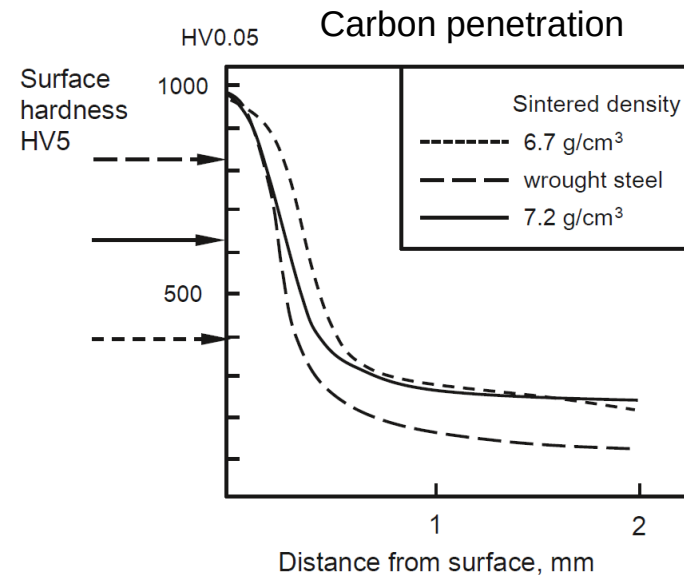
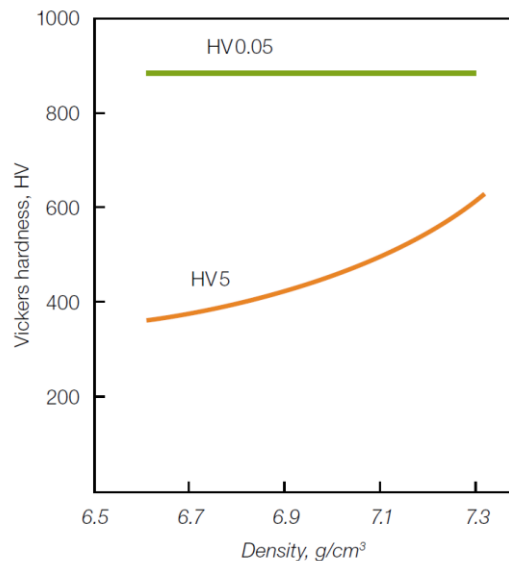
R&D gear

Number of teeth, z:	45
Module, m	2
Reference Ø, d:	90 mm
Root Ø, df:	85 mm
Tip Ø, da:	94 mm
Gear width, b:	14 mm

Carburising of sintered components

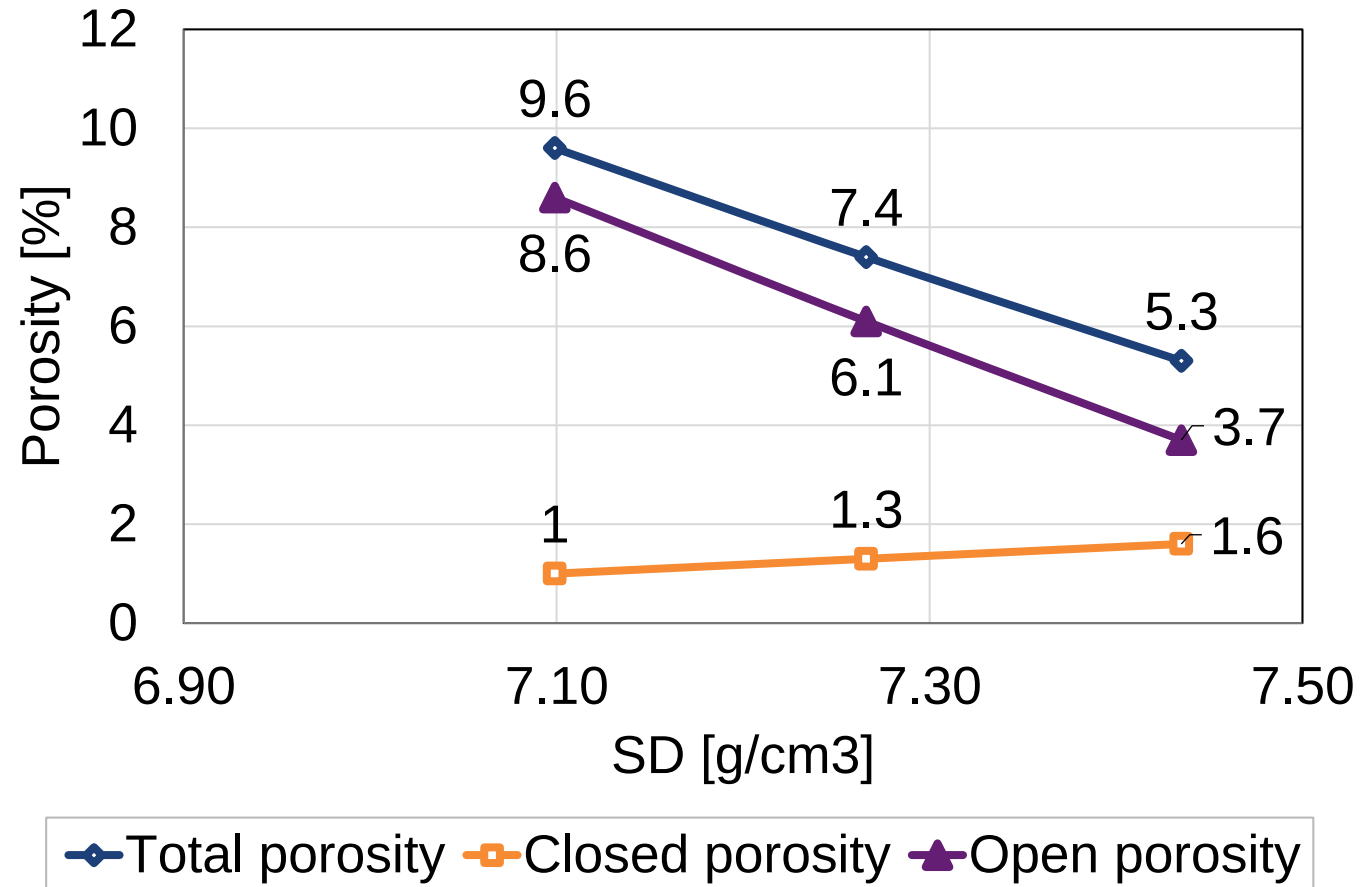
Influence of density i.e. porosity make its important to:

- » measure carburized hardness
- » control carburized depth
- » define carburized depth (CHD “case hardened depth”)



As-sintered properties

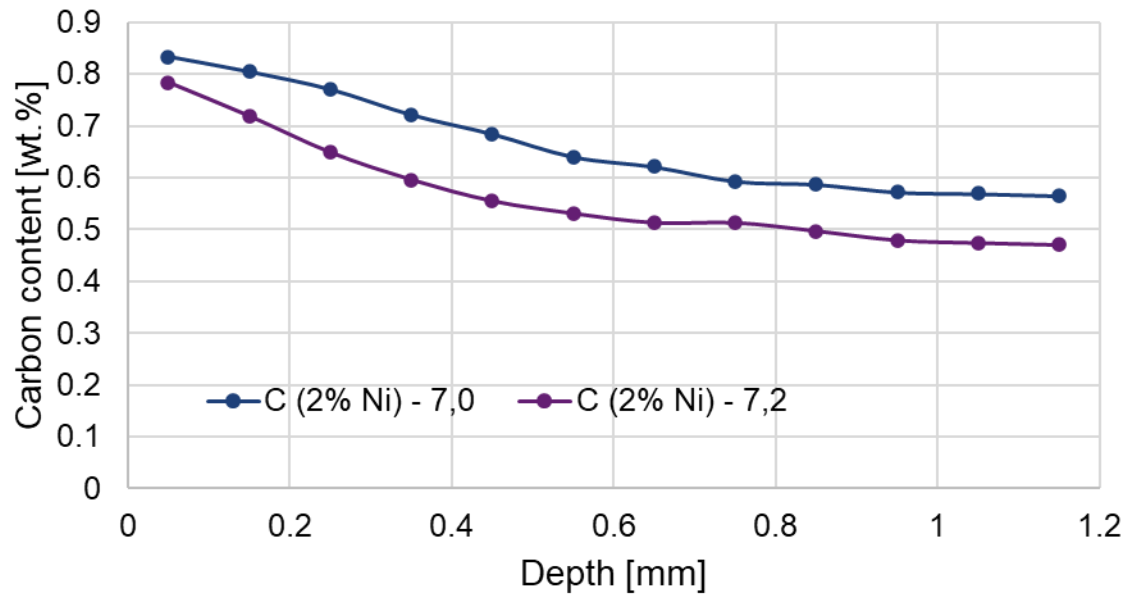
Open and closed porosity



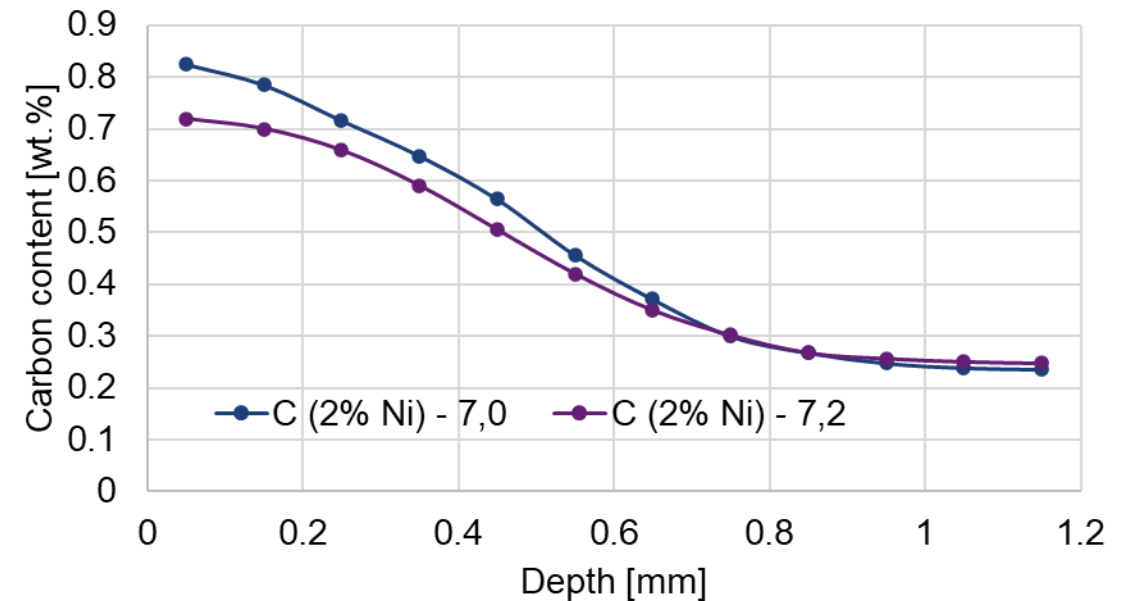
Carbon-profile: GC vs LPC of PM steels

Carbon profile - Astaloy CrA+2Ni+0.25C

Gas carburising

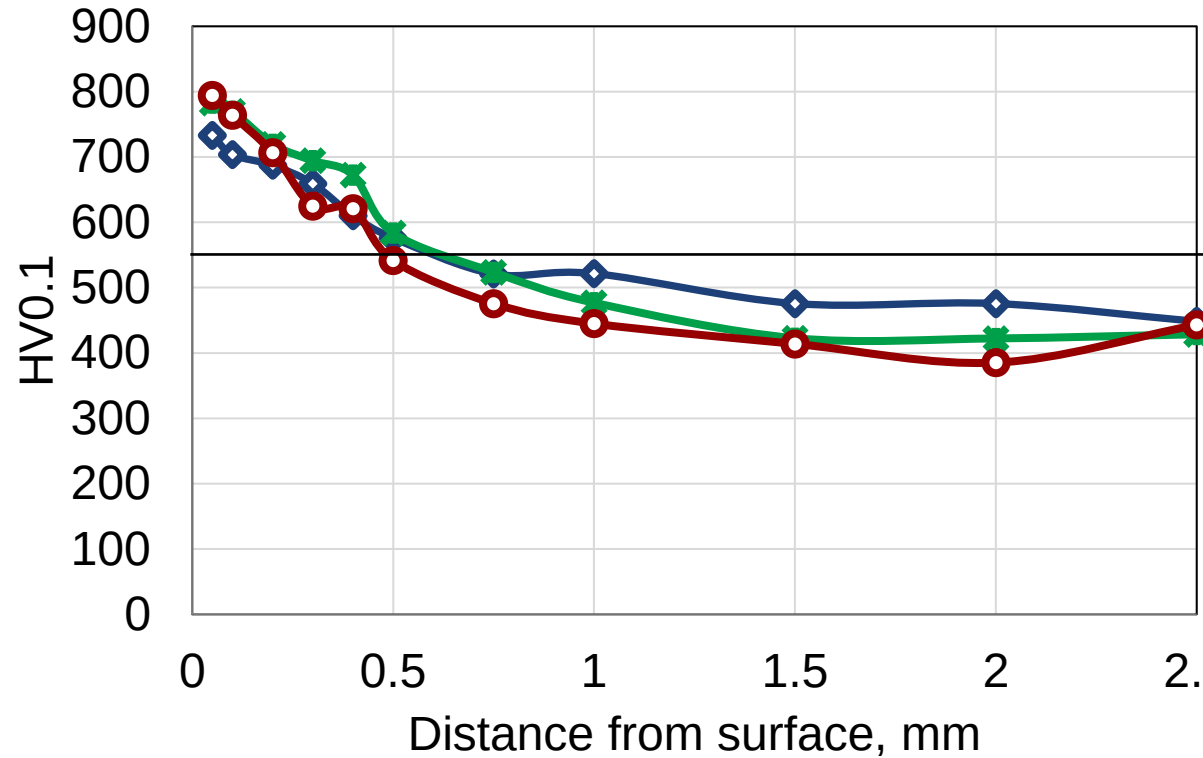


Low pressure carburising



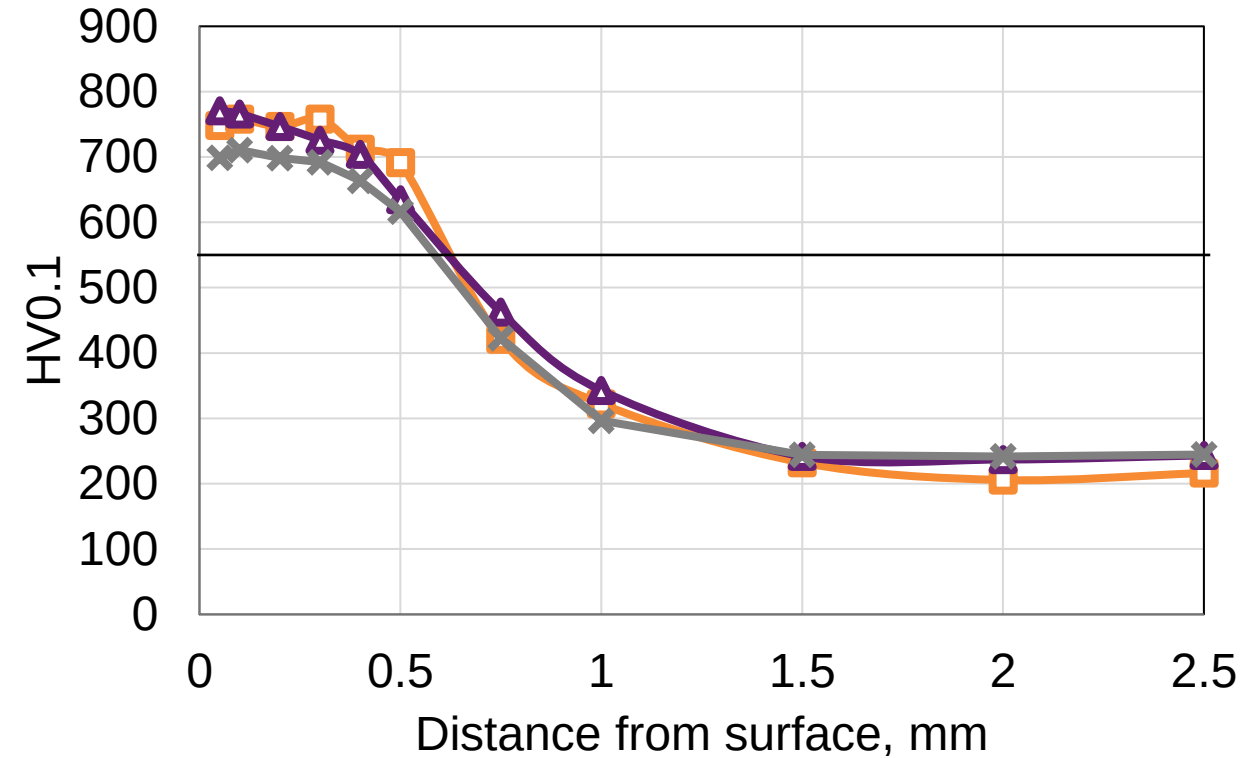
Influence of density

Astaloy CrS GC



CrS-7.1-GC CrS-7.25-GC CrS-7.4-GC

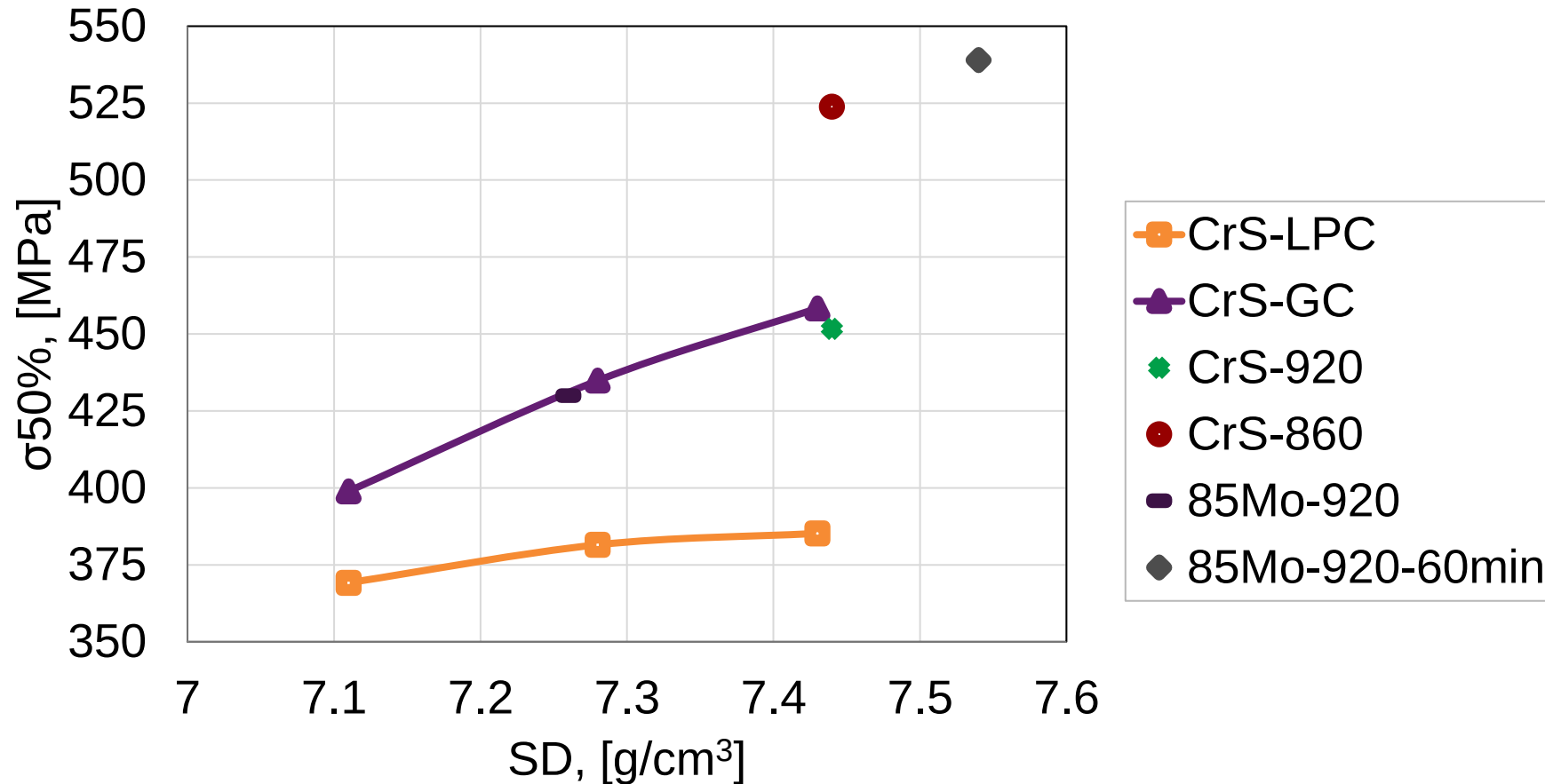
Astaloy CrS LPC



CrS-7.1-LPC CrS-7.25-LPC CrS-7.4-LPC

Fatigue data after heat treatment

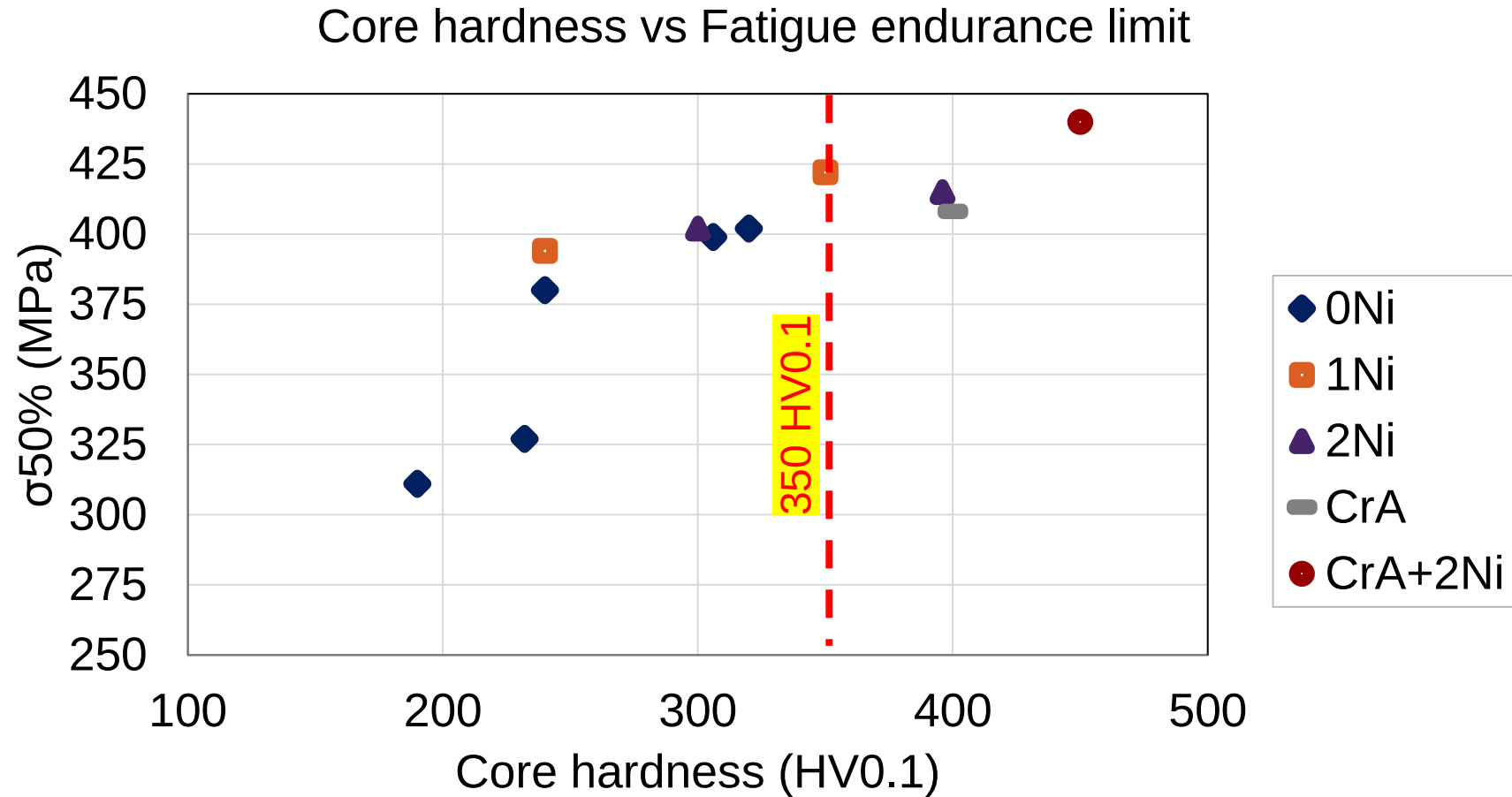
Endurance Limit



- All the samples were sintered at 1120°C – 30 mins in 0.2%Cp
- Unless otherwise specified, gas carburising was performed at 920°C-20 min with Cp of 0.95% and tempered at 200°C for 1h in air

Same LPC recipe

Core hardness vs FEL



One material is not for all components...

- » Many existing PM gears are often quite small
- » Gears for e-drives are typically bigger than existing PM components
- » Large component → slower quenching → need higher **hardenability**
- » Performance: Better hardenability / maintaining high compressibility

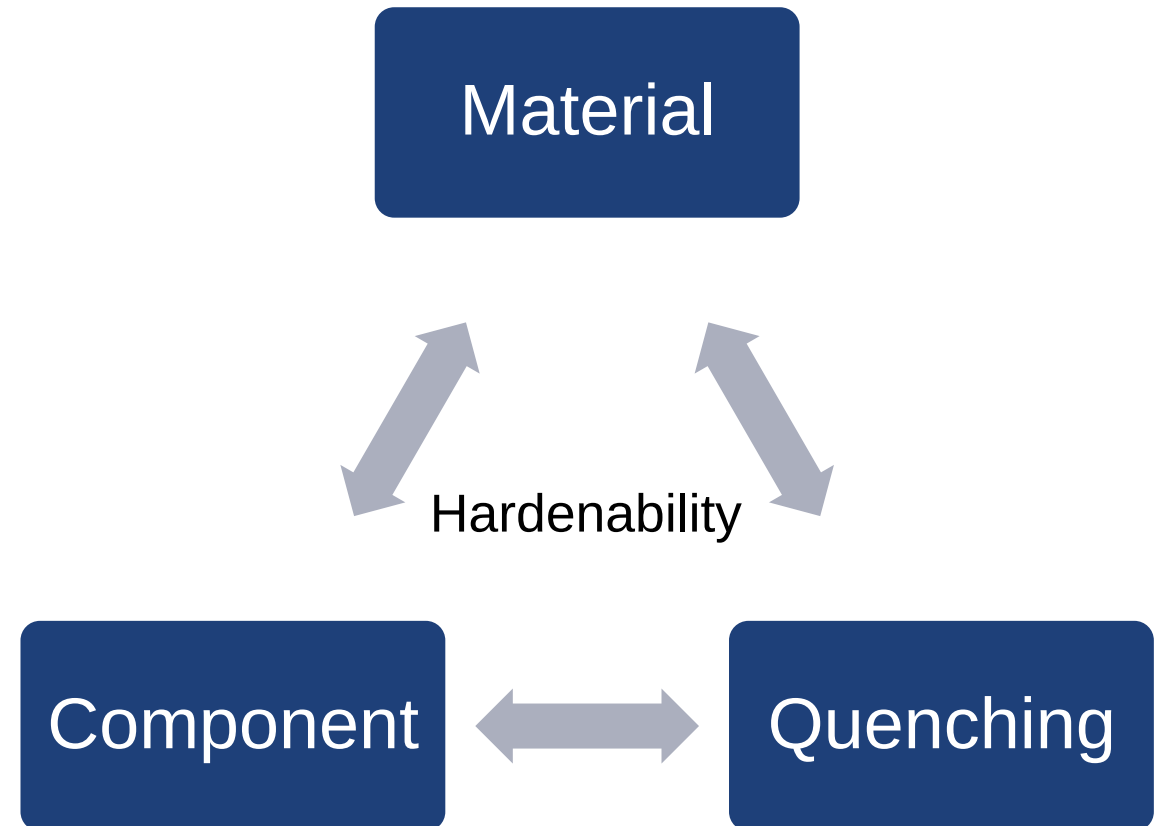


Hardenability: Material / Process/ size

Hardenability: ability to form martensite upon cooling from austenite

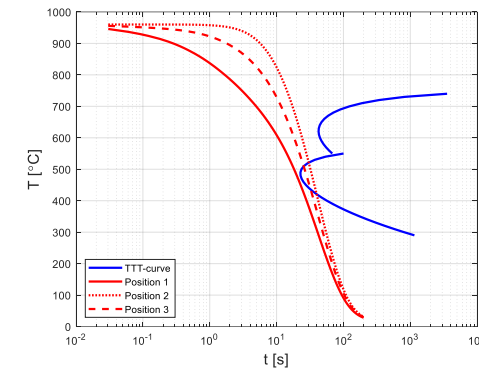
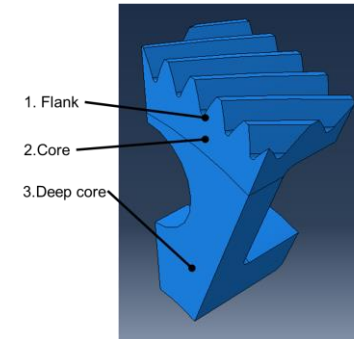
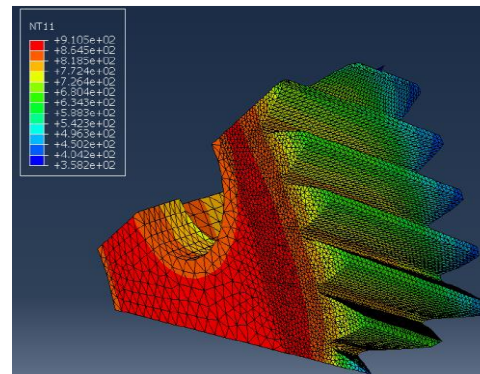
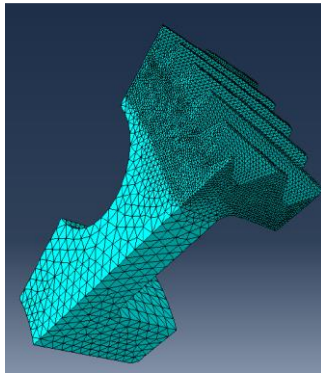
Influencing factors:

- » Component: surface area and mass
- » Quench medium: oil, gas (N₂, He, Ar)
- » Quench parameters: flow rate, temperature, pressure etc
- » Alloy composition: carbon and other alloying elements



Hardenability modelling

Modelling



- Gear geometry
- Drawing or CAD model

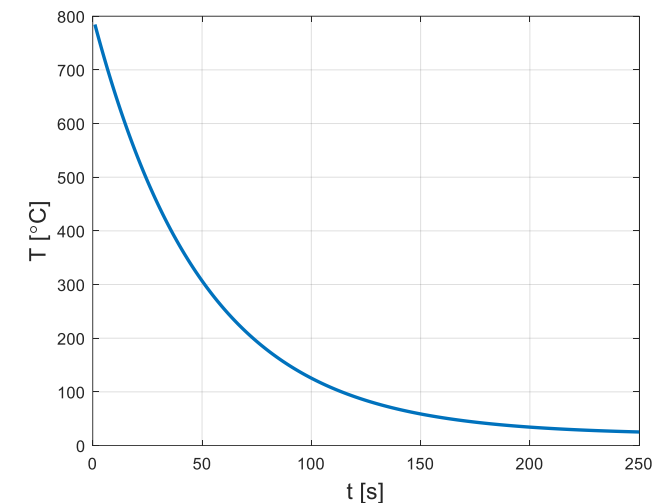
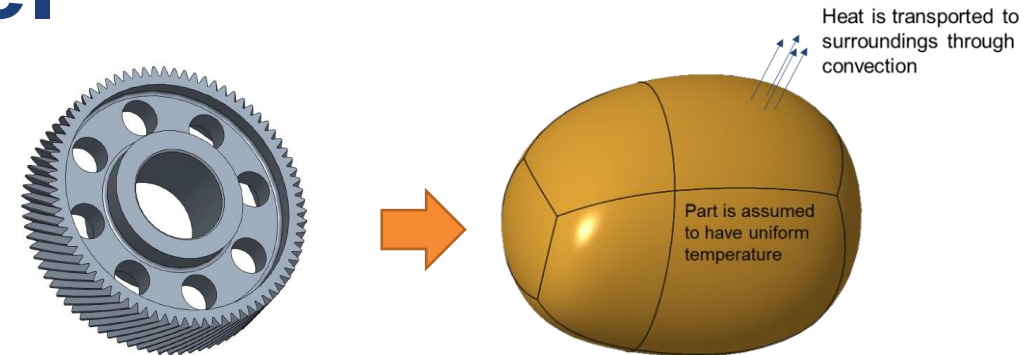
- FE model
- Geometry
- Thermal properties
- Process conditions

- Calculate how the components cools in different parts

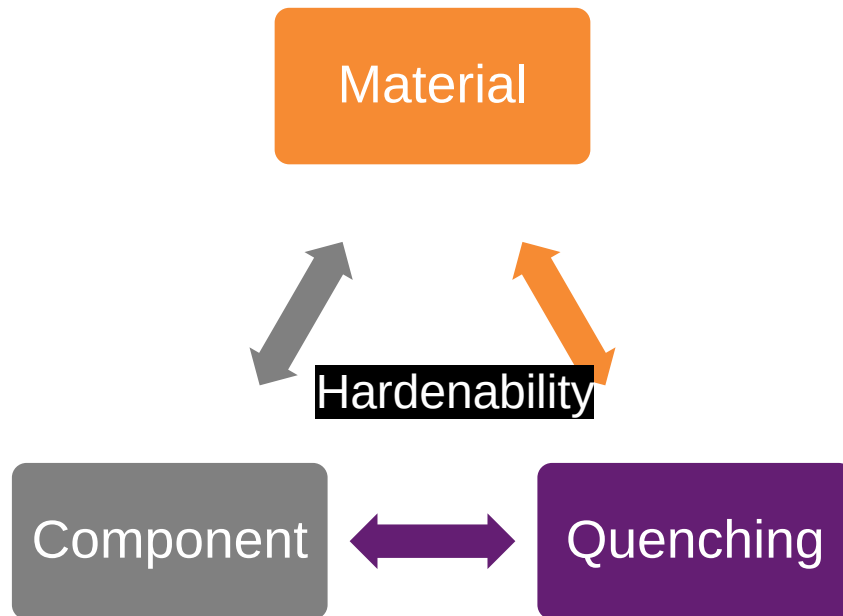
- Evaluate against hardenability data
- Select the right material

Simplified quenching model

- » Body at uniform temperature
- » Heat is transported away through convection
 - Heat transfer number
 - Data for different processes are in the calculator
- » Analytic model for heat transfer
- » Large component mass slows down cooling
- » Large surface area speed up cooling



Practical tool to predict hardenability



Hardenability Calculator 2023.4

Material

AstaloyCrS_075Ni_064C_20um

Adjust hardenability

Low High

Component

Volume [cm³] ☐ Calculate

Area [cm²]

Density [g/cm³]

Quench conditions

Heat transfer number

Heat transfer number [W/m²K]

Cooling rate [K/s]

Results

Hardenability is probably sufficient.

Estimated martensite= 91%

Eq grain=Nominal+ 6 um

h500=140 W/m²K

☒ Advanced mode

Fast vs slow cooling – 0.2 C

Höganäs hardenability calculator 2023

Material
Ast85Mo_02C_20um

Component
Volume [cm³] 302
Area [cm²] 897
Density [g/cc] 7.2

Quench conditions
Gas quench - fast
Heat tr. number [W/m²K]
Cooling rate [K/s]

Calculate

Help

Result
This material does not suit the application.
xm= 4%

☒ Advanced mode

Höganäs hardenability calculator 2023

Material
Ast85Mo_02C_20um

Component
Volume [cm³] 302
Area [cm²] 897
Density [g/cc] 7.2

Quench conditions
Gas quench - slow
Heat tr. number [W/m²K]
Cooling rate [K/s]

Calculate

Help

Result
This material does not suit the application.
xm= 0%

☒ Advanced mode



Fast vs slow cooling – 0.6 C

Höganäs hardenability calculator 2023

Material
Ast85Mo_06C_20um

Component
Volume [cm³] 302
Area [cm²] 897
Density [g/cc] 7.2

Quench conditions
Gas quench - fast
Heat tr. number [W/m²K]
Cooling rate [K/s]

Calculate

Help

Result
Hardenability is probably sufficient.
xm= 92%

☒ Advanced mode

Höganäs hardenability calculator 2023

Material
Ast85Mo_06C_20um

Component
Volume [cm³] 302
Area [cm²] 897
Density [g/cc] 7.2

Quench conditions
Gas quench - slow
Heat tr. number [W/m²K]
Cooling rate [K/s]

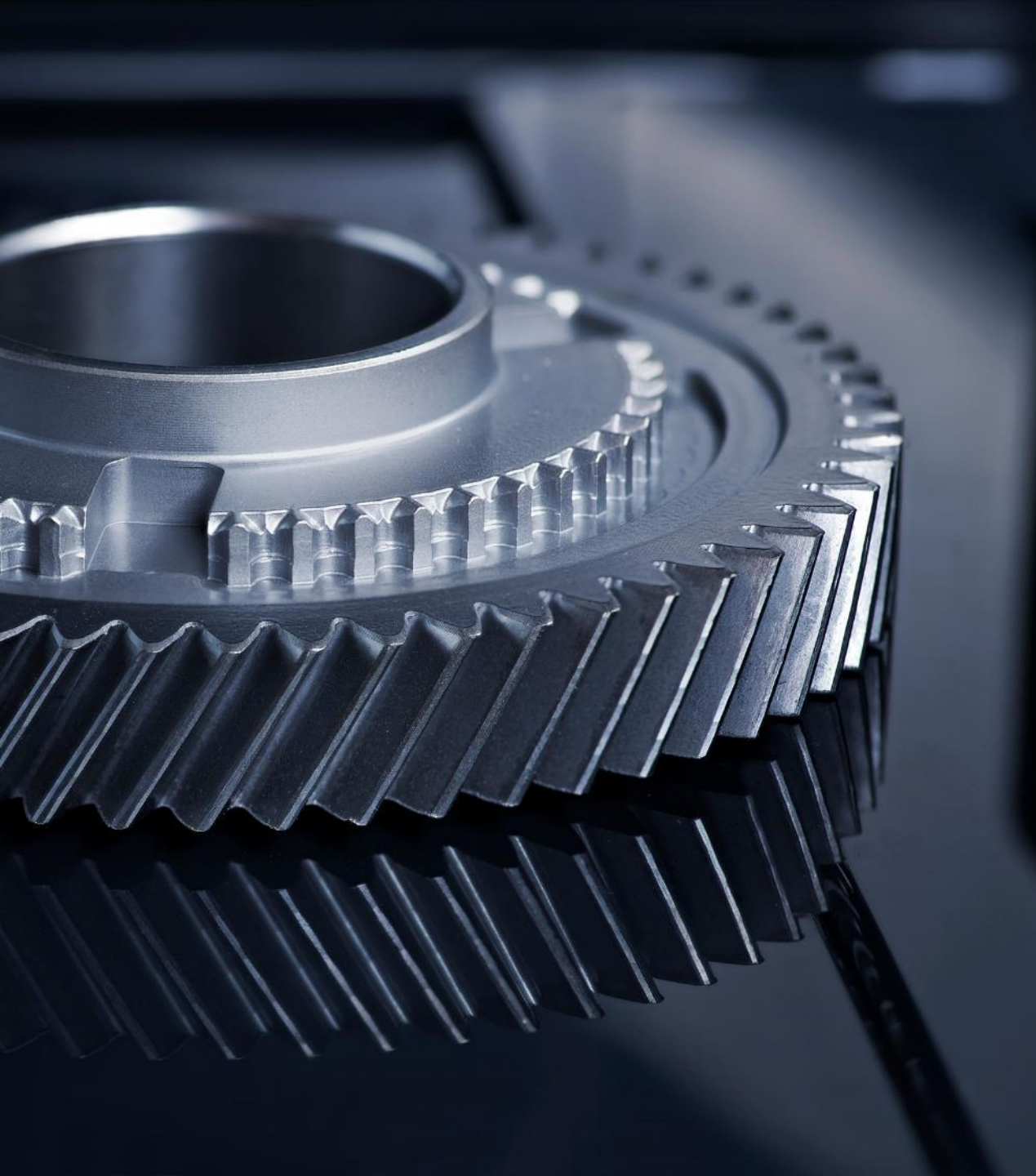
Calculate

Help

Result
Hardenability is on the limit.
Further tests are needed.
xm= 83%

☒ Advanced mode





Summary

- » Properties of alloys can be improved by changing the chemical composition and by a suitable heat treatment.
- » Ferrous PM parts can be heat-treated like the conventional parts
- » Consider the following
 - Porosity
 - Heterogeneous alloy systems in some cases
 - Difference in response
- » Through simulations right materials can be selected for the processes



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Thank you!

