Gears with top in-service performance developed for hybrid and electric vehicles – General Overview

Aachen, 08/04/2025
FINAL WORKSHOP of RFCS TOPGEAR Project
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This project has received funding from the Research Fund for Coal and Steel under grant agreement No 101033989

WORKSHOP Agenda

General presentation of the TOPGEAR project (SIDENOR)

LPVC+WSQ technology (ALD)

Fatigue testing of the 4 studied steels and surface hardening technologies (CRF)

Development of a gear test rig for very high speeds (12000 rpm) (WZL)

Comparison of gear performance at very high speeds of reference and alternative technologies (WZL)

Life Cycle Assessment of reference and alternative technologies (i2m)

Economic analysis and possibilities of application to BEV gearboxes (CRF)

MOTIVATION AND OBJECTIVES

Background

In 2020, when the proposal was submitted, the shift to battery electric vehicles also showed a trend to higher motor speeds

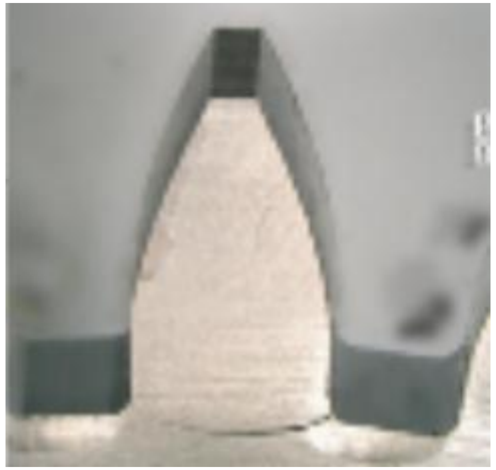
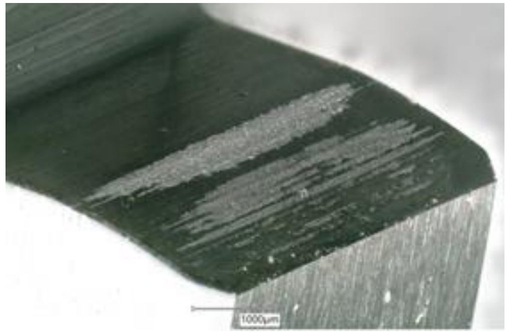
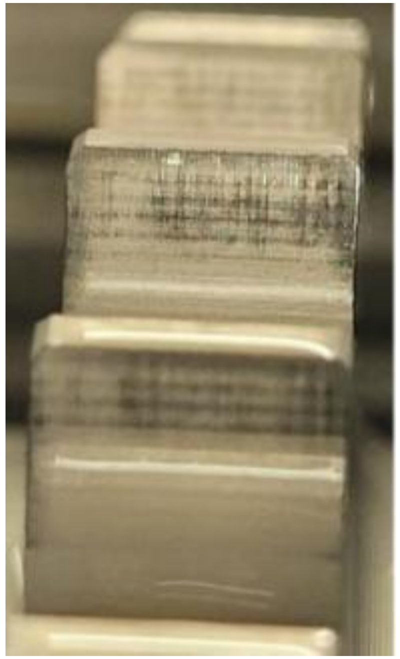
An ICE engine runs at 6-8,000 rpm, but an electric motor goes up 15,000 rpm (now a TESLA Model S achieves 20,000 rpm and a BYD aims to attain almost 30,000 rpm)

At very high speeds, lubrication is no so effective and new gear failure modes might appear due to severe adhesion wear

However, there are not gear test rigs running at such high speeds and evaluate the performance of steels and gears adequately

Tesla model S gearbox

Main gear failure modes

Tooth root bending fatigue	Pitting	Scuffing
Cracking at the tooth root due to exceeding the bending fatigue limit	Surface flaking caused by rolling contact fatigue	Adhesion wear where metal from one gear tooth transfers to another due to insufficient lubrication
	 	

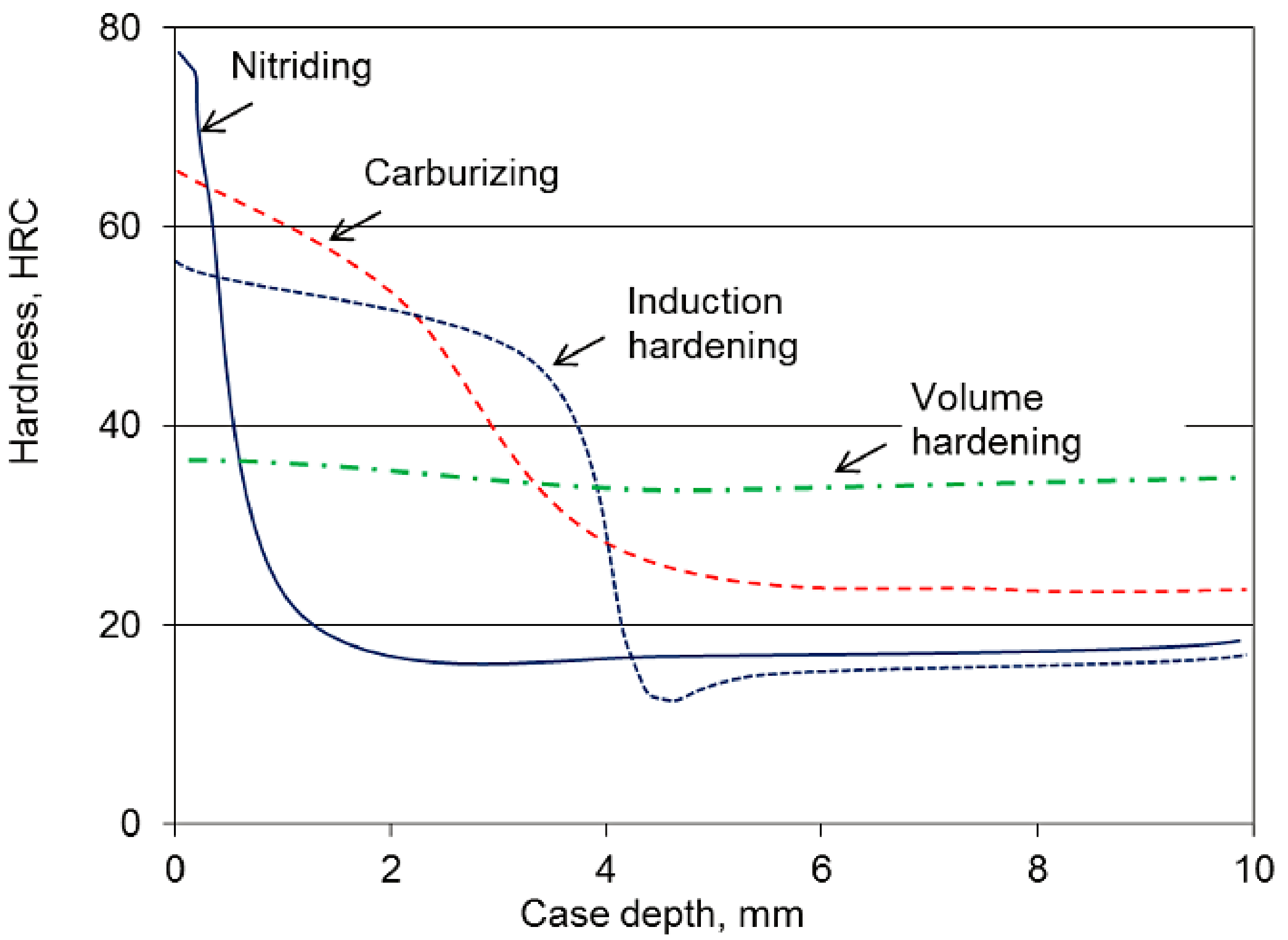
Surface hardening treatments

To transmit the torque and cope with bending and rolling contact loads, gears are surface hardened

The goal is to combine good toughness at the core, good strength at the subsurface and very high surface hardness to avoid wear

Each surface heat treatment is suitable for certain steel grades and working conditions

To avoid scuffing a very high surface hardness should be convenient

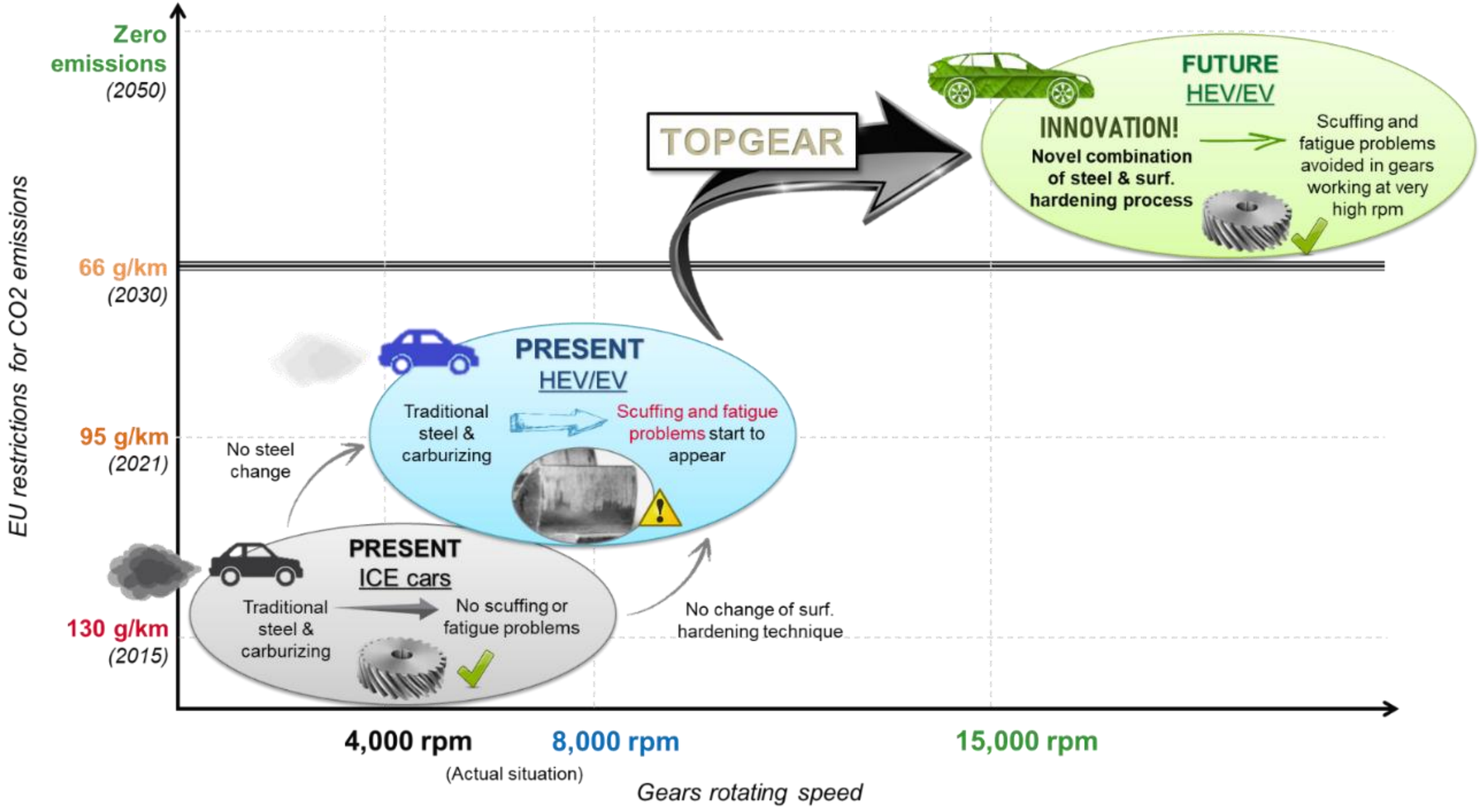


Objectives of the TOPGEAR project

Determine the optimal combination of steel grade and surface hardening treatment for electric vehicles running at >15,000 rpm without fatigue and scuffing issues

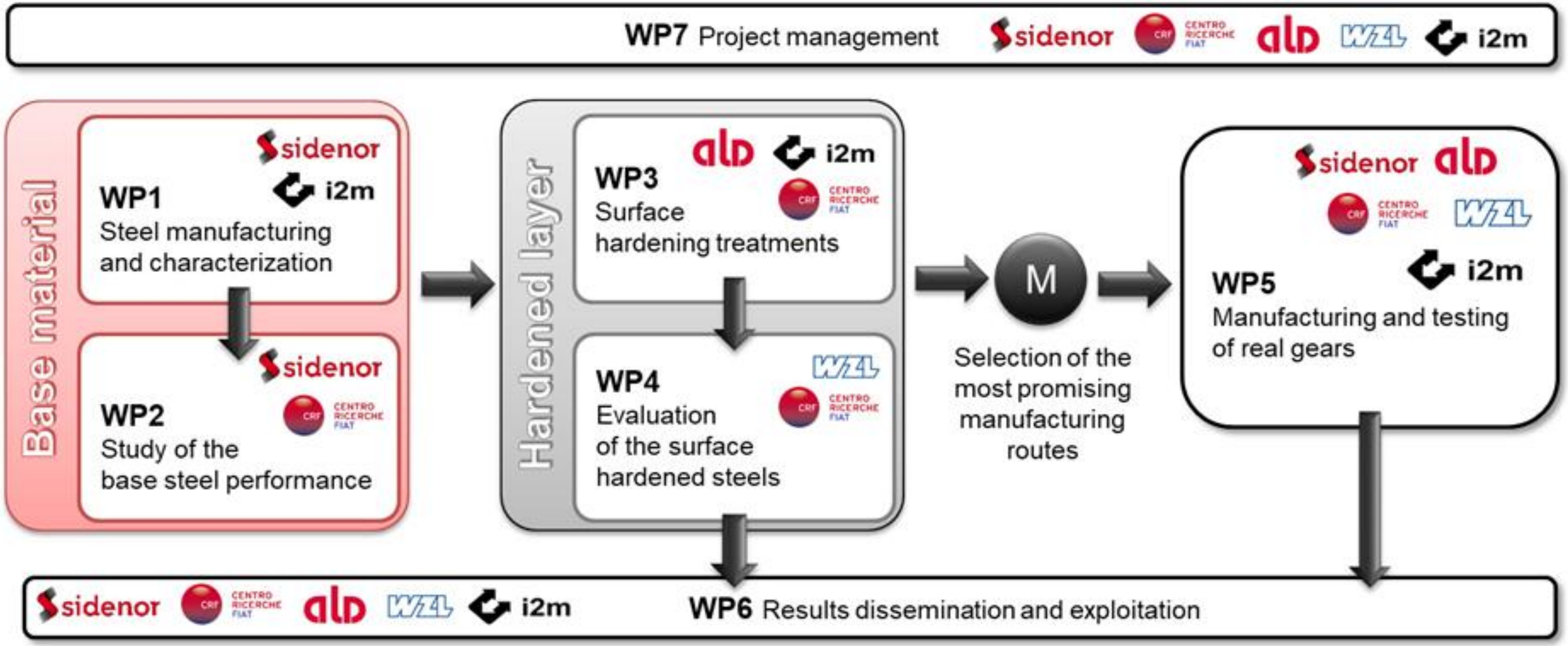
Evaluate experimentally the failure modes of gears at very high speed

Analyse the cost of the selected gear manufacturing routes

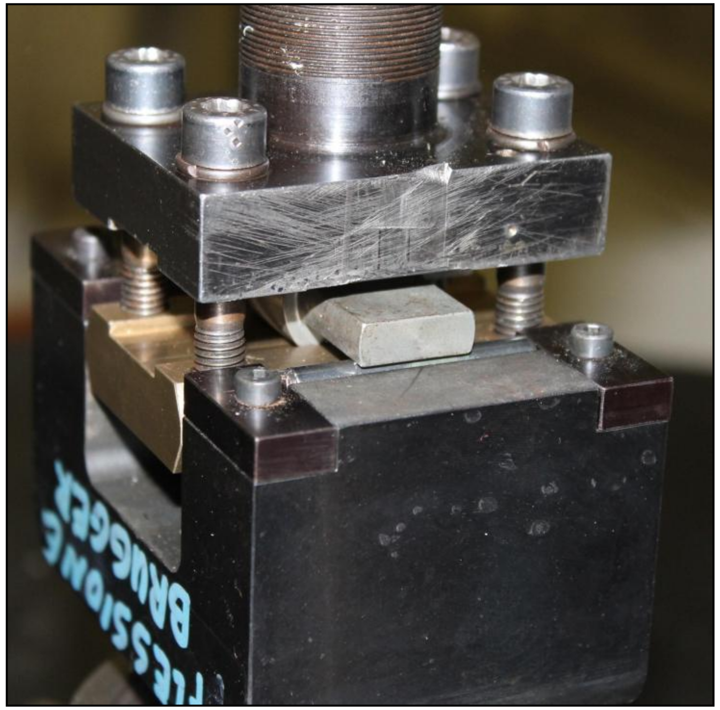


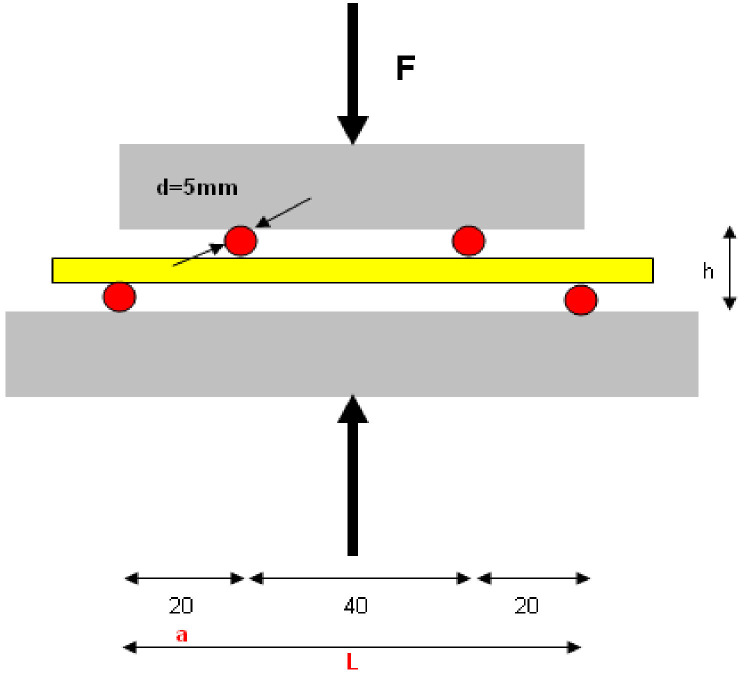
Consortium and project workplan

Partners of TOPGEAR project:



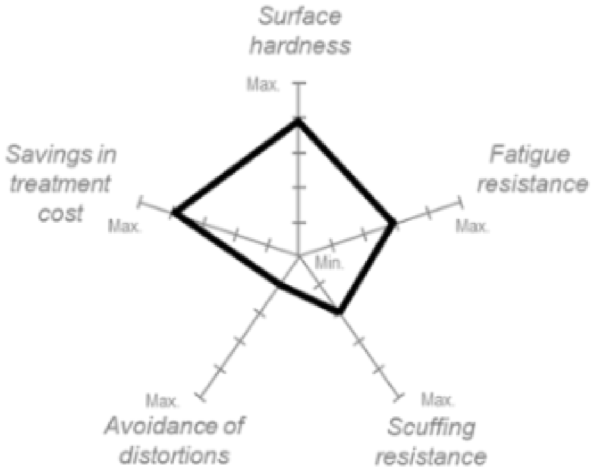
EXPERIMENTAL CHARACTERIZATION





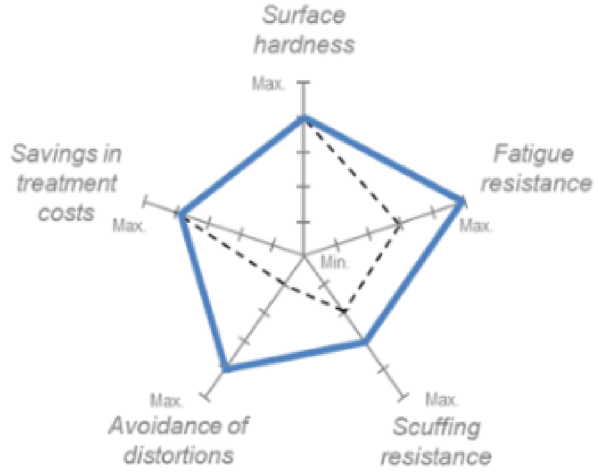
Steels and surface hardening treatments

Traditional carburizing



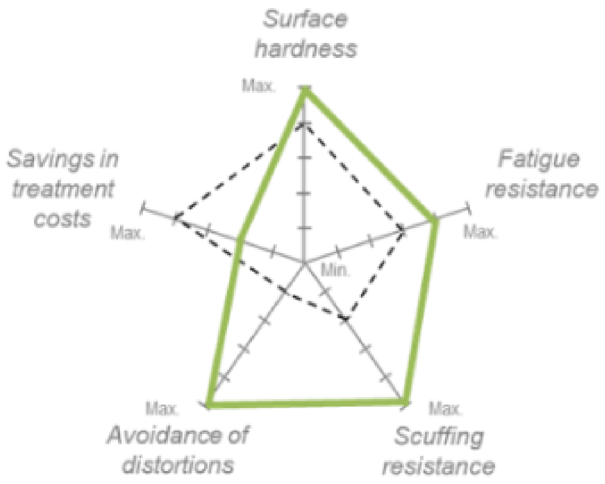
27MnCr5

Newly developed carburizing



20NiCrMo2

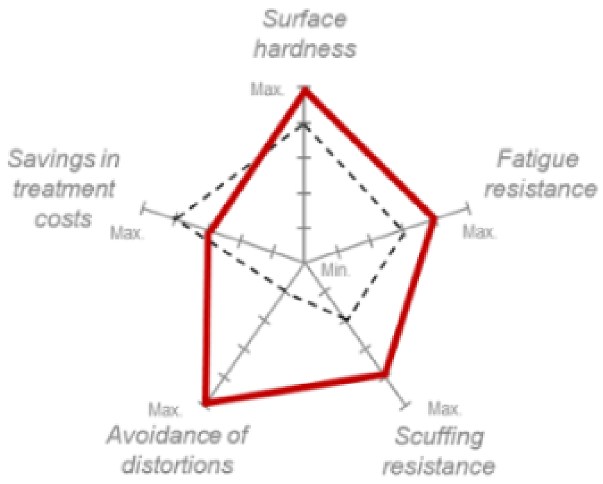
Nitriding



40CrMoBi4

36MnSiV4

Nitrocarburizing



36MnSiV4

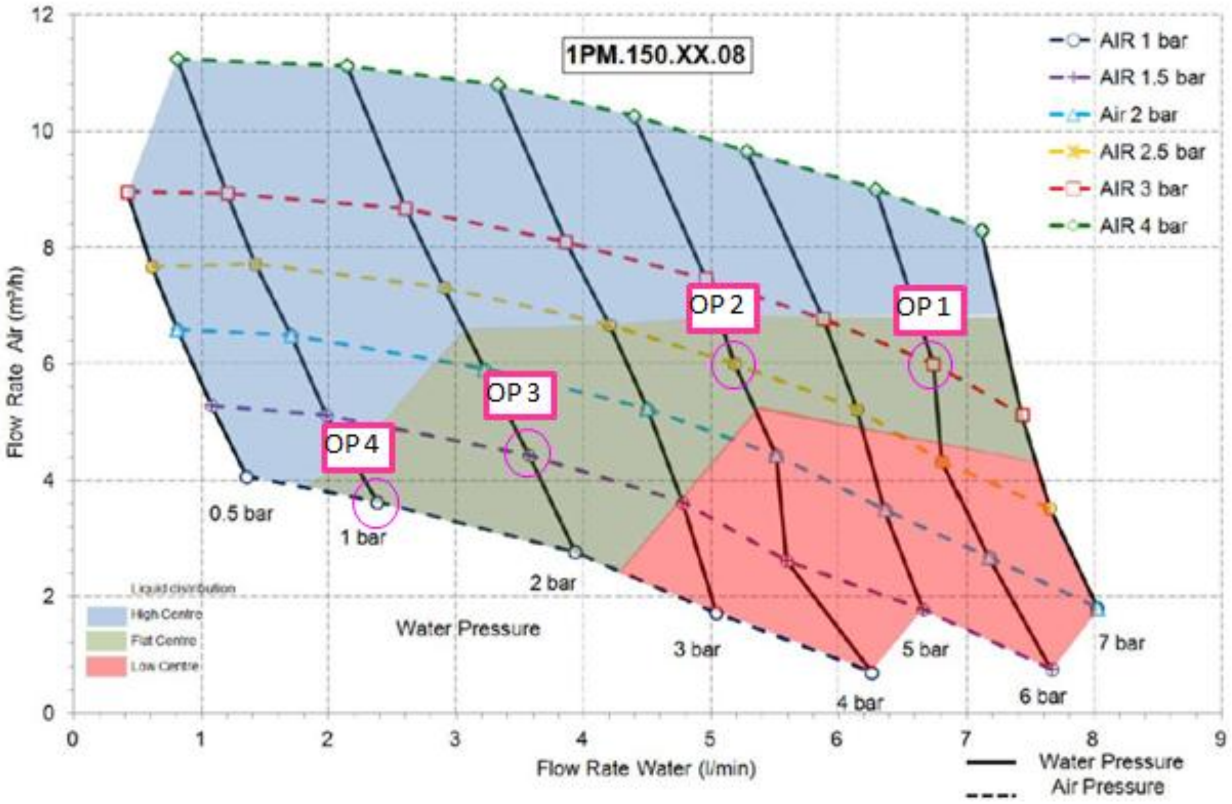
40CrMoBi4

Steel Grade	C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu	Al	Ti	N	Bi
27MnCr5	0,25	1,24	0,24	0,017	0,032	1,09	0,17	0,04	0,004	0,16	0,026	0,002	0,0120	0,001
40CrMoBi4	0,39	0,78	0,31	0,013	0,030	1,02	0,10	0,182	0,002	0,13	0,005	0,002	0,0060	0,024
20NiCrMo2	0,21	0,89	0,35	0,012	0,032	0,59	0,51	0,161	0,003	0,17	0,030	0,003	0,0117	0,001
36MnSiV4	0,35	1,07	0,58	0,013	0,030	0,17	0,14	0,036	0,27	0,16	0,010	0,016	0,0185	0,001

Newly developed carburizing process

A new patented process of Low-Pressure Vacuum Carburizing and Water Spray (Mist) Quenching (LPVC+WSQ) has been compared to the traditional LPVC+GC (gas quenching)

LPVC+WSQ is supposed to create higher compressive residual stresses and improve gear fatigue performance



Alternative manufacturing routes

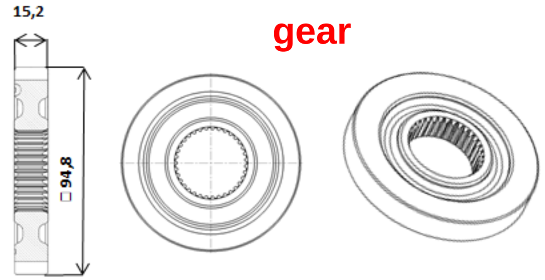
Surface heat treatments and, mainly, rough and finishing machining operations are the most significant factors influencing the economic feasibility of possible alternatives

27MnCr5

GREEN TURNING | GREEN BROACHING | HOBBING And CHAMFERING | HEAT TREATMENT | HARD BROACHING | HARD TURNING | TEETH GRINDING

Pre Heating – Low pressure Carburizing C2H2 – Gas Quenching N2 – Stress Relieving

ICE gear



20NiCrMo2

GREEN TURNING | HOBBING And CHAMFERING | HEAT TREATMENT | HARD TURNING/ GRINDING | TEETH GRINDING or POWER HONING

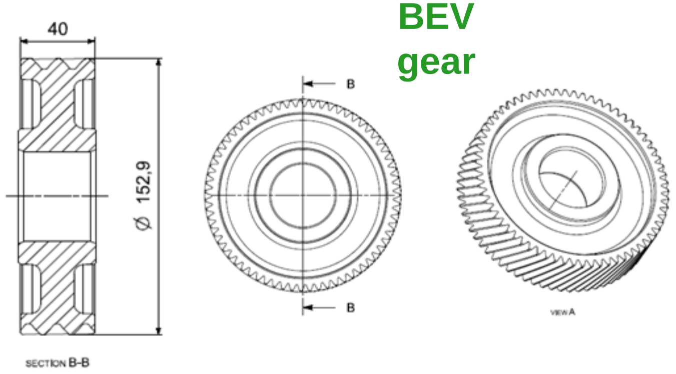
Pre Heating – Low pressure Carburizing – Water Mist Quenching – Stress Relieving

40CrMoBi4

36MnSiV4

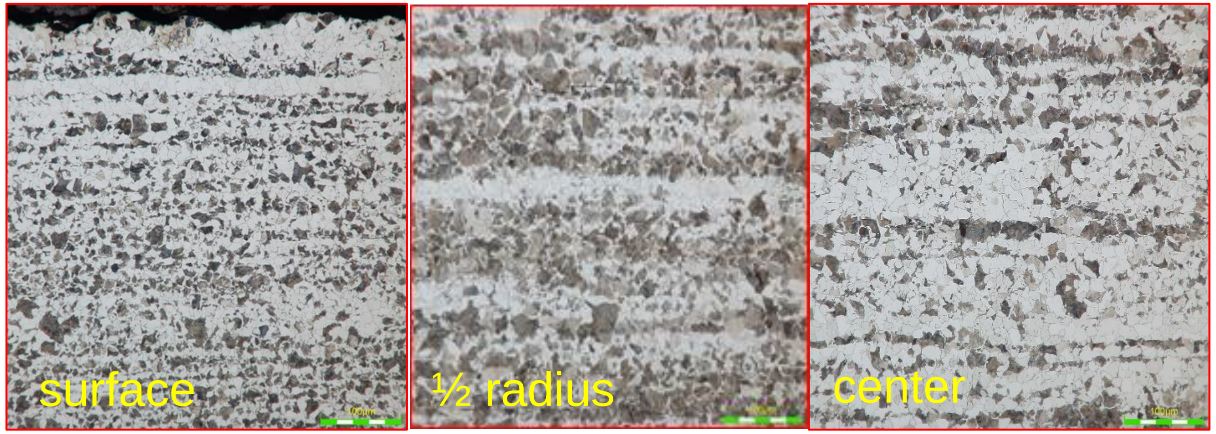
FORGING and preliminary HT | HARD TURNING | HOBBING And CHAMFERING | NITRIDING/NITROCARBURIZING

BEV gear

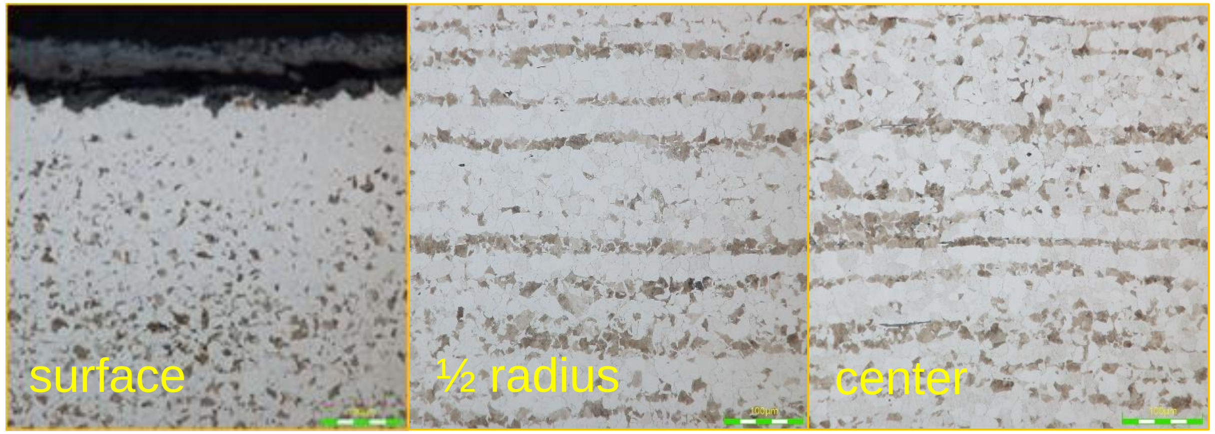


Microstructure in as-supplied condition

As gears were not forged in the project, steels were supplied heat treated in similar conditions as gears are received at the machining shops

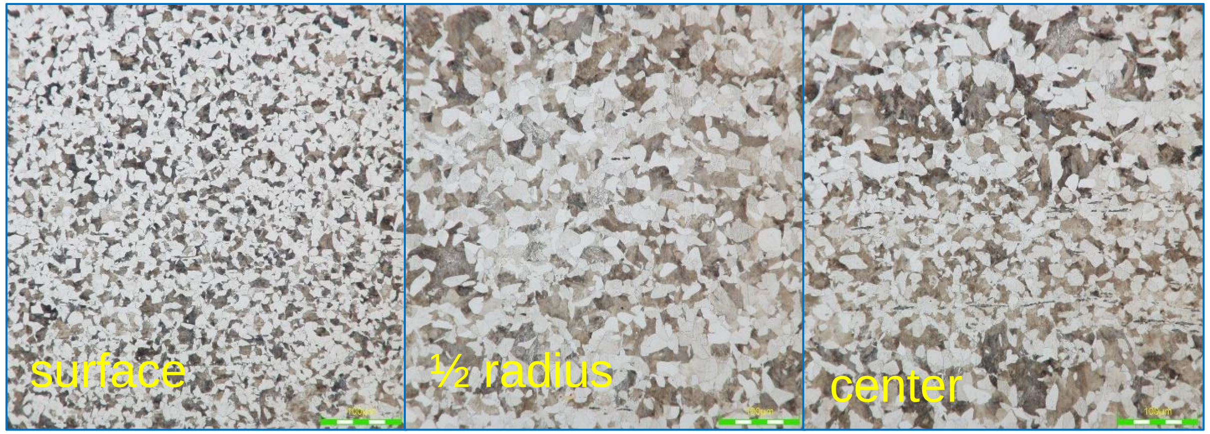


27MnCr5 *Isothermal annealing*



20NiCrMo2 *Isothermal annealing*

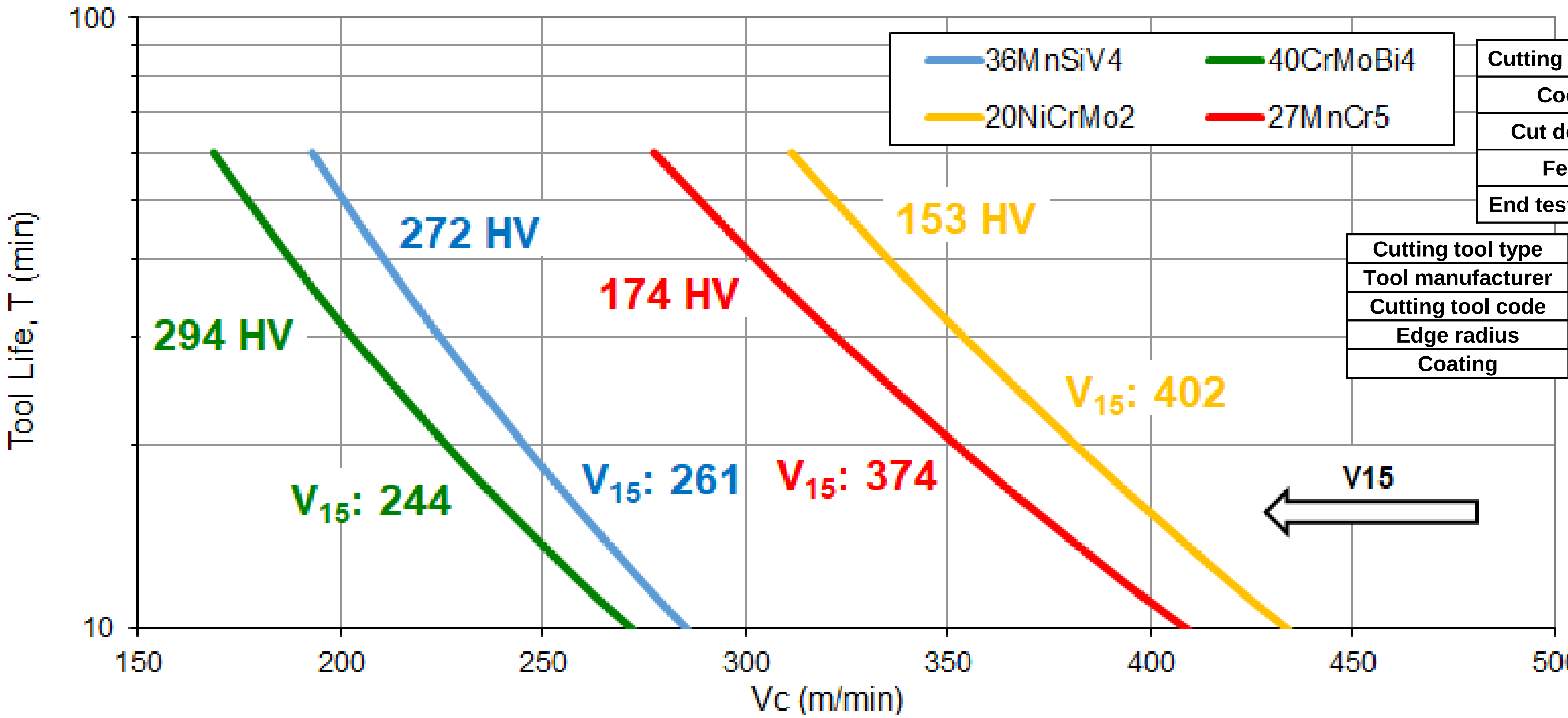
40CrMoBi4 *Quenched and tempered*



35MnVS4 *As-rolled*

Rough machining testing

In carburizing routes, rough machining is carried out in annealed (soft) condition, but in nitriding and nitrocarburizing routes is performed in a harder state



Cutting operation	External turning
Coolant	Dry cutting (no coolant)
Cut depth, a_p	2 mm
Feed, f	0.3 mm/rev
End test criterion	VB=300µm or tool death

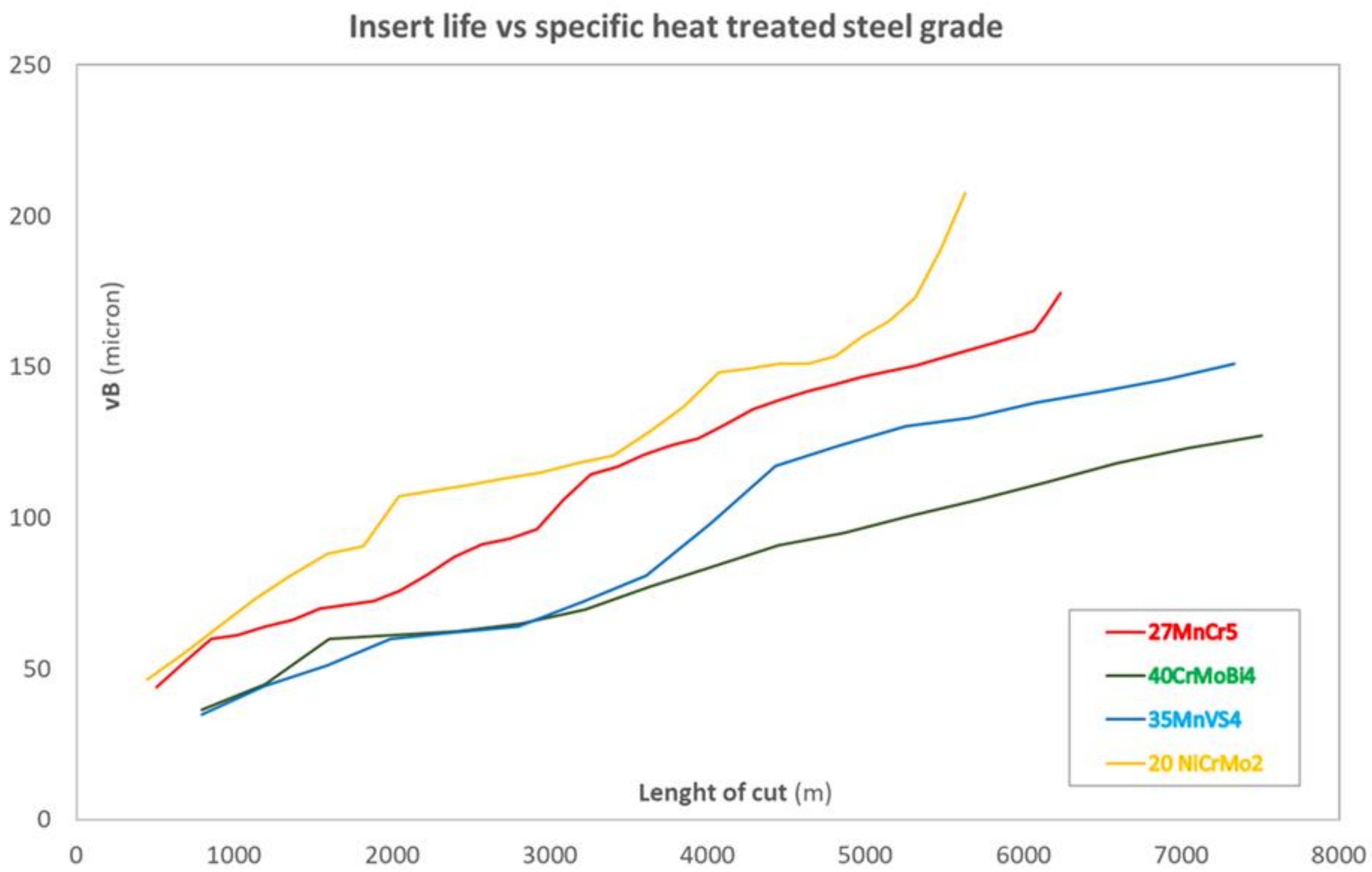
Cutting tool type	Sintered carbide
Tool manufacturer	SANDVIK
Cutting tool code	CNMG 120408 PM 4015 (GC4015)
Edge radius	0.8 mm
Coating	TiCN-Al2O3-TiN, 14µm

Hard machining testing (finishing operations simulation)

However, once hardened, the machinability of carburizing steels (quenched and stress relieved, not carburized) is much lower than the nitriding steels

Evaluation of machining costs is difficult without an accurate estimation of the weight of rough and finishing operations on the total gear cost

That estimation was done at the last stage of the project during gear machining



Hardened case specifications

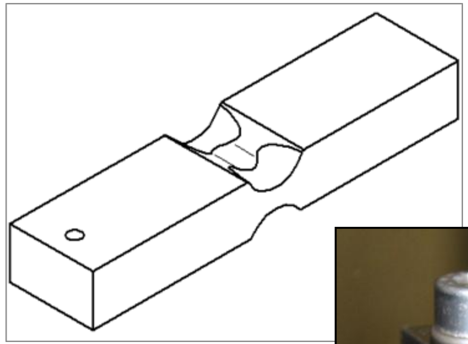
For each steel, the surface hardening treatment was chosen to fulfil the STELLANTIS specifications for core hardness, surface hardness and case-hardened depth (CHD for carburized layer and NHD for nitrided layer)

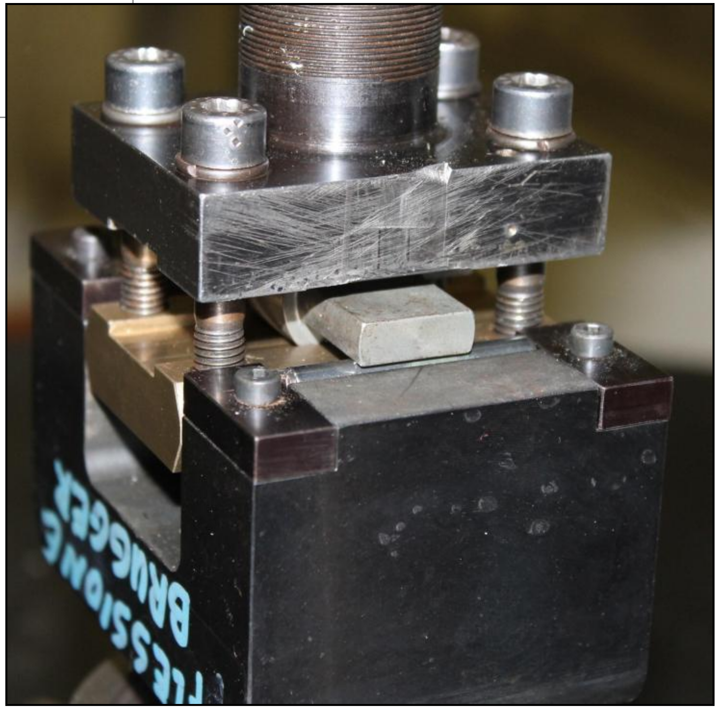
Parameter	27MnCr5	20NiCrMo2
Surface hardness	> 59HRC	> 59HRC
CHD	0.35-0.55mm measured at $650HV_{0,5}$	0.5-0.7mm measured at $525HV_{0,5}$
Core hardness	380 – 420 HV10	340-380 HV10

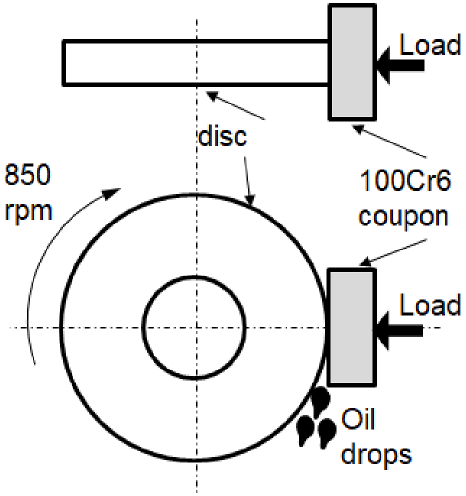
	35MnVSi4	35MnVSi4	42CrMo4B	42CrMo4B
Parameter	Nitriding	Nitrocarburizing	Nitriding	Nitrocarburizing
Surface hardness	> 450 HV1	> 450 HV1	550-600 HV1	550-600 HV1
NHD	0.1-0.3mm measured at core hardness +100HV	0.1-0.3mm measured at core hardness +100HV	0.1-0.3mm measured at core hardness +100HV	0.1-0.3mm measured at core hardness +100HV
Core hardness	Similar to 300-330 HV	Similar to 300-330 HV	Similar to 300-330 HV	Similar to 300-330 HV
White layer	Hardness 900-1200 HV; 20µm	Hardness 900-1200 HV; 20µm	–	–

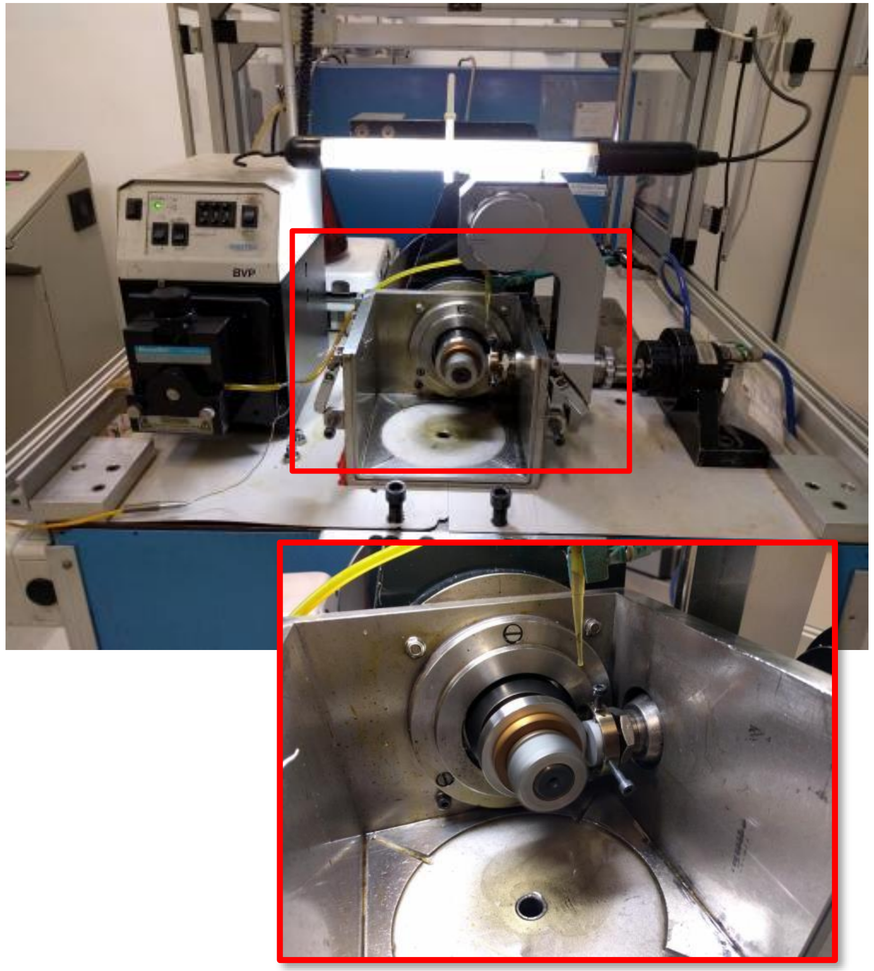
Bending fatigue and tribological testing

The selection of the most promising “Steel + Hardening treatment” for upscaling to gear manufacturing and testing was made by alternating bending fatigue tests and tribological tests at CRF



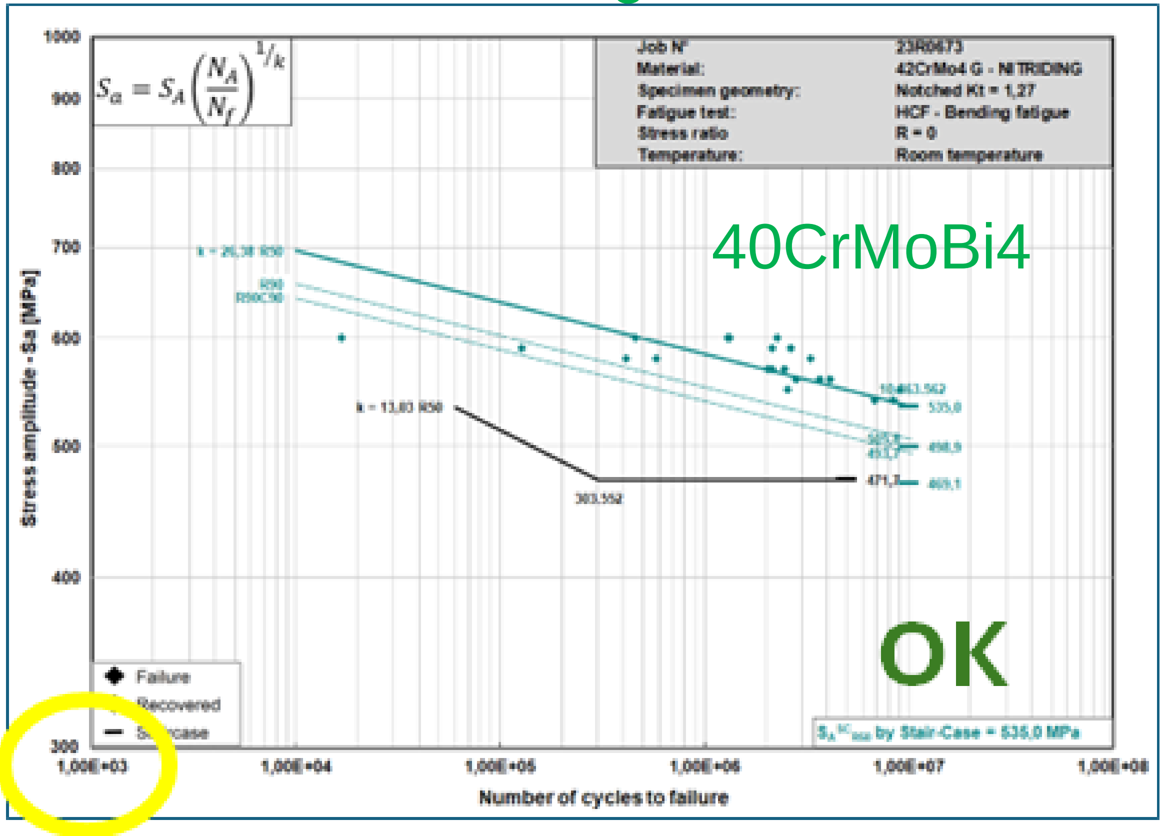






Selection of most promising Steel & Surface Treatment

Nitriding



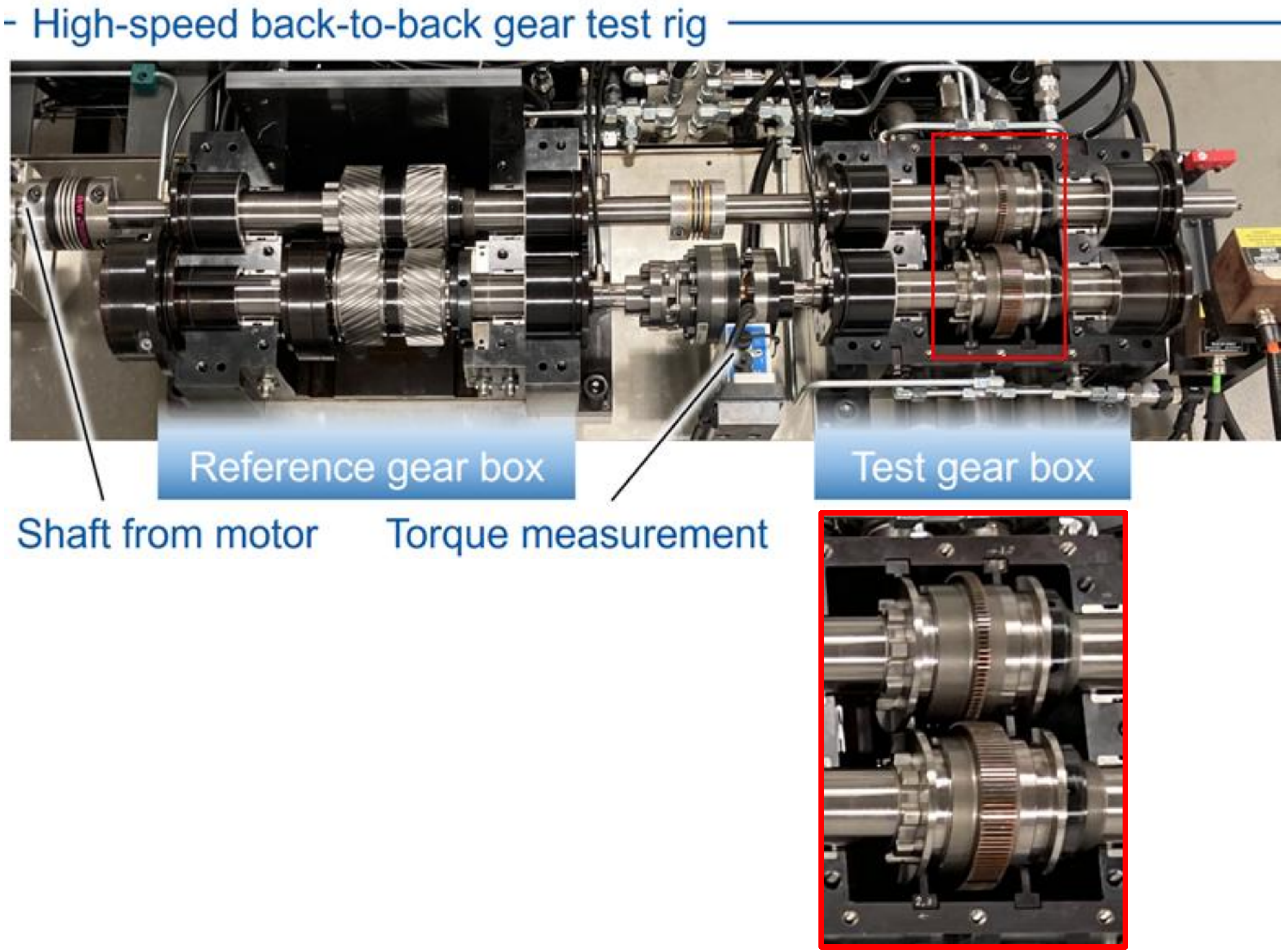
The best alternative to the 27MnCr5 with conventional carburizing treatment (LPVC+GQ) was the steel grade 40CrMoBi4 Q&T with nitriding

Despite the efforts, LPVC+WSQ didn’t achieve the right profile of compressive residual stresses

Nitrocarburizing gave a response similar to traditional carburizing, without any special gain

The microalloyed steel, despite its high fatigue limit, showed an excessive scatter in lives to be suitable for high speed gears

GEAR FATIGUE TESTING



Gear fatigue analysis on test rig

WZL designed specific gear geometries to promote pitting and scuffing failures and test gear resistance to tooth bending fatigue, and pitting and scuffing fatigue failures at high speed (12,000 rpm)

Variant 01: Reference Material – 27MnCr5

Raw material → Sawing & soft turning → Hobbing → Heat treatment → Surface & bore grinding → Gear grinding → Quality control & testing

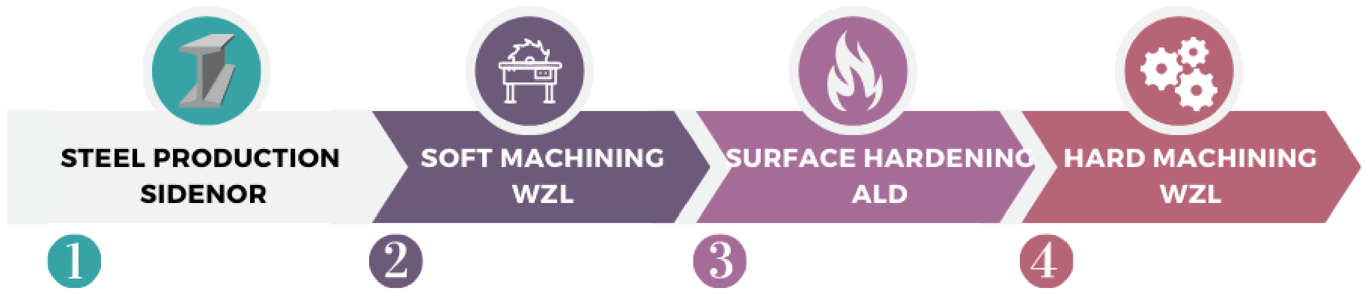
Pitting Test Gear
for high speed tests

Scuffing Test Gear
for high speed tests

Variant 02: 40CrMoBi4

Raw material → Sawing & soft turning → Hobbing → Gear Grinding → Heat treatment → Surface & bore grinding → Quality control & testing

LIFE CYCLE ASSESSMENT AND ECONOMIC EVALUATION



Conclusions and acknowledgements

TOP GEAR

The main conclusions of the TOPGEAR Project are:

- At very high speeds, the gear failure modes change respect to standard testing speeds and earlier failures might appear
- There are technically valid alternatives to traditional carburizing process for high-speed gears, optimizing manufacturing processes and surface hardening treatments

This project has received funding from the Research Fund for Coal and Steel, a programme managed by the European Commission, supporting research in the coal and steel sectors in Europe under grant agreement No. 101033989

Funded by the European Union

Research Fund for Coal & Steel

Thank you for your attention!

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