Steel design and high speed machining aspects in the transition from case hardening to induction hardening of automotive transmissions (MAC D)

Scope of the MAC D project:

➔ **To replace carburizing with induction hardening of transmission components**

Method:

=> Investigate the feasibility of induction hardening of a few demonstrators.

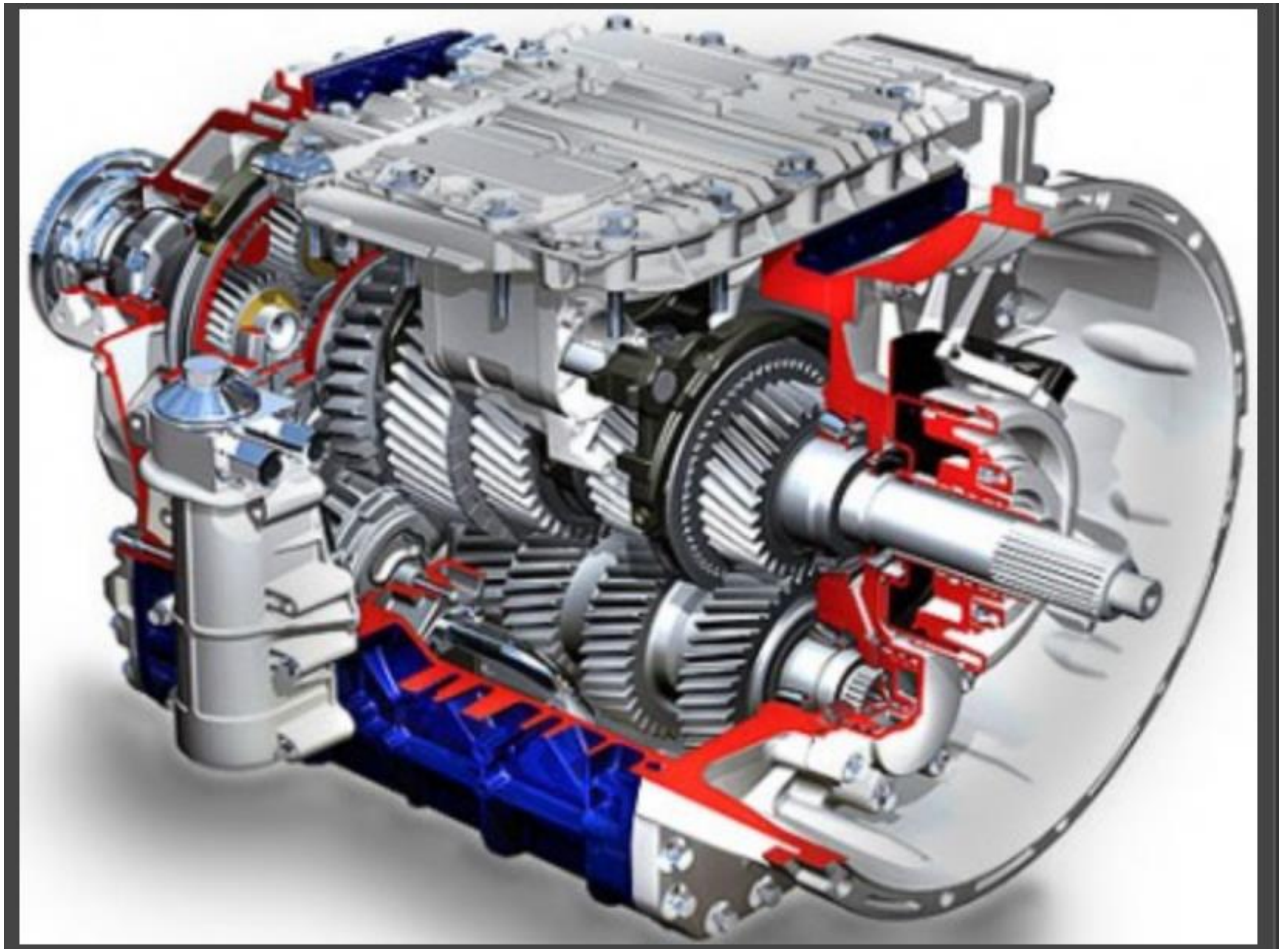
=> Compare rough turning, hob milling and hard turning machining, carburizing steel vs induction hardening steels.

=> Compare mechanical properties of samples and demonstrators of the two hardening treatments.

=> Actually manufacture some 20-50 demonstrator parts, w induction hardening.

=> Make comparison of manufacturing costs.

The use of automotive steels



Heat treatments:

All gears are carburized

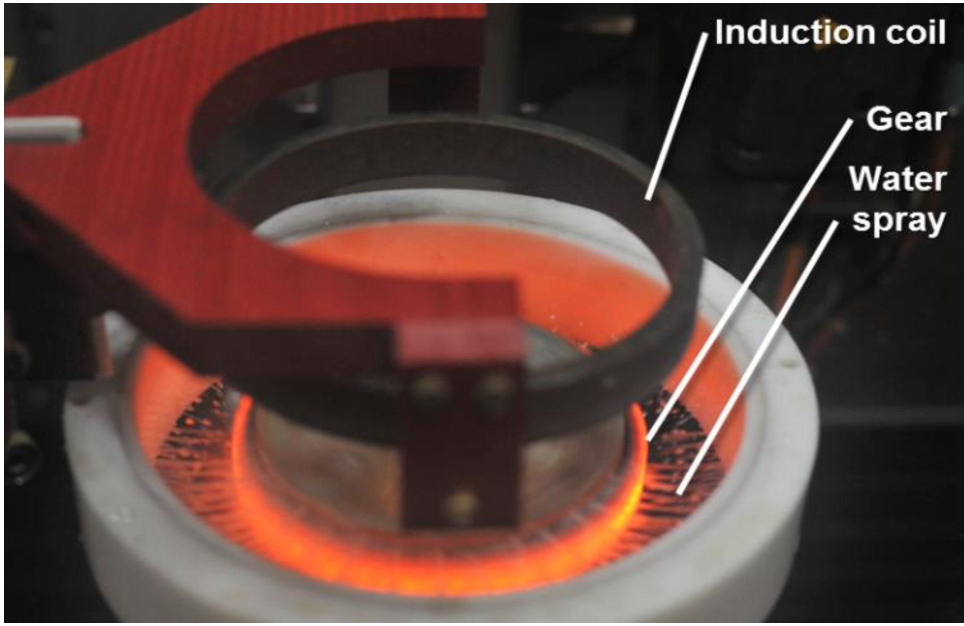
Most shafts as well

Some shafts are induction hardened

The MAC D project is about:

…moving from here

…to here



…as heat treatment route of transmission components

Consortium

swerea | KIMAB

EFD

OVAKO
a feel for steel

GERDAU
SIDENOR I+D

MONDRAGON
UNIBERTSITATEA

CRF
CENTRO
RICERCHE
FIAT

WZL
RWTHAACHEN

Project facts

Duration: 2011-2014
Budget: GT=1.9 M€

Materials

		wt%							ppm	
Steel grade	MAC D Name	C	Mn	Si	S	Cr	Ni	Mo	O	Ca
18CrMo4	**C**	**0,19**	0,81	0,29	0,024	1,06	0,12	0,16	10	7
35CrMo4	**QL**	**0,34**	0,81	0,31	0,026	1,12	0,11	0,18	12	8
50CrMo4	**QH**	**0,50**	0,68	0,23	0,035	0,98	0,21	0,19	8	2
100Cr6	**B**	**0,97**	0,31	0,28	0,012	1,41	0,20	0,06	5	3

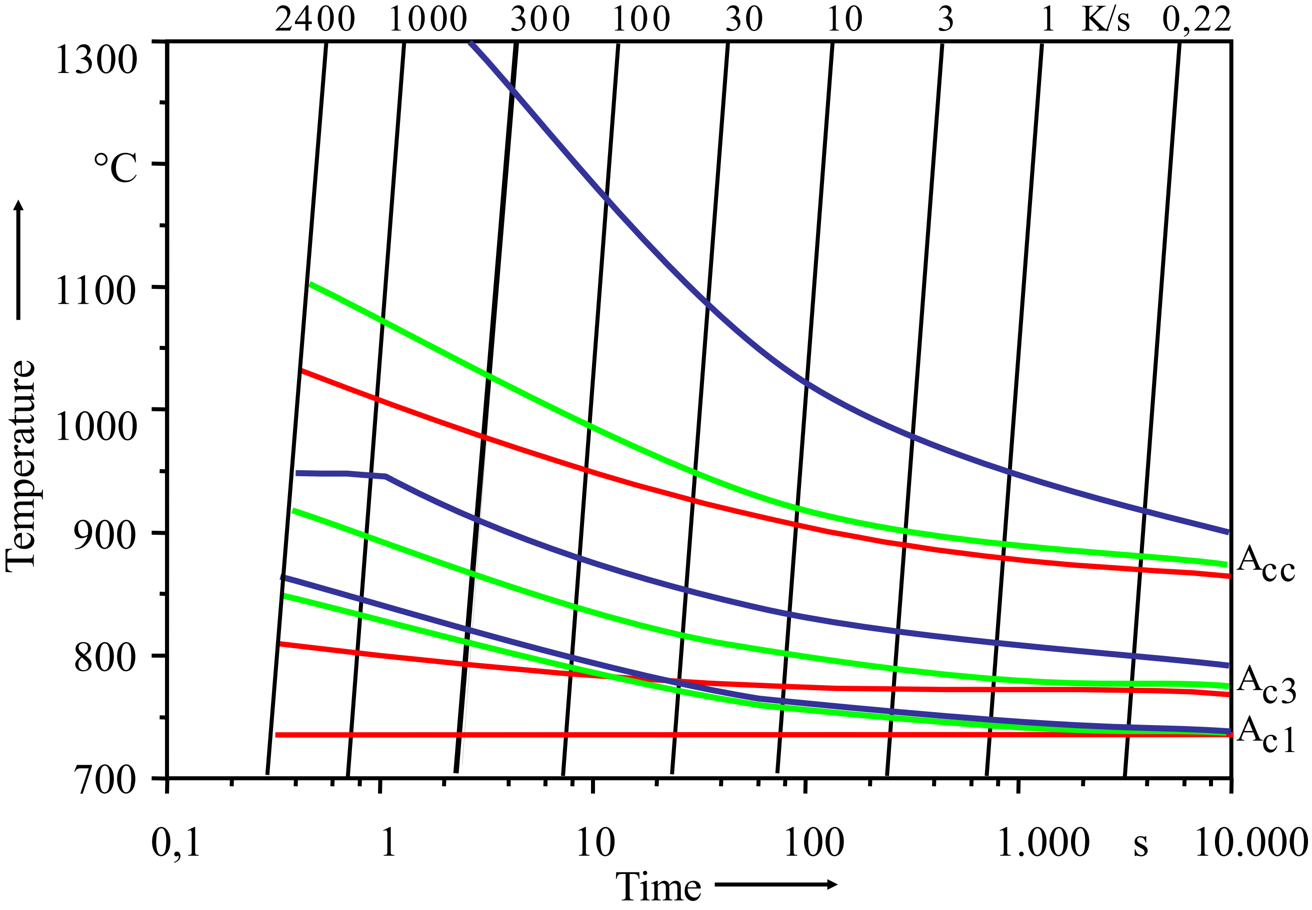
As-delivered conditions

Steel grade	18CrMo4	35CrMo4	50CrMo4	100Cr6
Short name	C	QL	QH	B
Supplier	Gerdau	Gerdau	Ovako	Ovako
Heat treatment				
Quench & tempering I		● QL-T1 240 HB	■ QH-T1 350 HB	
Quench & tempering II		● QL-T2 287 HB	■ QH-T2 315 HB	
Annealing**	▲ C-IA 160 HB			◆ B-SA 200 HB

Reference

Most attention of R&D

The necessity of high hardness prior to induction hardening (TTA-diagrams)



Start structure:

W Soft annealed

P Pearlitic

M Martensitic

Transformation-temperature depends of:

- Heating time
- Start structure

50CrMo4 (1.7228)

Source: Orlich J., Rose A.: Atlas zur Wärmebehandlung der Stähle, Band 3, ZTA-Schaubilder

Materials in the hardened state

Steel grade	18CrMo4	35CrMo4	50CrMo4	100Cr6
Short name	C	QL	QH	B
Supplier	Gerdau-Sidenor	Gerdau-Sidenor	Ovako	Ovako
Heat treatment				
Induction hardening I	▲ C-H1	● QL-H1	■ QH-H1 58 HRC	
Induction hardening II		● QL-H2	■ QH-H2	
Through hardening				◆ B-H1 61 HRC

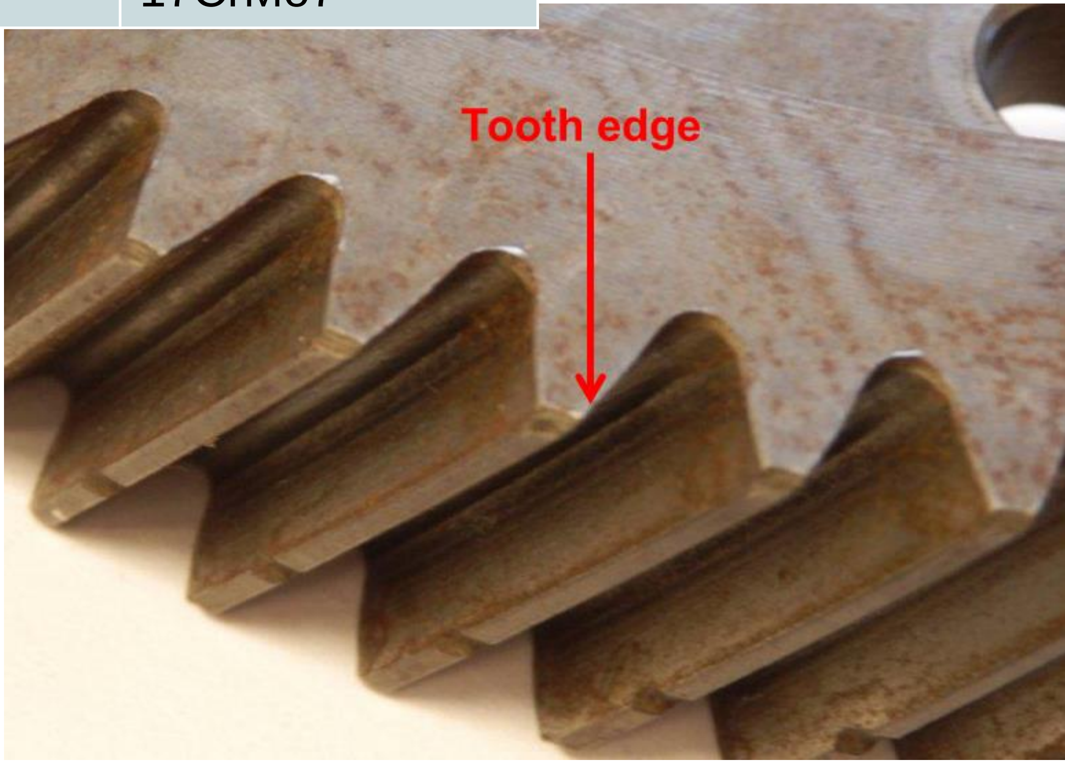
Reference

Most attention of R&D

- … was aimed at a 2nd gear shaft of Fiat gear box

Demonstrator component

Gear module:	2.35
Outer diameter	168 mm
Helical angle	20°
Current steel	17CrMo7

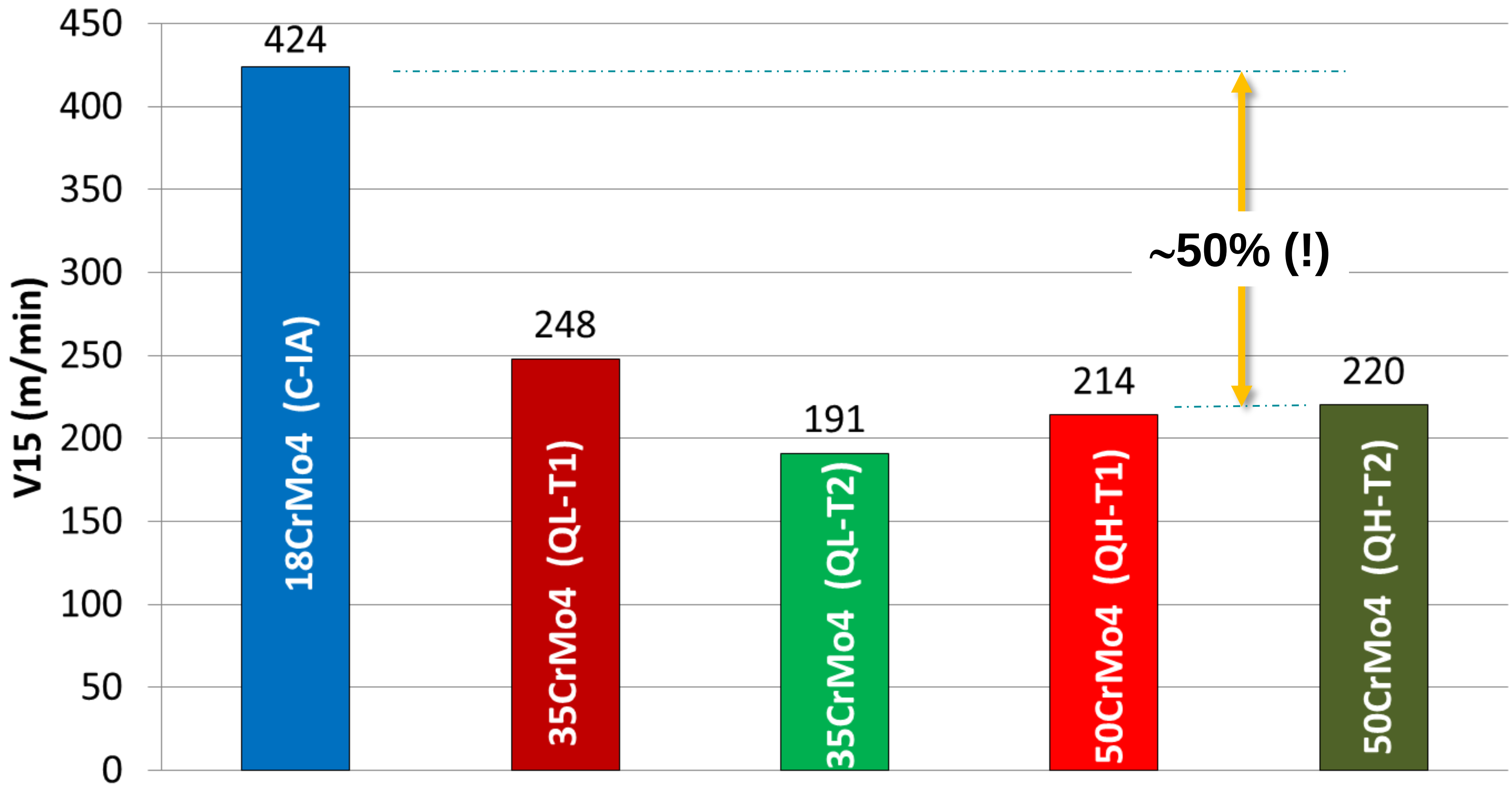


Rough machining

…was made up of:

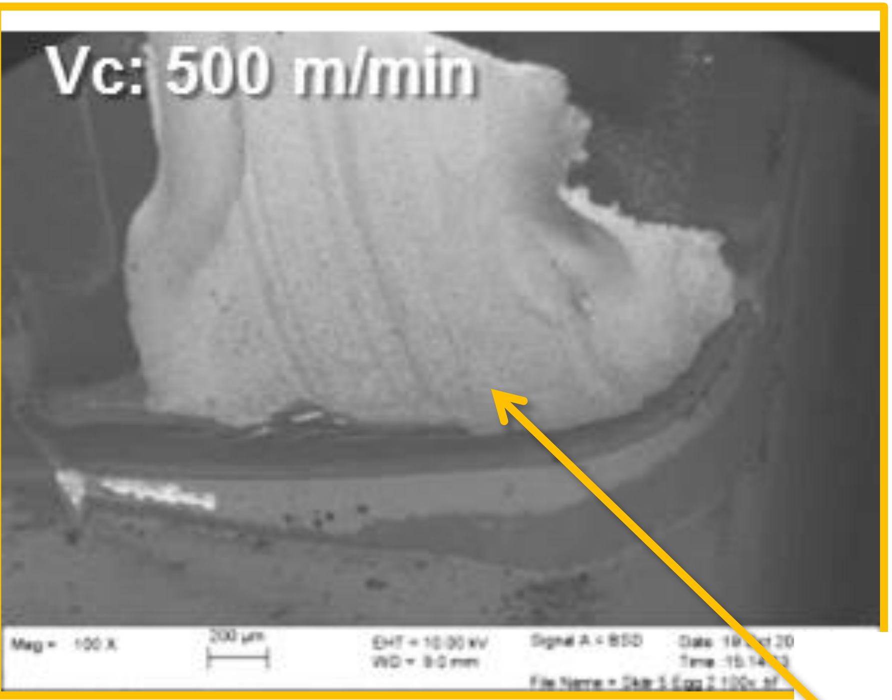
- Tool life tests in rough turning
- Tool life tests in experimental gear hobbing
- Tool wear studies and chip study
- Fundamental studies of the intermittent cutting process characteristics of gear hobbing.

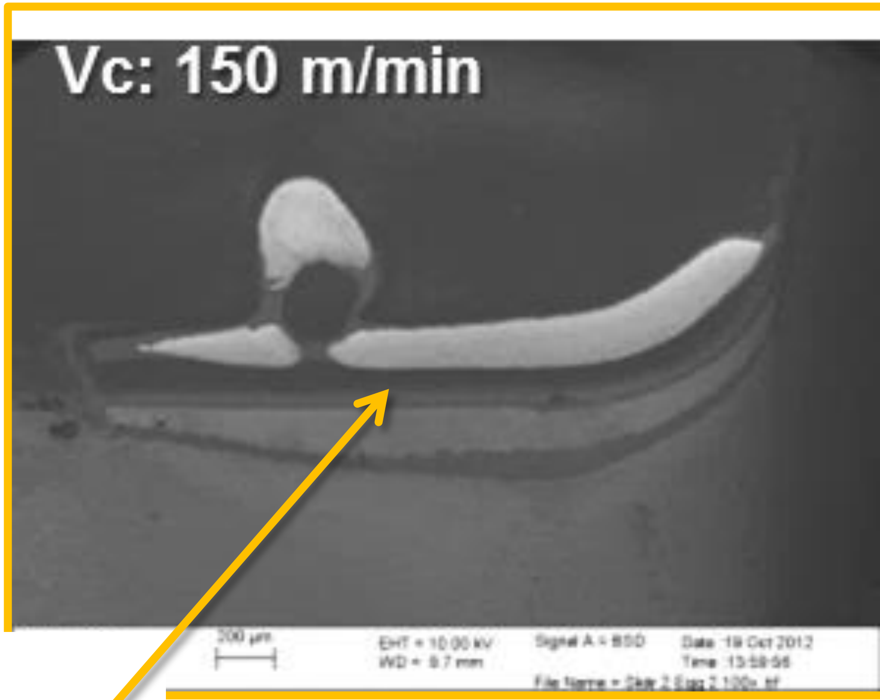
Tool life in rough turning

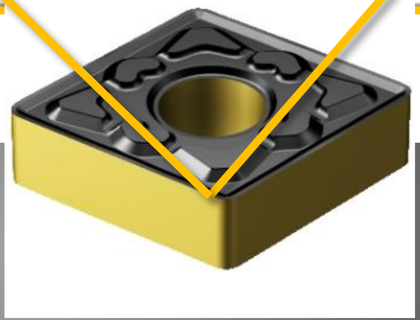


Tool wear behaivour in rough turning

C-IA (18CrMo4) 160 HB	QL-T2 (35CrMo4) 287 HB



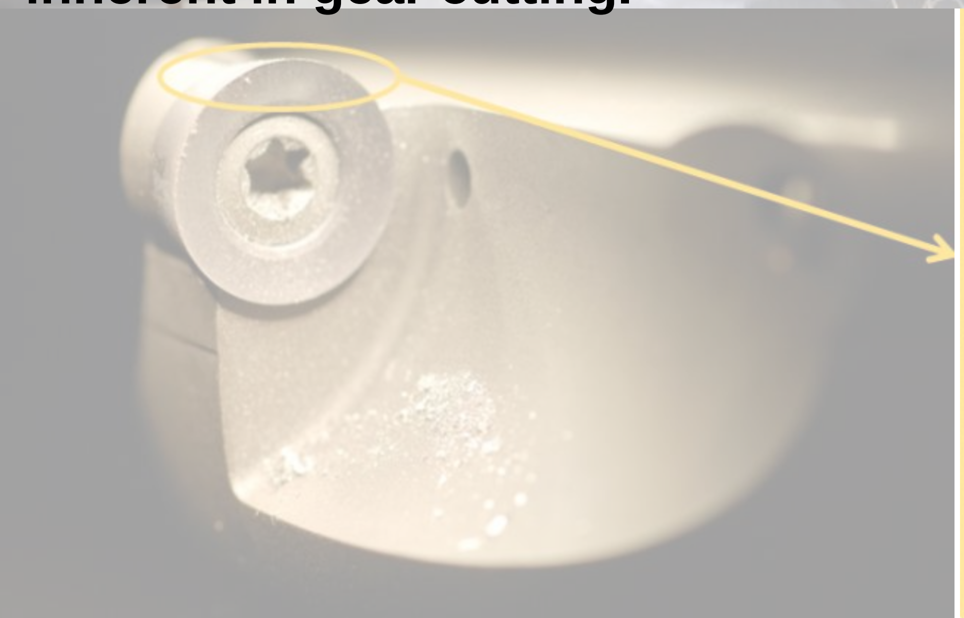




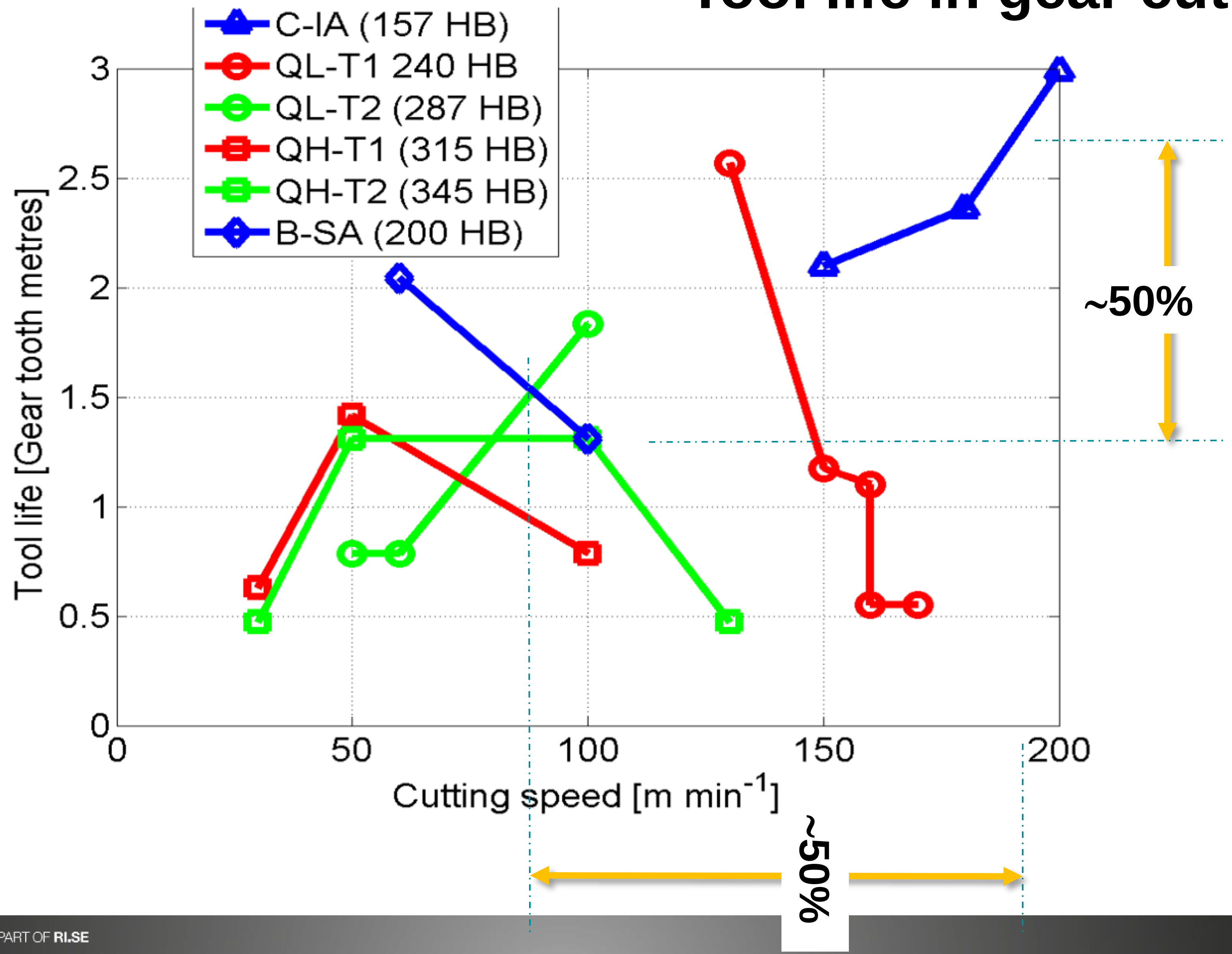
Gear cutting through experimental simulation

The test mimics:

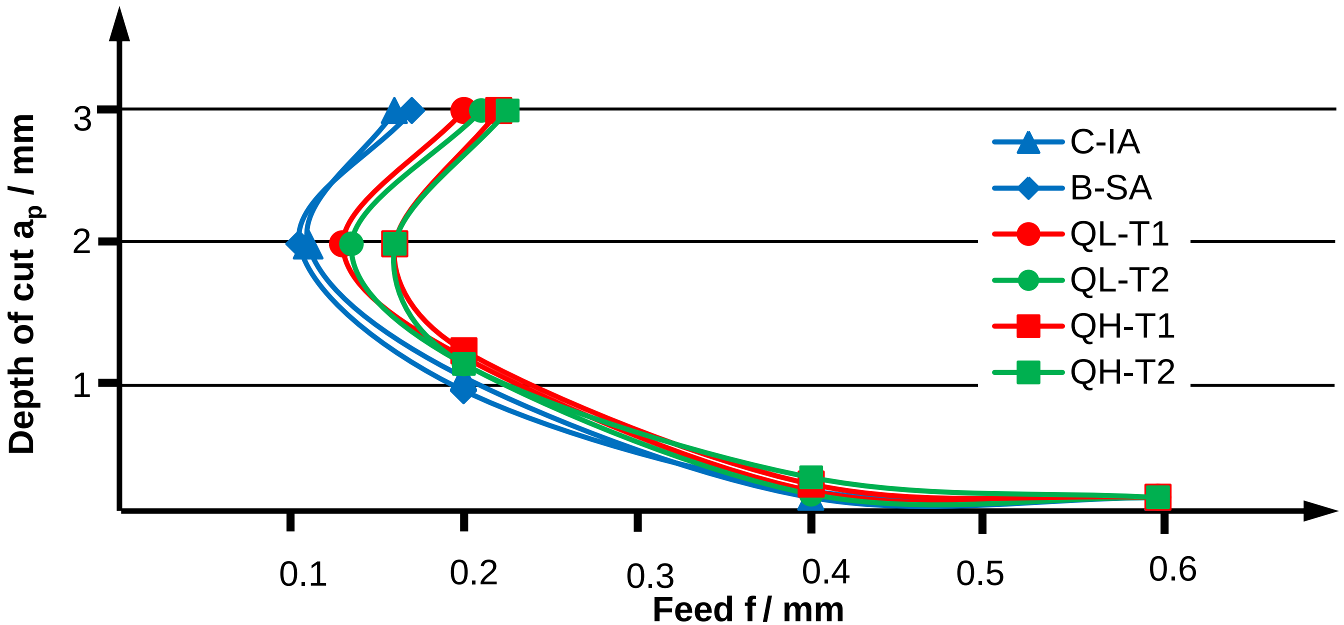
- **Realistic tool life**
- **Tool wear mechanisms of actual gear hobs**
- **The variation in chip thickness inherent in gear cutting.**



Tool life in gear cutting

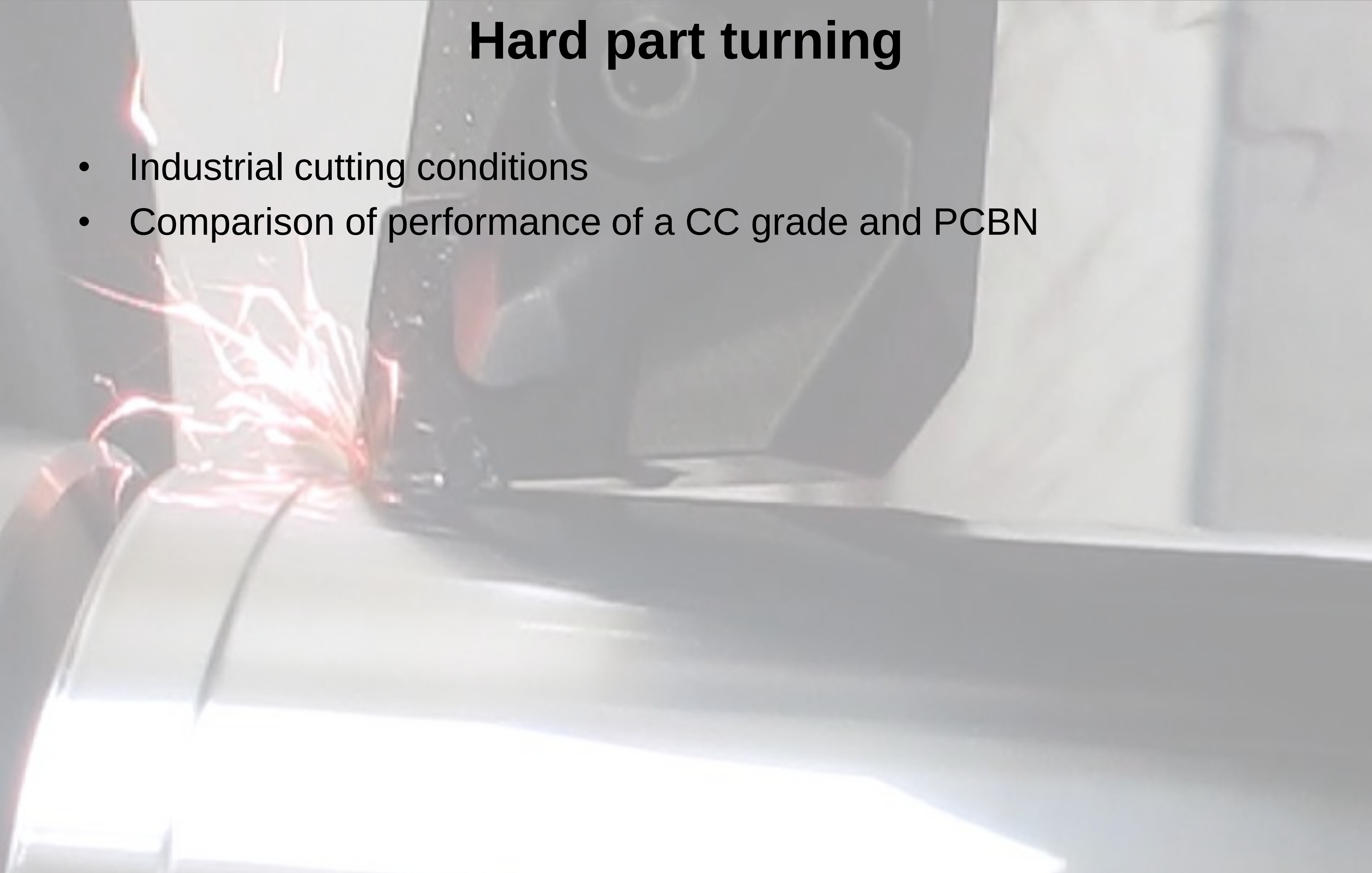


Chip breakability



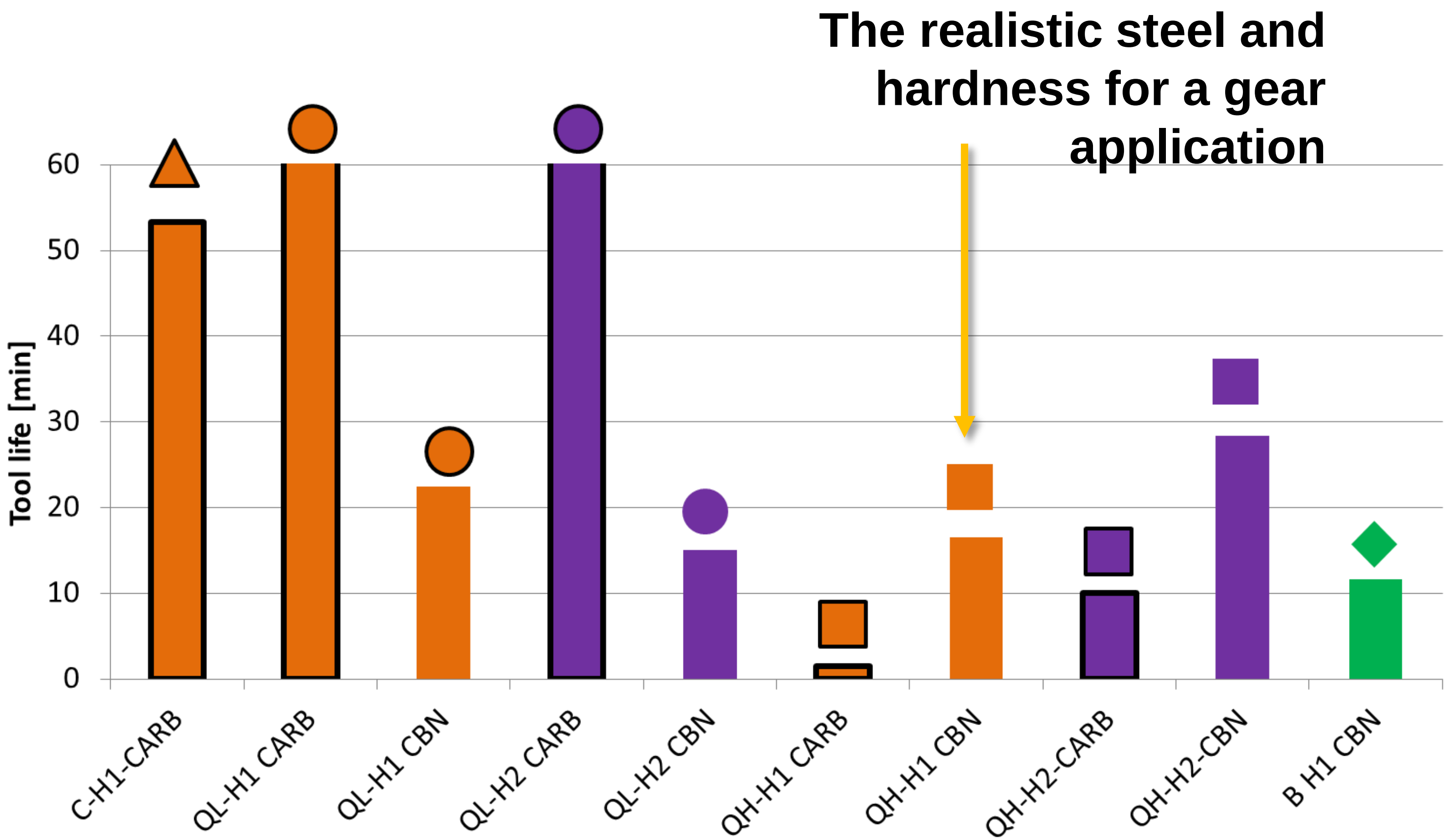
Material:	varying	Cutting speed:	v_c = 225 m/min	Grade:	WC 4215
Tool holder:	DCLNL 2525M12	Cooling:	Dry	Geometry:	CNMG120408PM

Hard part turning



- Industrial cutting conditions
- Comparison of performance of a CC grade and PCBN

Tool life in hard part turning



Conclusions green turning, gear hobbing & hard part turning

- Roughly 50% loss of productivity in rough turning (in this comparison)

⇒ Significant improvement in productivity with harder carbide grade (P05).

- Roughly 50% loss of productivity in gear hobbing (in this comparison).

=> A solution is to implement carbide hobbing for sufficient productivity in gear cutting of 350 HB

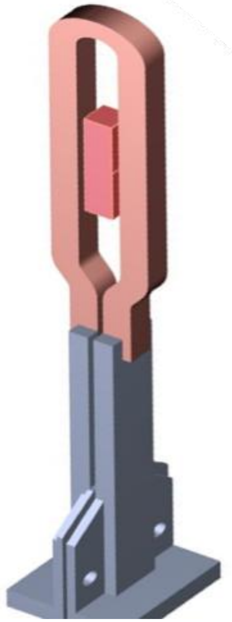
- Minimised distortion in induction hardening => Possibility to minimise/eliminate the need of hard part turning (?)

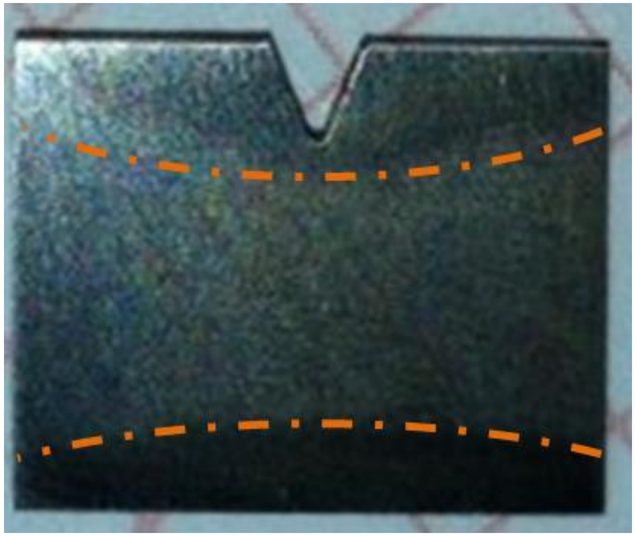
Mechanical properties and fatigue strength of the induction hardened 50CrMo4

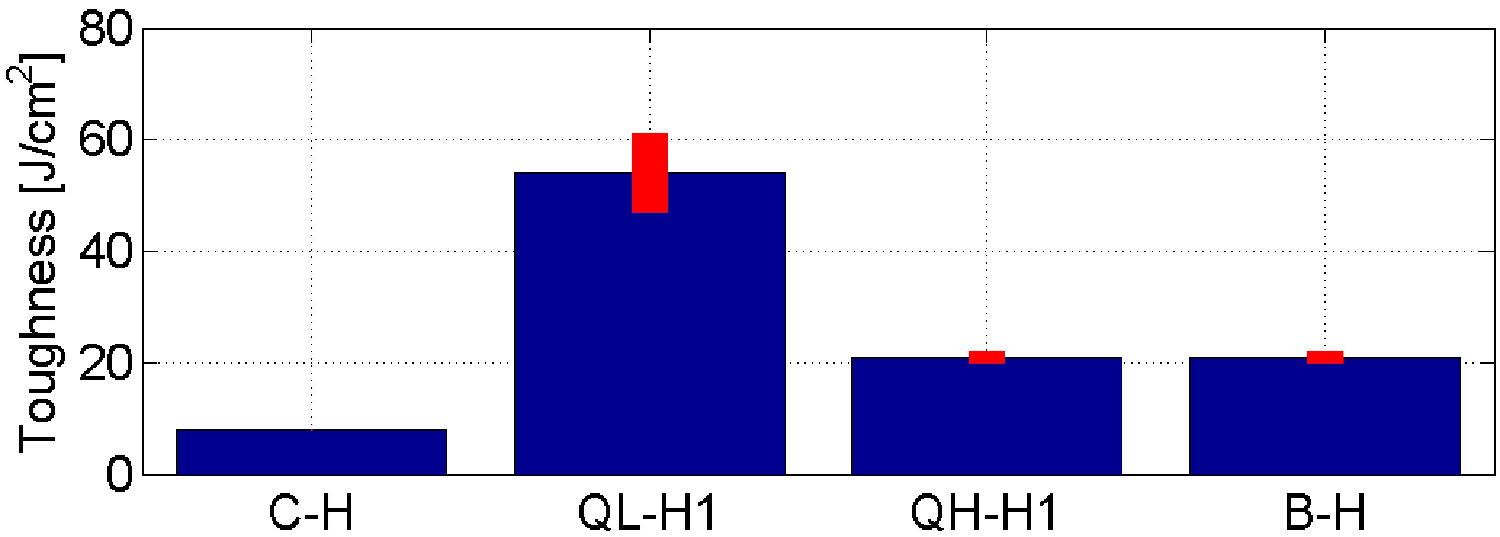
IMPORTANT: Induction hardening is very geometry dependent. => All pre-tests should be made on the actually aimed component!

(Though very difficicult in a world that is used to evaluation that is optimised more to the test geometry than to the heat treatment)

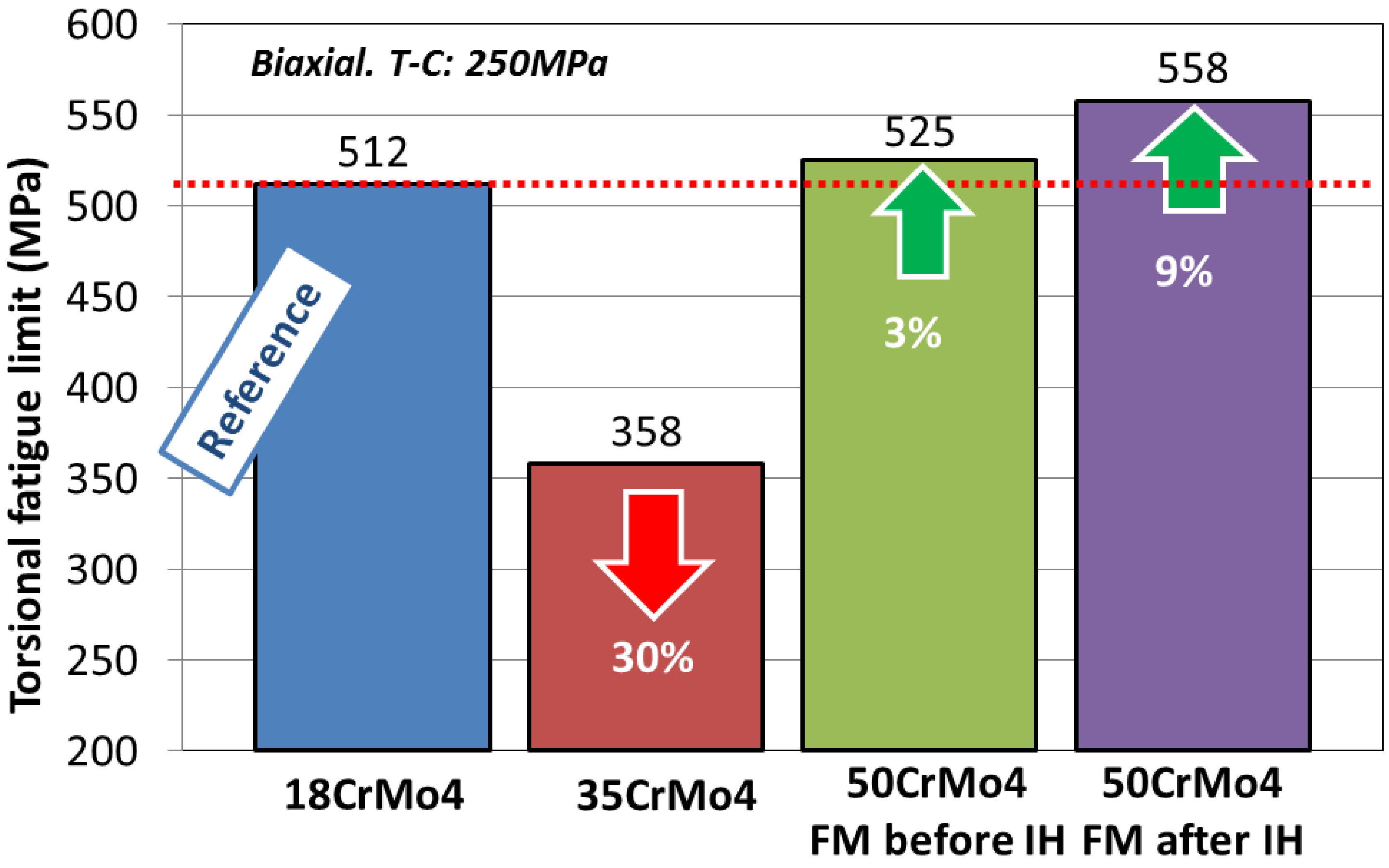
Toughness



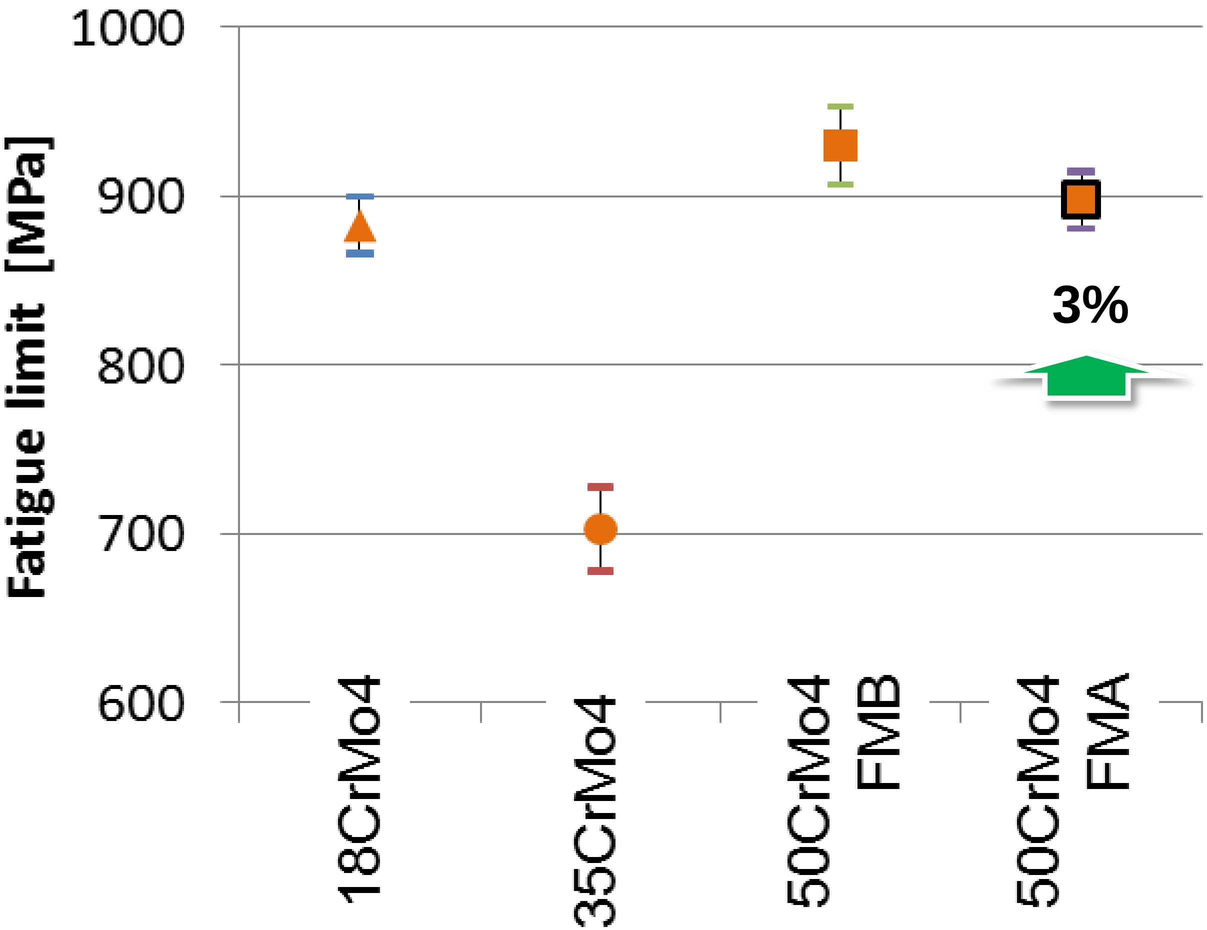




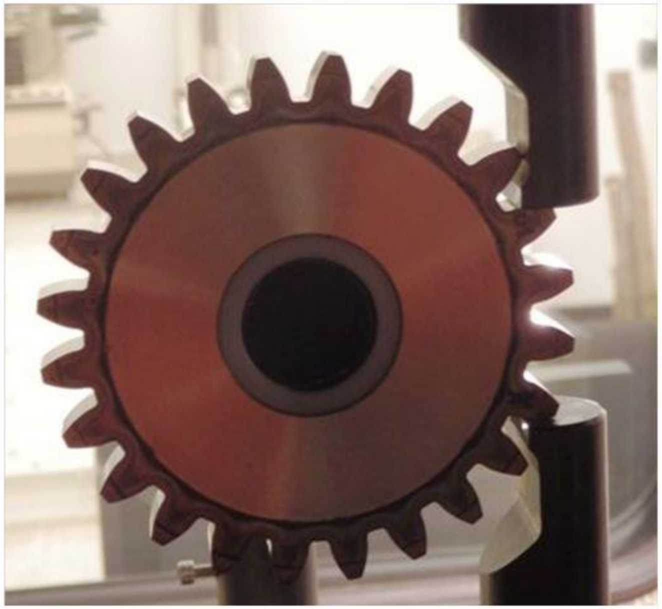
Multiaxial fatigue strength

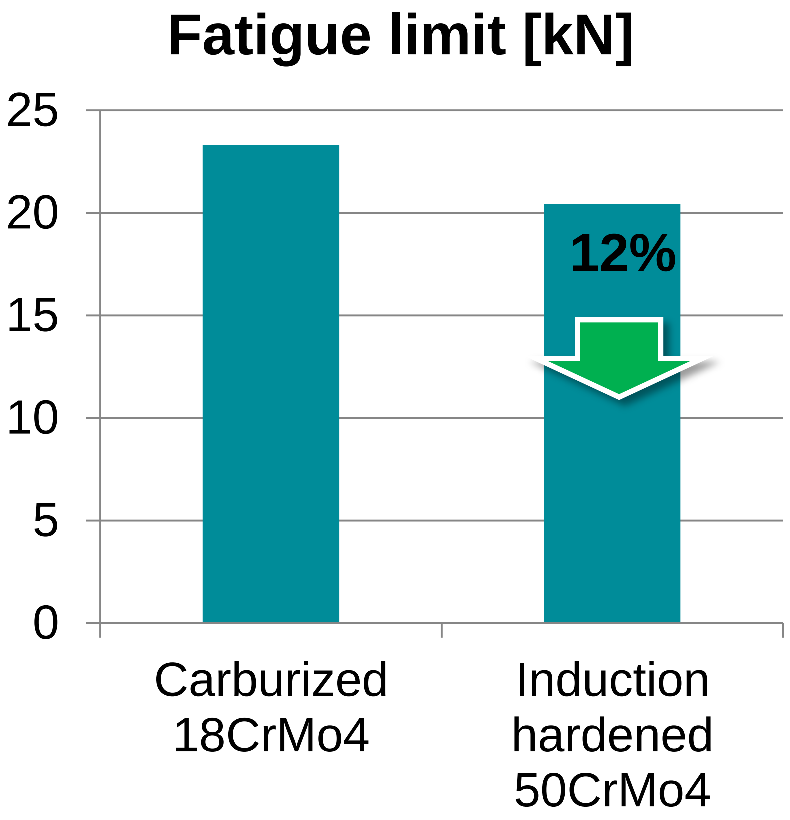


Rotating beam fatigue tests



Root testing of actual gear





S=0.025%	**S=0.035%**

Impossible to line-up fatigue loads of the helical demonstrator gear => spur gear was used in this task

Fatigue strength of induction hardened 50CrMo4
Summary

- Results very dependent on geometry!

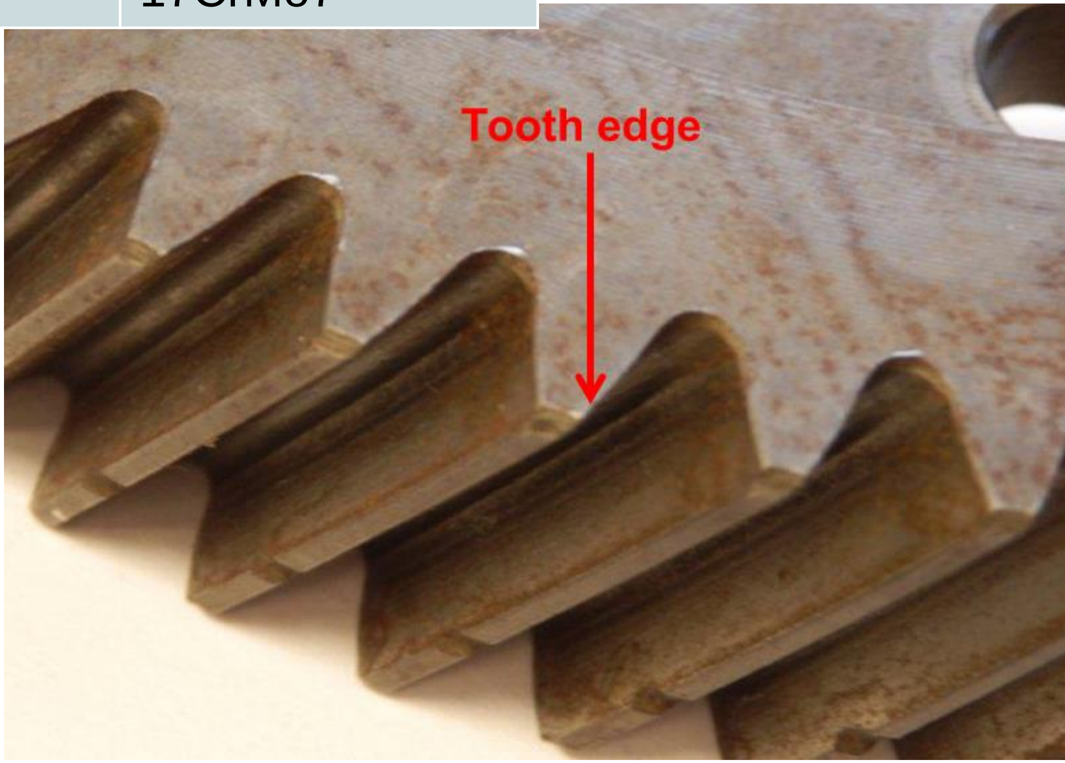
- Fatigue strength of induction hardened 50CrMo4 is on par or (probably) slightly better than that of carburized 18CrMo4.

- Important to compare steels of similar sulphur content!

(18CrMo4: S=0.025%   50CrMo4: S=0.035%)

Demonstrator component

Gear module:	2.35
Outer diameter	168 mm
Helical angle	20°
Current steel	17CrMo7



Manufacturing steps

No.	Sequence	Operation
1	Supply of steel as bar from the steel producer to the forging company.	
2	Blank forging & heat treatment	
3	Arrival of gear blank at Fiat Powertrain.	
4	Turning operations. (& dimensional check)	OP10
5	Gear cutting.	OP30
6	Chamfering and snagging.	OP40
7	Washing.	OP50
8	Drilling.	OP60
9	Washing.	OP70
10	Carburizing.	OP80
11	Shot blasting of gear roots.	OP80
12	Fine turning of end surfaces.	OP100
13	Grinding of gear tooth flanks.	OP110

Manufacturing of demonstrator gears of 50CrMo4

1. Forging to gear blanks of Ovako 528E at Fomas HotRoll (~ 70 pcs)

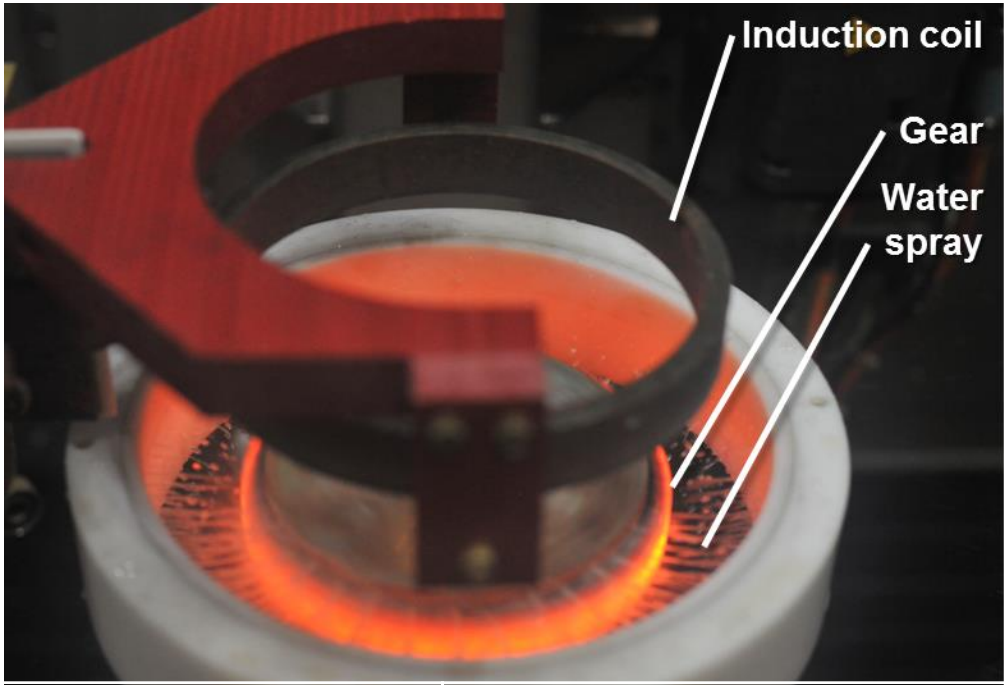
2. Heat treatment at HotRoll specified to 350 HB.

3. At RWTH WZL: Turning and hob milling (~ 30 pcs)

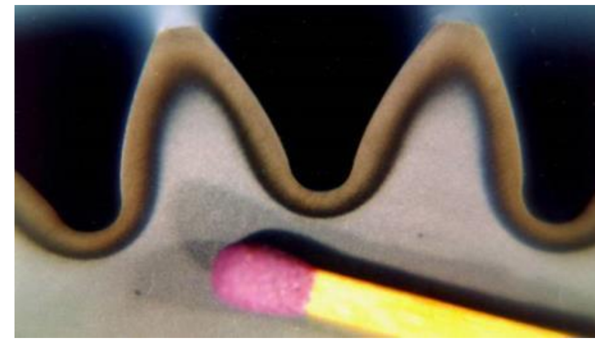
4. At Fiat: Chamfering of gear teeth.

5. EFD Induction: Induction hardening trials & evaluation

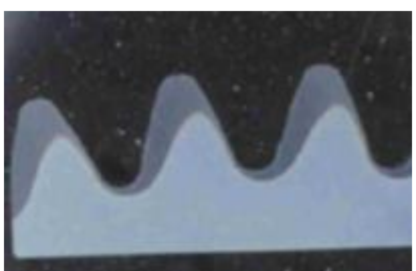
The induction hardening process and trials at EFD Induction



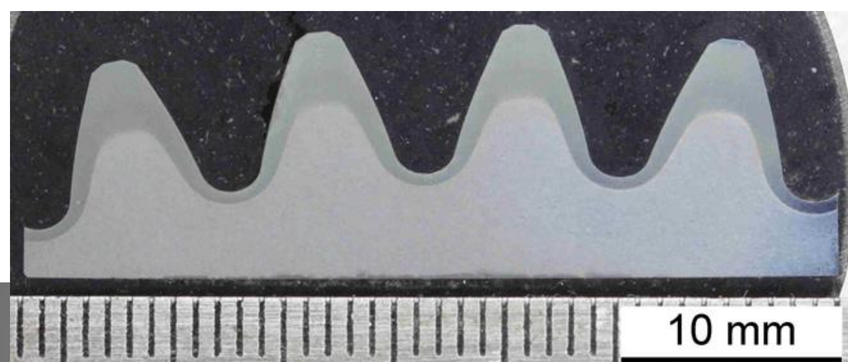
Typical case contour of carburized gear



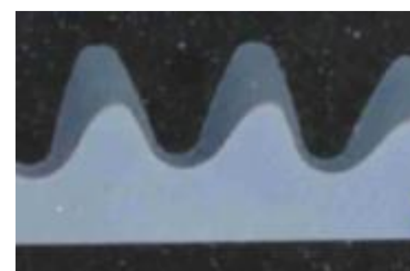
Left edge



Middle



Right edge



Comparison of the two heat treatment processes: Carburizing vs Induction hardening

Based on a yearly production of 550 000 gears at the Mirafiori plant of Fiat Powertrain

Aspects dealt with:

- Process time
- Energy consumption
- Cost of investment and maintenance
- => Total cost of heat treatment

Machining processes:

- Tooling
- Manpower
- Machine cost
- Machining engagement times

Process time

<u>Carburizing:</u>

- Carburizing: 2.5 h
- Tempering time: 3 h

=> Total: 510 min

<u>Induction hardening:</u>

- Hardening cycle: <30 s
- Induction tempering: 60 s (in a parallel low power setup)

=> Total: 2 min

Cost of heat treatment

Carburizing:

- Investment: 0.45 €
- Energy cost: 1.6 €

=> Total: 2.4 €

Induction hardening:

- Investment: 0.27 €
- Energy consumption: 0.3 €

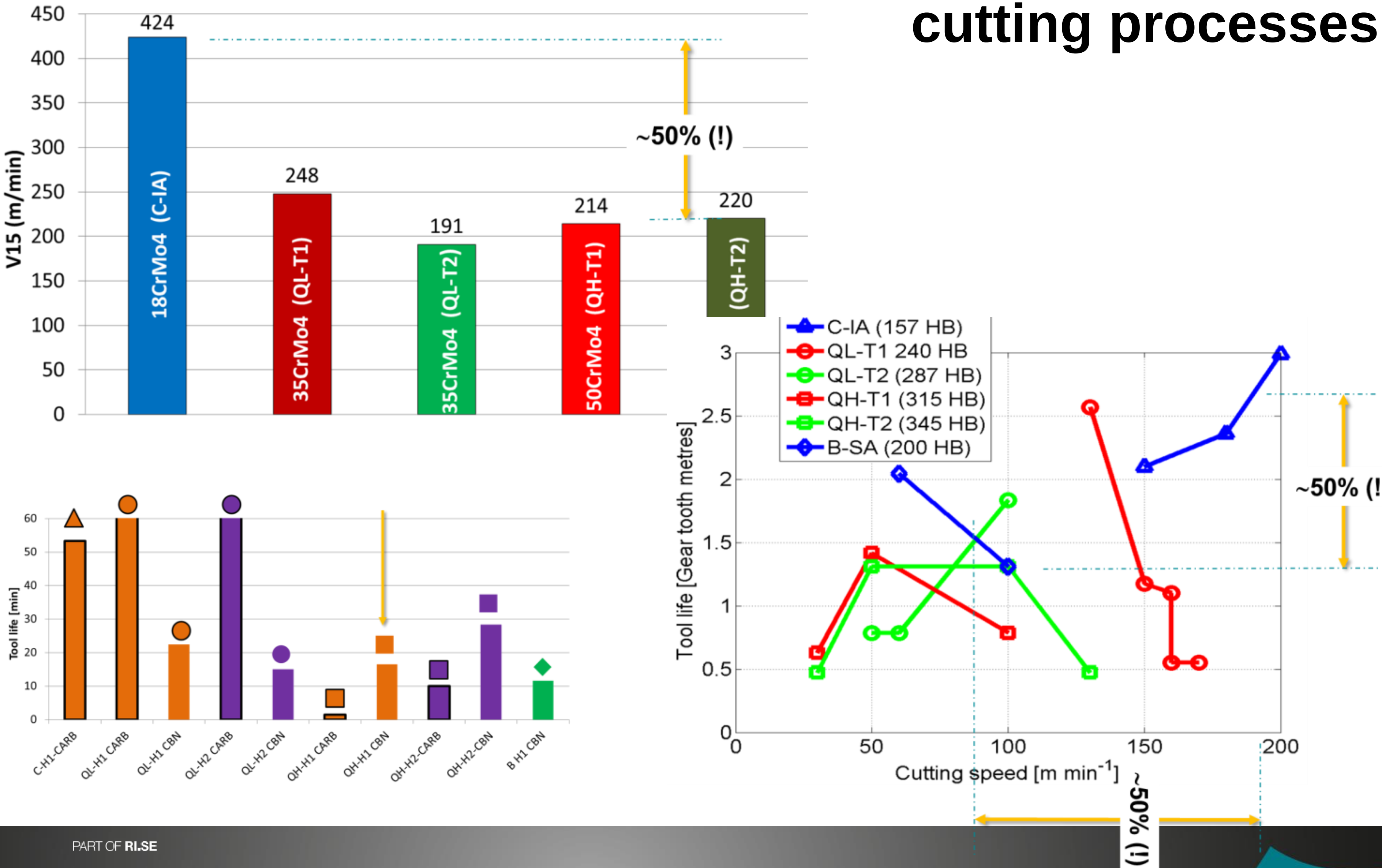
=> Total: 0.6 €

Machining costs

We have considered the following machining operations:

Operation	Engagement time [s] in today's production at Fiat
Internal facing	13
External facing	13
Finishing facing	8
Turning and facing	13
Turning and finishing facing	23
Finishing facing	13
Finishing facing	8
Hob milling	116
Chamfering	15
Snagging	15
Drilling	11
Boring	7
Hard part turning	26
Tooth grinding	125

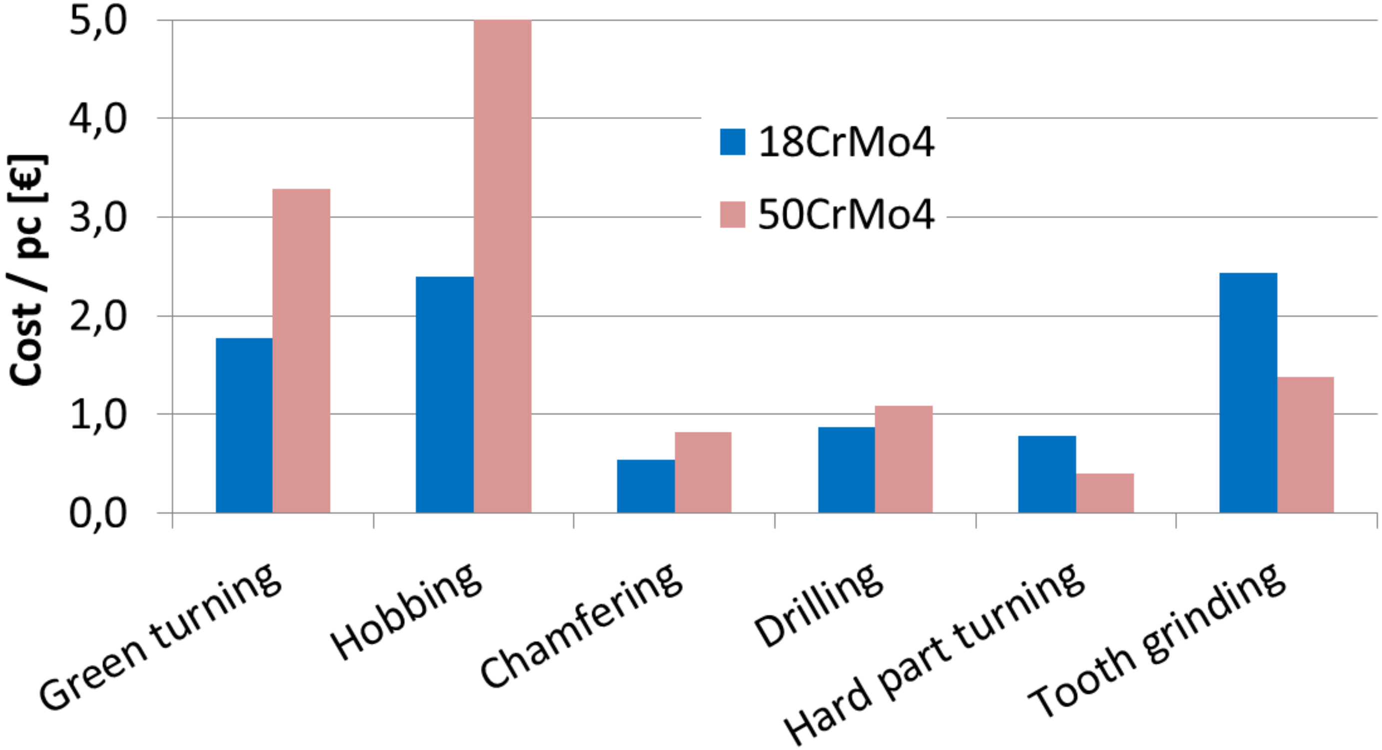
Introduced the following modifications of cutting processes



Spreadsheet to alter machining costs

	Operation	Tools [#]	Staff cost [€/h]	Tooling cost (€/tool)	Machine cost [€/h]	Sharpening [€]	Time in machine [h]	Set-up time [s]	Machining time [s/pc]	Cost (€)/year
Gree	**Tooling**	1000		10						10 000
	Machine				40		16130	15	90,6	645 200
	Staff		20				16130	15	90,6	322 600
Hobbing	**Tooling new hobs**	45		1000						45 000
	Tooling sharpening	360				200				72 000
	Machine				40		20070	15	116,4	802 800
	Staff		20				20070	15	116,4	401 400
Cha	**Tooling**	50		500						25 000
	Machine				40		4580	15	15	183 200
	Staff		20				4580	15	15	91 600
Drill-	**Tooling**	200		50						10 000
	Machine				40		7850	40	11,4	314 000
	Staff		20				7850	40	11,4	157 000
Finis	**Tooling**	550		100						55 000
	Machine				40		6230	15	25,8	249 200
	Staff		20				6230	15	25,8	124 600
Grin	**Tooling**	50		200						10 000
	Machine				40		22120	20	124,8	884 800
	Staff		20				22120	20	124,8	442 400
	Total cost/year (€)									**4 846 k€**
	Total cost/pc									**9 €**

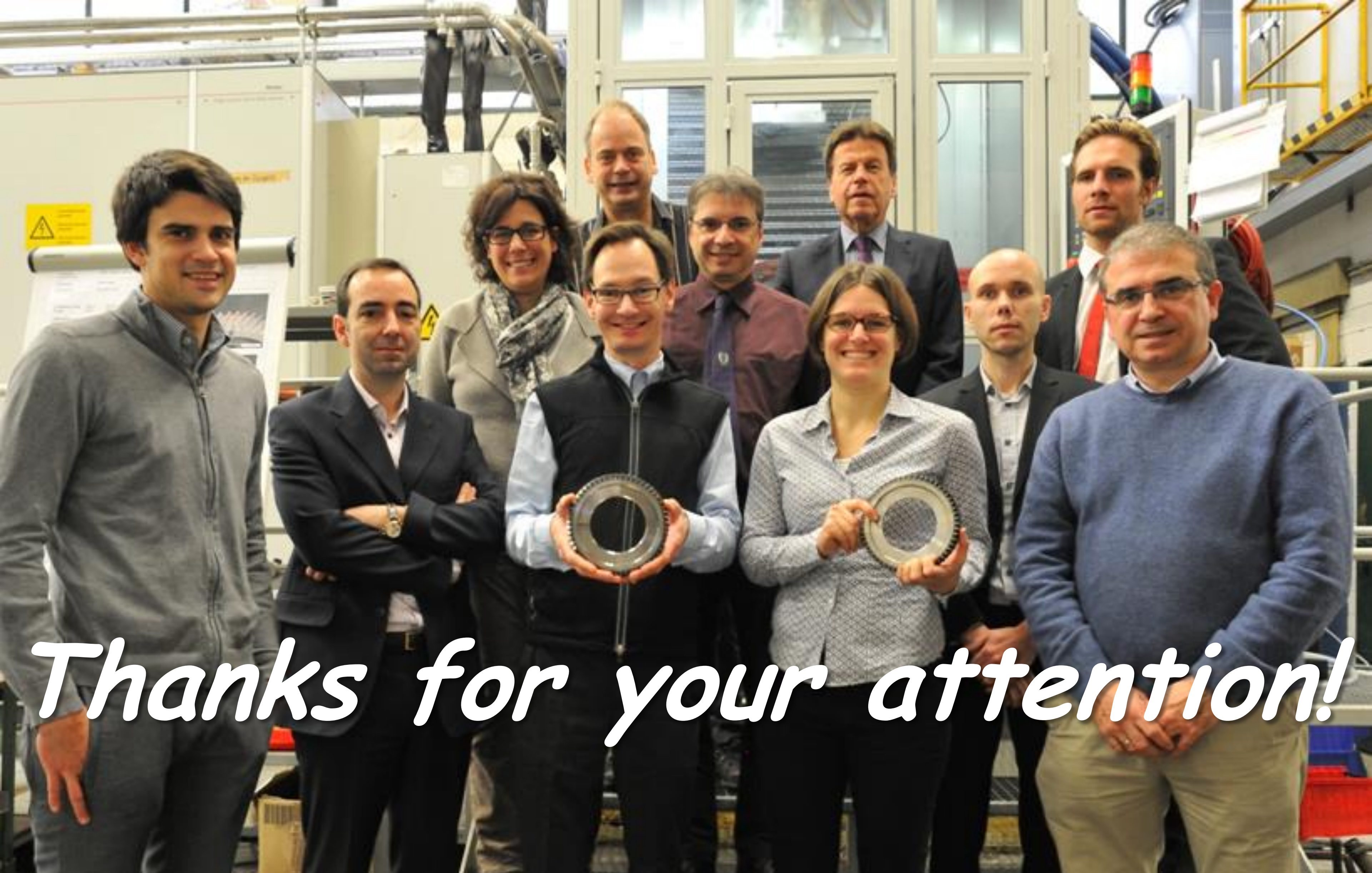
Machining costs



	Total machining costs
Carburizing	9 €
Induction hardening	12 €

Major conclusions and thoughts of the project

- Induction hardening is a technical challenge to implement on helical gears due to the uneven hardening profile of the tooth.
- Induction hardening is on par or better than carburizing, from the mechanical strength, toughness and fatigue strength aspects.
- The component that was actually chosen as demonstrator makes lot of influence on the outcome o this project. A shaft (or king pin) would have been much more viable and straightforward.
- Rule of thumb: The less machining of a component the higher the potential of induction hardening.
- The process time of induction hardening is extremely short compared to carburizing => great potential!!
- The process time and lead time are key aspects in this comparison. The complete shift from batch process to in-line process showed too complex to evaluate in this project.
- The direct cost of IH is lower. (0.64 € vs 2.41€)
- The machining cost of carburizing is lower (9 € vs 12 €).



Thanks for your attention!