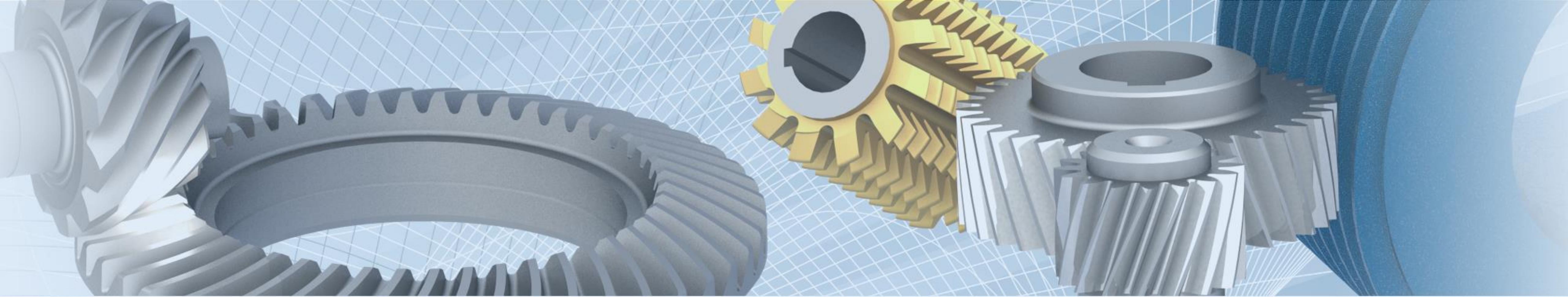


Gears with top in-service performance developed for hybrid and electric vehicles – TOPGEAR

Workshop in Aachen 08. April, 2025

Laboratory for Machine Tools and Production Engineering (WZL)
RWTH Aachen University
Chair of Machine Tools

Funding:

European Commission

Research Fund for Coal & Steel

This report is part of a project that has received funding from the Research Fund for Coal and Steel of the European Union (EU) under grant agreement No 101033989.

Gear Manufacturing
Gear Manufacturing Process Chain of both Material Variants

Variant 01: Reference Material – 27MnCr5

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

Pitting Test Gear
for high speed tests

TOP GEAR

Scuffing Test Gear
for high speed tests

Variant 02: 40CrMoBi4

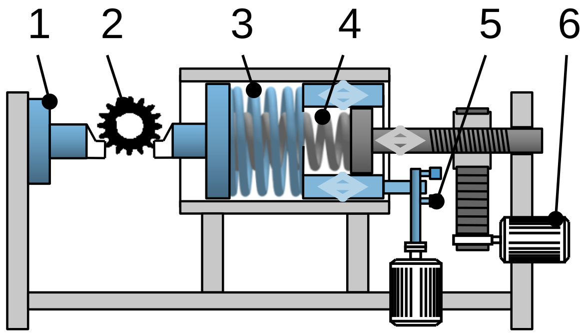
Raw material → Sawing & soft turning → Hobbing → Spline Shaft → Surface & bore grinding → Gear Grinding → Heat treatment → Quality control & testing

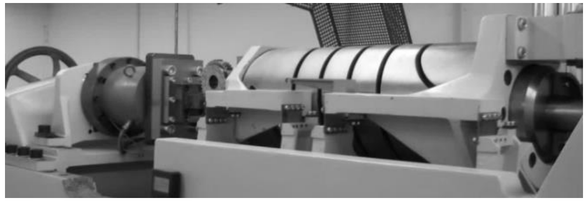
Agenda

1	Toth Root Bending Strength
2	Flank Load Capacity
3	Scuffing Load Capacity
4	Conclusions

Operating Principles of Pulsator Test Rigs

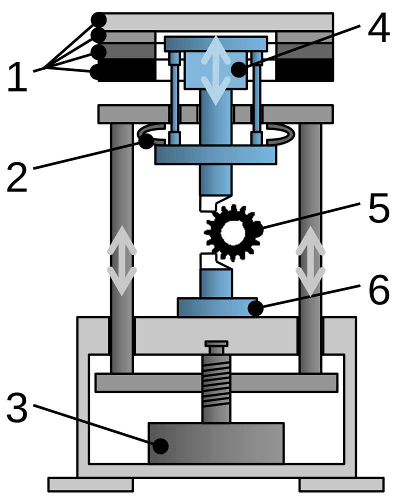
Imbalance-Excited Resonance Pulsator





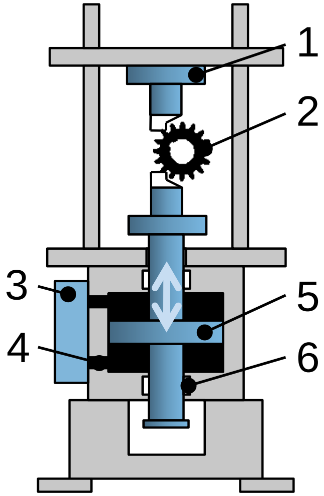
1 **Load Cell**
2 **Test Gear**
3 Pulsating Spring
4 Medium Load Spring
5 Centrifugal Excicter
6 Medium Load Drive

Magnetic Resonance Pulsator



1 Variable Excitation Mass
2 Medium Load Spring
3 Medium Load Drive
4 Excitation Magnet
5 **Test Gear**
6 **Load Cell**

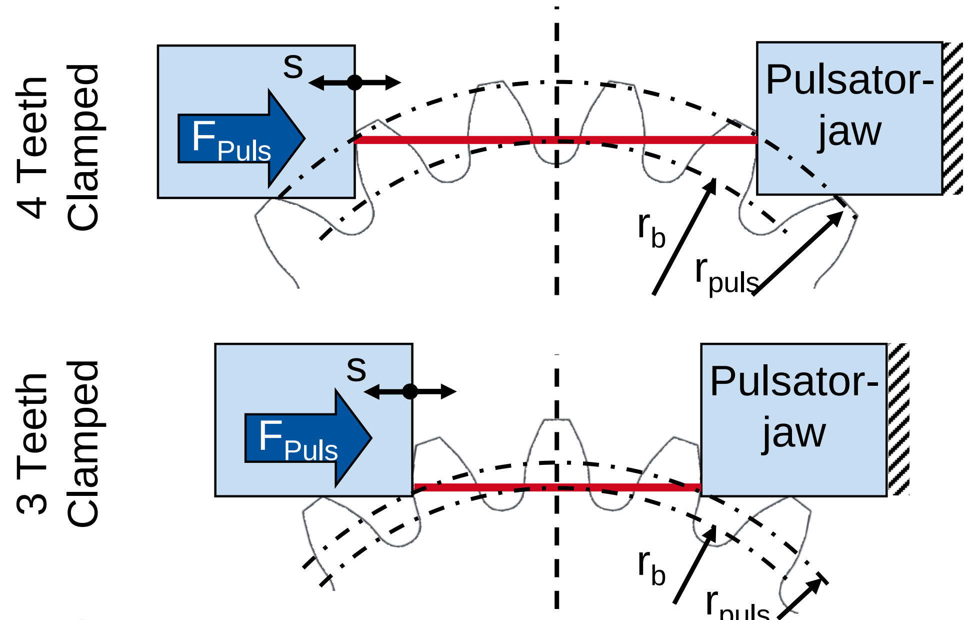
Hydraulic Pulsator



1 **Load Cell**
2 **Test Gear**
3 Servo Valve
4 Oil Input
5 Piston
6 Hydrostatic Bearing

Comparison of Stresses of Running Test and Pulsator Test

Location of the Contact Line Depends on the Number of Teeth



1 2 Teeth in Operation

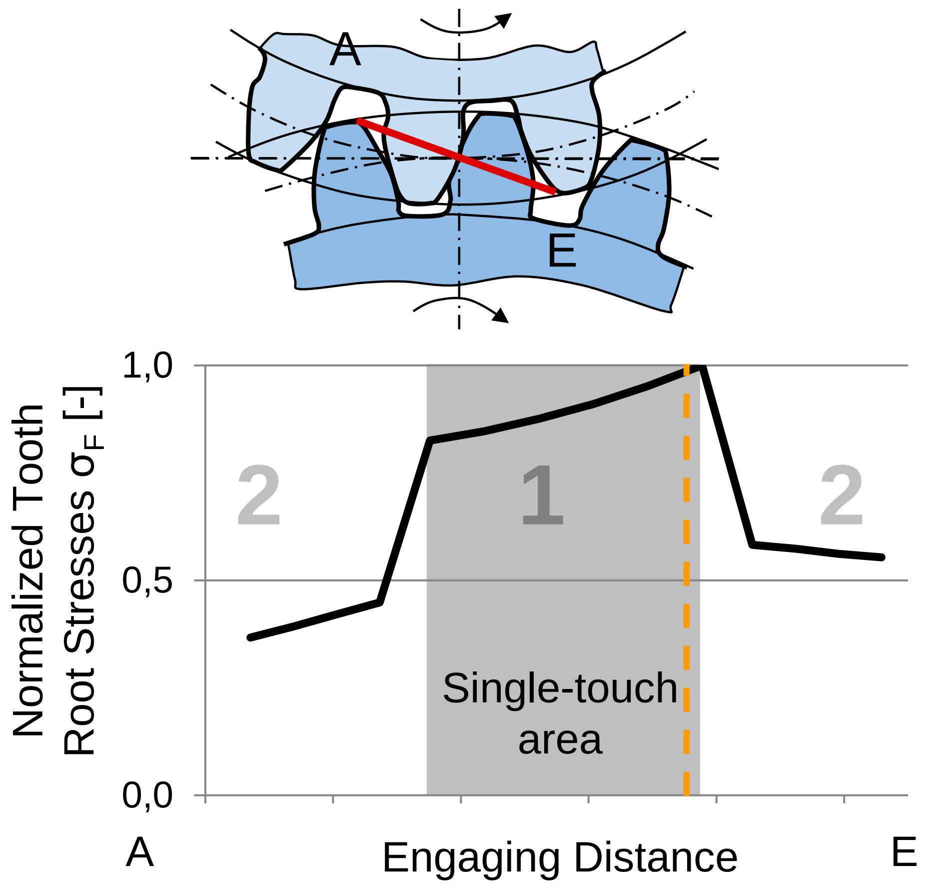
– – Contact Line which is to Adjust

— Resulting Contact Line

r_b Base Radius

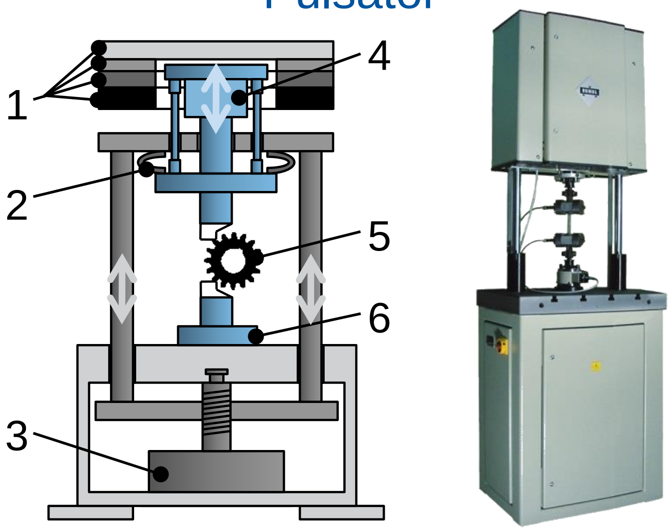
r_{puls} Radius of the Contact Line which is to Adjust

Pulse line next to the outer single-touch area

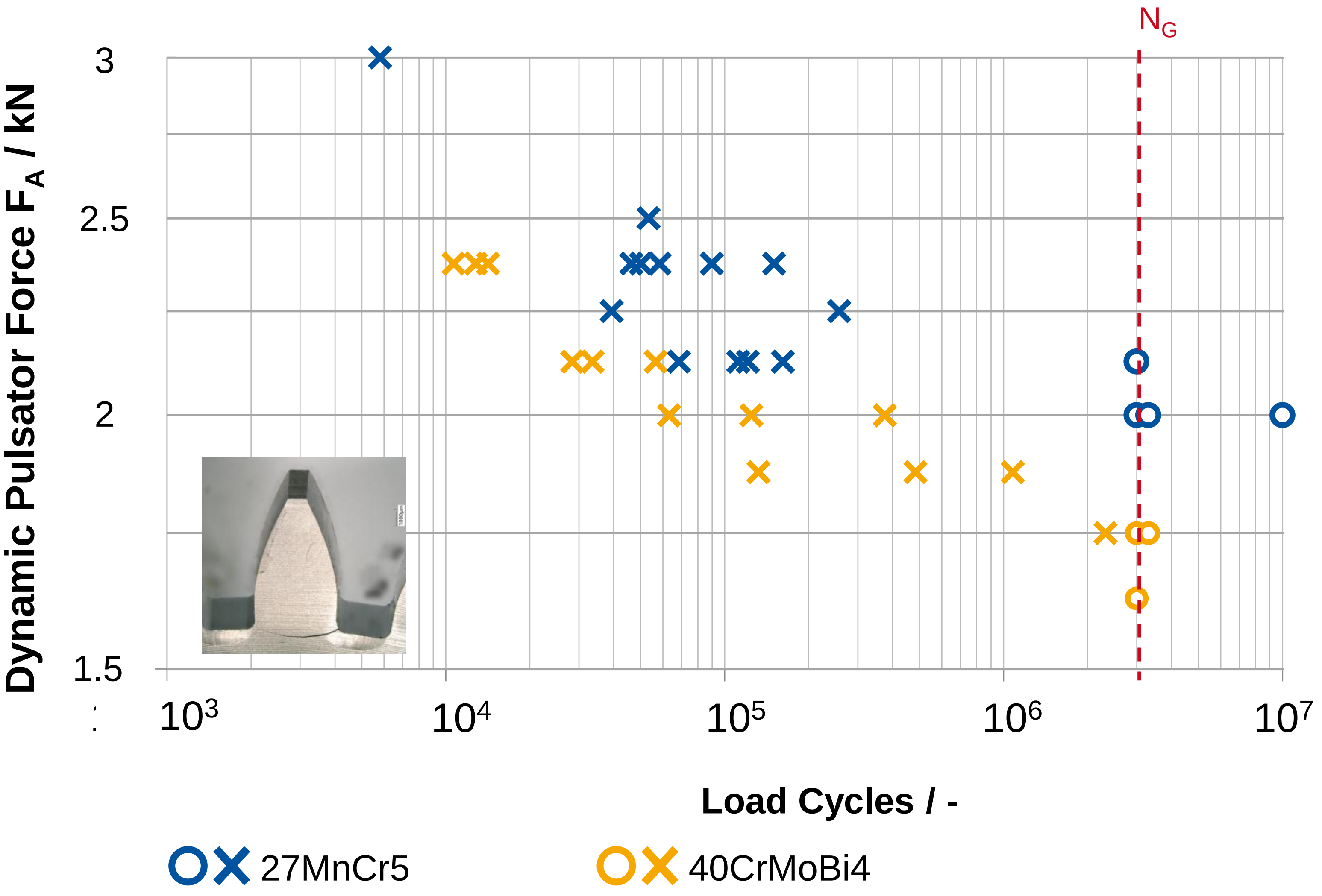


Testing Pulsator Test Rig (Tooth Root Bending)
27MnCr5 Scuffing Geometry / 40CrMoBi4 Scuffing Geometry

Magnetic Resonance Pulsator



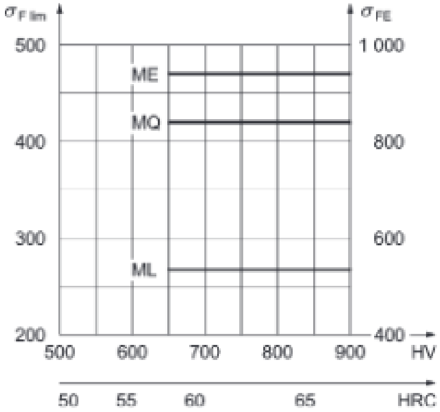
1 Variable excitation mass
2 Mean load spring
3 Mean load drive
4 Excitation magnet
5 Test gear
6 Load cell

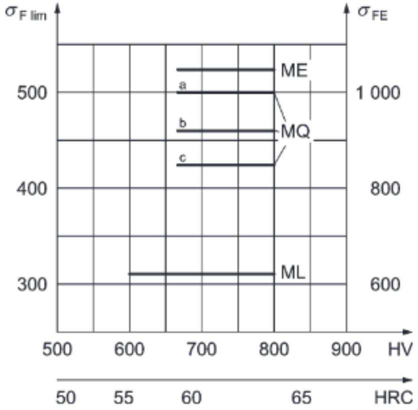


Testing Pulsator Test Rig (Tooth Root Bending)
27MnCr5 Scuffing Geometry / 40CrMoBi4 Scuffing Geometry

Conclusion

- Case-hardened steel (27MnCr5) has a higher time and fatigue strength compared to nitriding steel 40CrMoBi4
- the lowest runout level of 27MnCr5 is **<u>23 %</u>** higher than that of 40CrMoBi4, ISO6336 → ca. 10%





Agenda

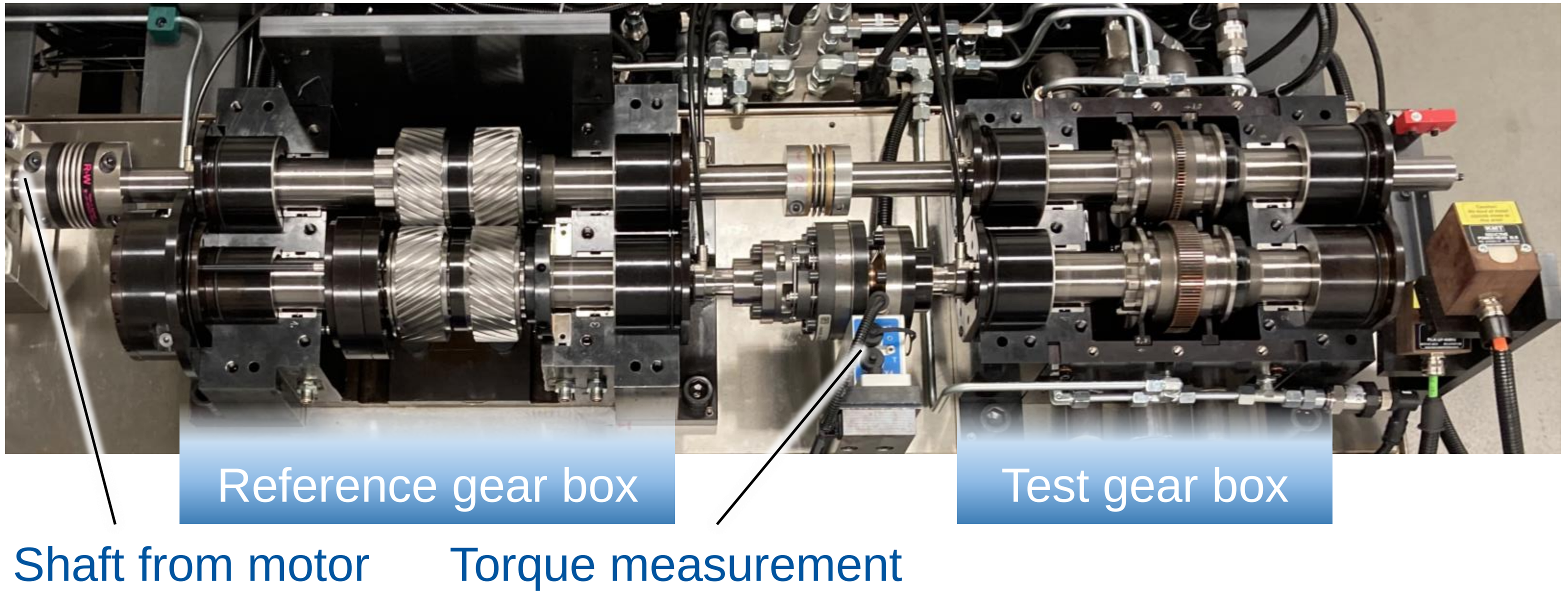
Test rig data

- a = 99.5 mm
- n_{max} = 12,000 rpm
- M_{max} = 200 Nm
- Oil = Aeroshell 555
- Qoil = 40 L/min

Test geometry pitting

Test geometry scuffing

High-speed back-to-back gear test rig



Predefined parameter:

Centre distance a = 99.5 mm

Tooth ratio z_1 / z_2 = 99/102 or 33/34

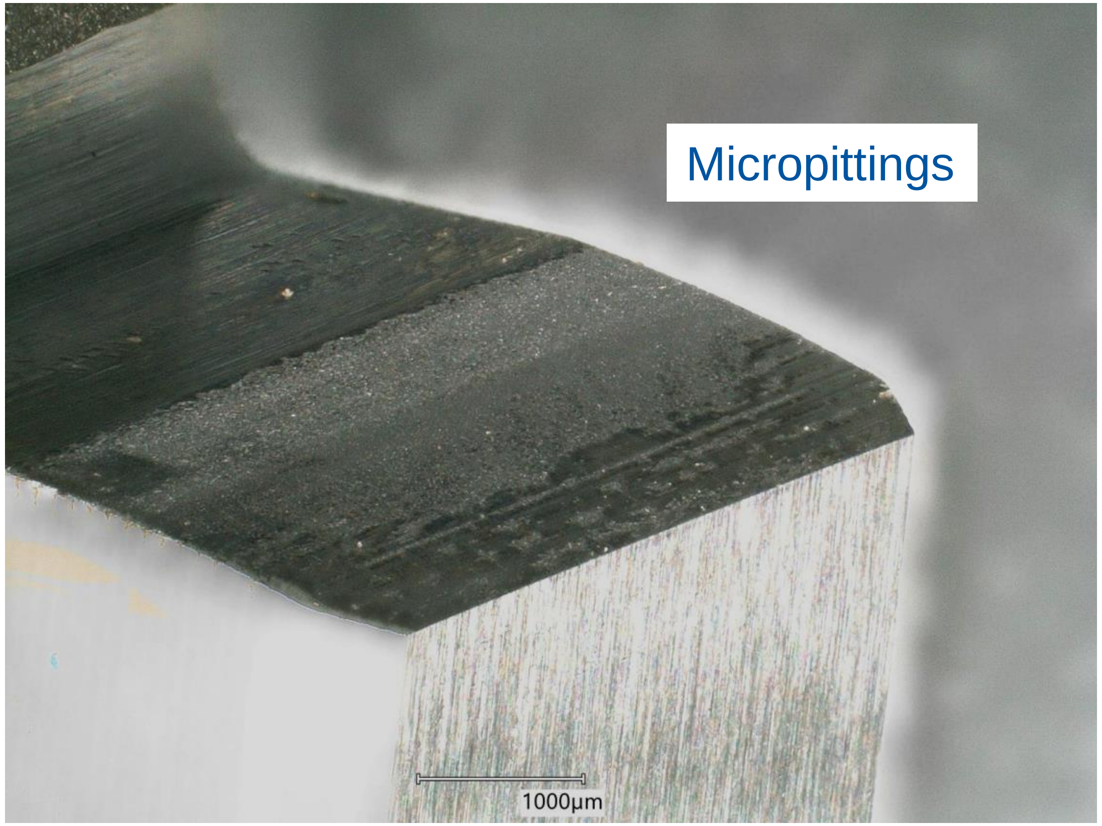
Max. torque $M_{in,max}$ = 200 Nm

Hub – Shaft connection by spline shaft

Axial displacement of test wheel due to torque application

Direct comparison of Gars after 50,000,000 Load cycles at 120 Nm and 12,000 RPM

27MnCr5
M = 170 Nm N = 50,000,000 Load cycles

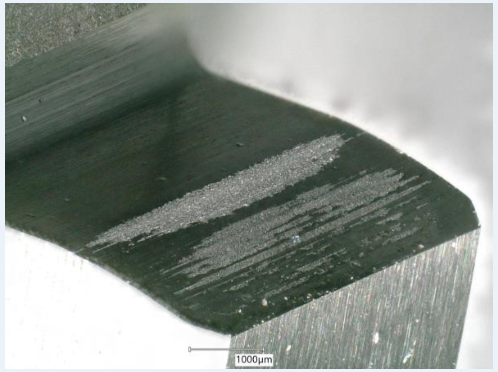
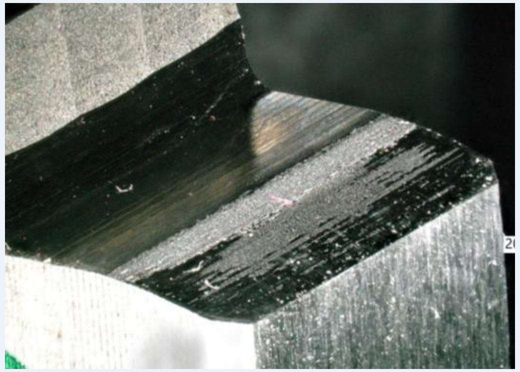
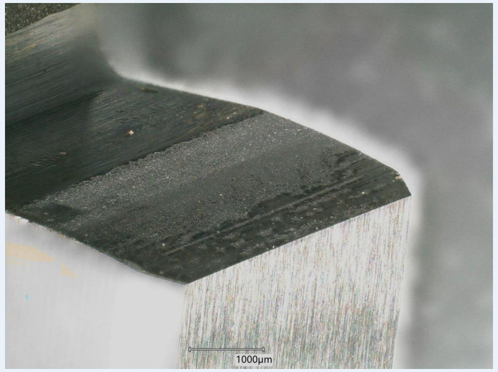
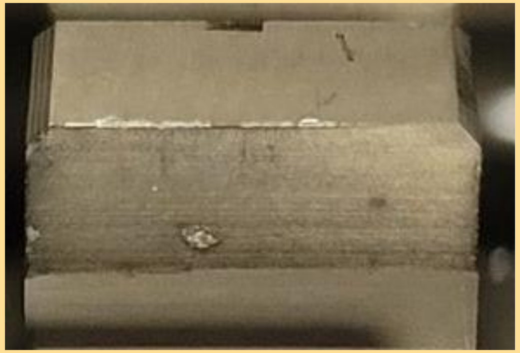


40CrMoBi4
M = 170 Nm N = 50,000,000 Load cycles

Testing Mini M4T Test Rig
27MnCr5 Pitting Geometry / 40CrMoBi4 Pitting Geometry

Test gear geometry
- m_n = 3.06 mm
- z_1 / z_2 = 33 / 34
- b_1 / b_2 = 7 / 25 mm
- a = 99.5 mm
- α_n = 18°
- β = 0°
- x_1^* / x_2^* = -0.5073 / -0.3176
- d_{a1} / d_{a2} = 101.5 / 103.5 mm

Test data
- n = 12,000 rpm
- M = 170 Nm
- T_{oil} = 40° C
- Oiltype : Aeroshell 555
- Run in: 10 min at 40 Nm

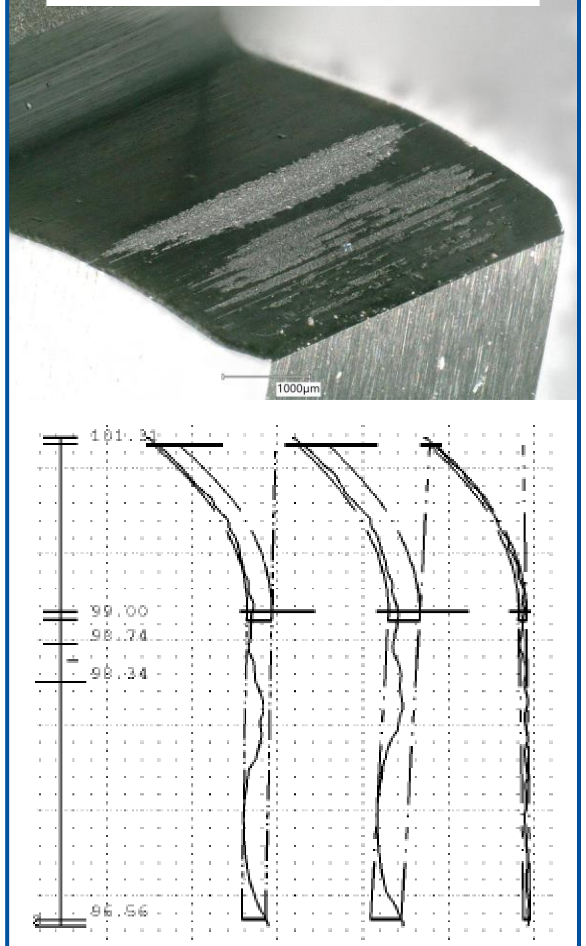
12,000,000 Lastwechsel	24,000,000 Lastwechsel	50,000,000 Lastwechsel
		
		

Pinion WSM1-A-28108 Micropitting (170 Nm)

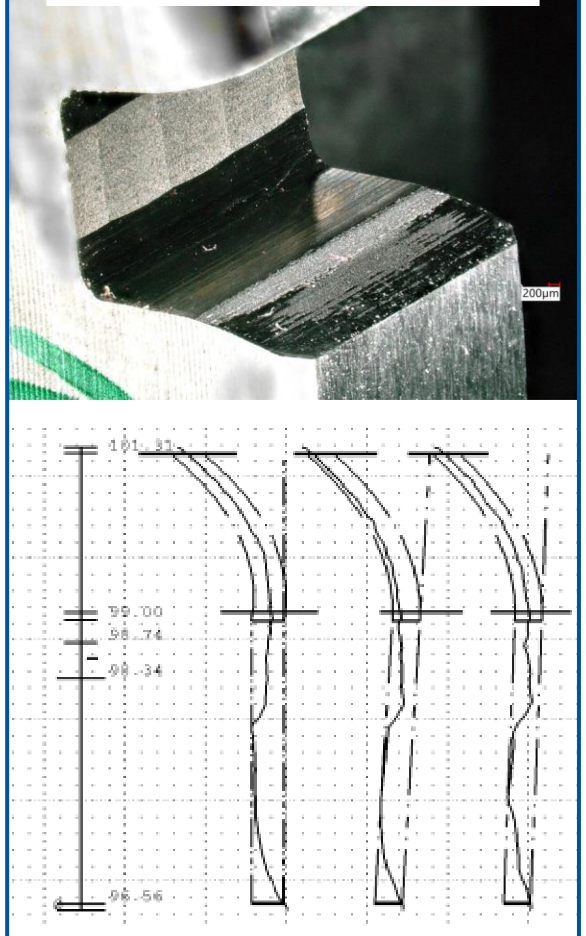
Pitting test

- m_n = 2.95 mm
- z_1 / z_2 = 33 / 34
- b_1 / b_2 = 7.5 / 25.6 mm
- a = 99.5 mm
- α_n = 15°
- β = 0°
- x_1^* / x_2^* = 0.15 / -0.1

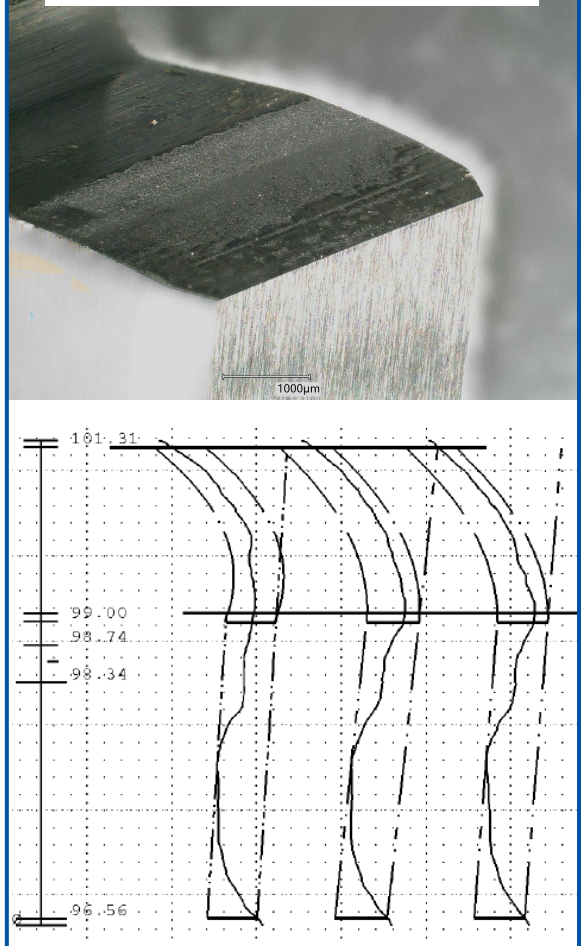
12,000,000 Load cycles



24,000,000 Load cycles



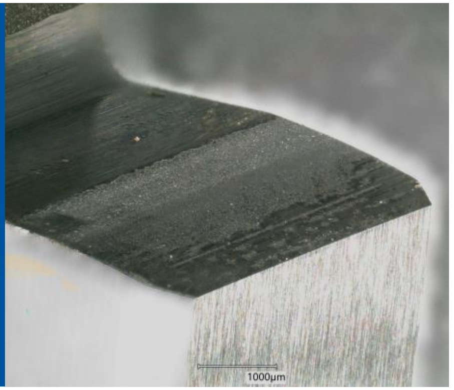
50,000,000 Load cycles



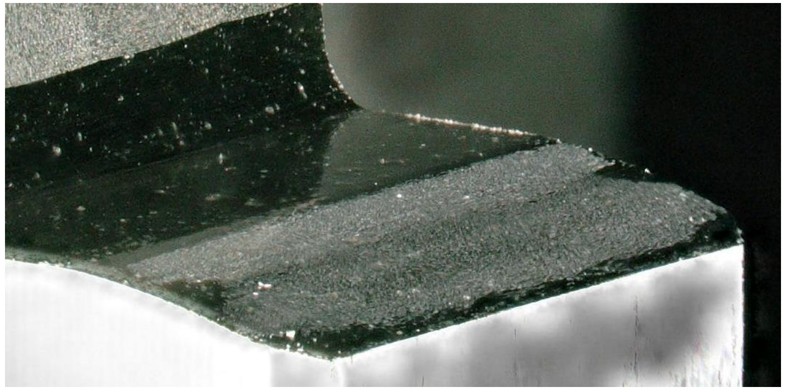
Testing Mini M4T Test Rig
27MnCr5 Pitting Geometry / 40CrMoBi4 Pitting Geometry

27MnCr5 at 170 Nm and 12,000 rpm

Test 1



Test 2



40CrMoBi4 at 170 Nm and 12,000 rpm

Test 1

Test 2

Test 2

Testing Mini M4T Test Rig
27MnCr5 Pitting Geometry / 40CrMoBi4 Pitting Geometry

27MnCr5 at 170 Nm and 12,000 rpm

40CrMoBi4 at 170 Nm and 12,000 rpm

Conclusion

- Case-hardened and nitrided steel fail under the same test conditions and with the same surface roughness due to different damage mechanisms
- 27MnCr5 → Micropittings
- 40CrMoBi4 → Pittings / Damage at the tip

Agenda

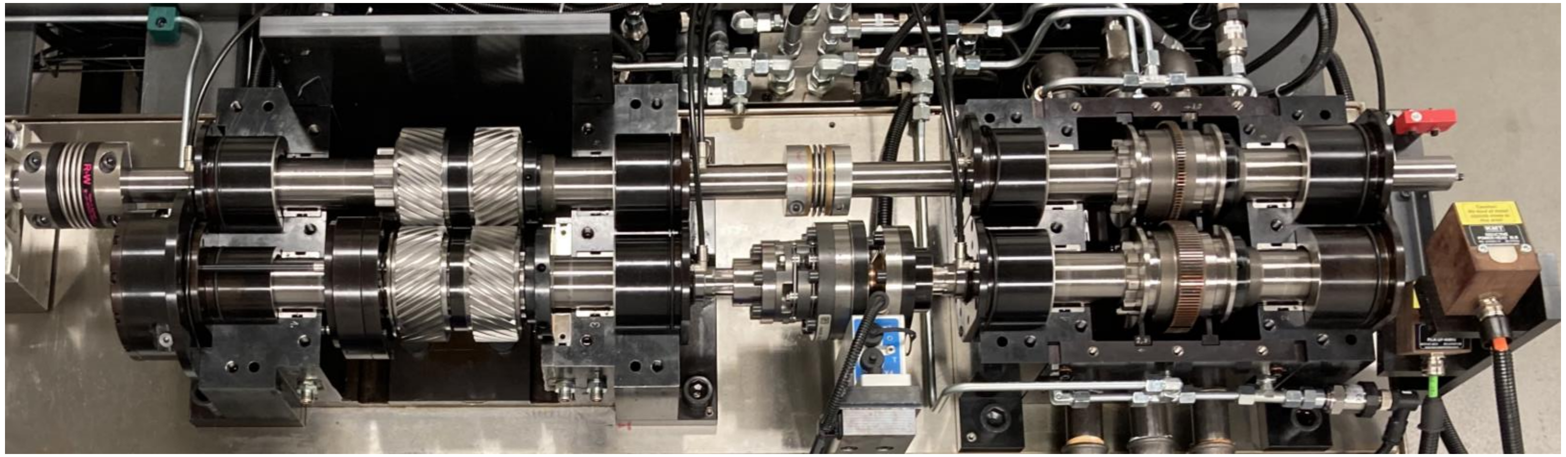
1	Toth Root Bending Strength
2	Flank Load Capacity
3	Scuffing Load Capacity
4	Conclusions

Test rig data

- a = 99.5 mm
- n_{max} = 12,000 rpm
- M_{max} = 200 Nm
- Oil = Aeroshell 555
- Qoil = 40 L/min

Test geometry scuffing

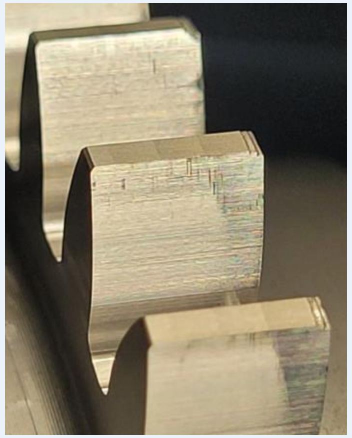
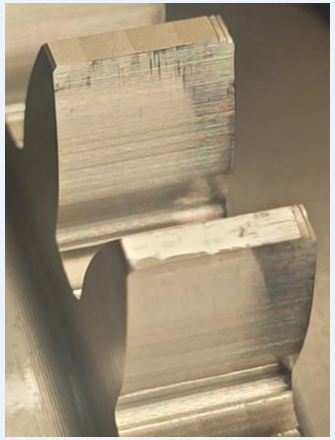
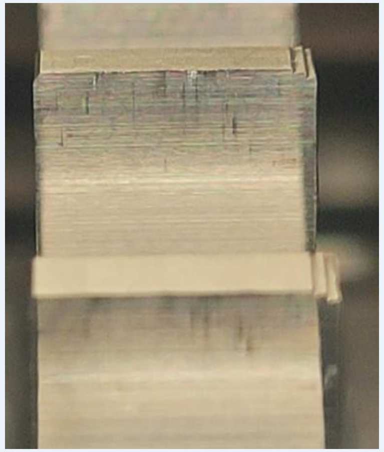
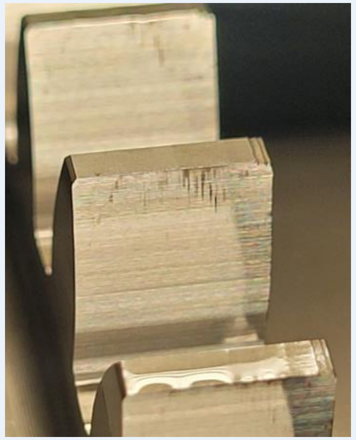
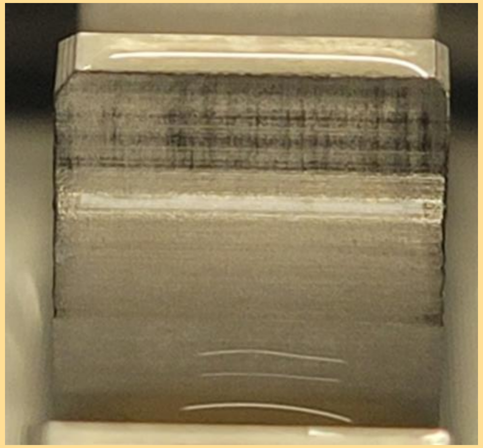
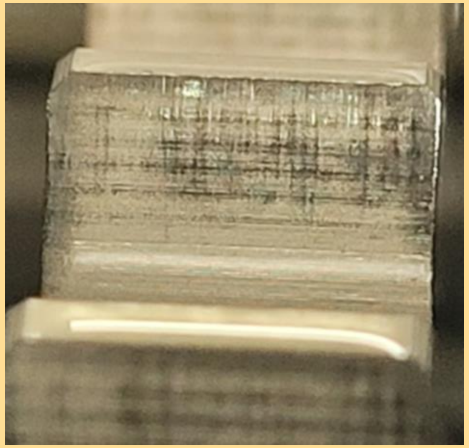
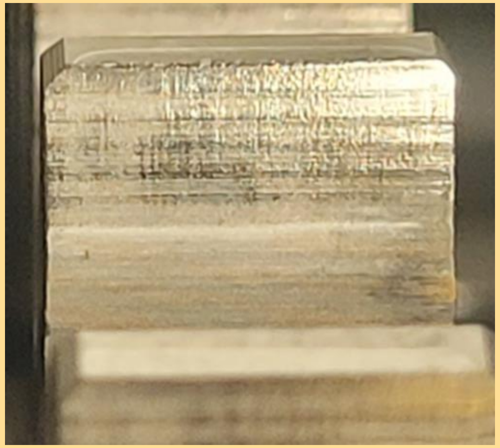
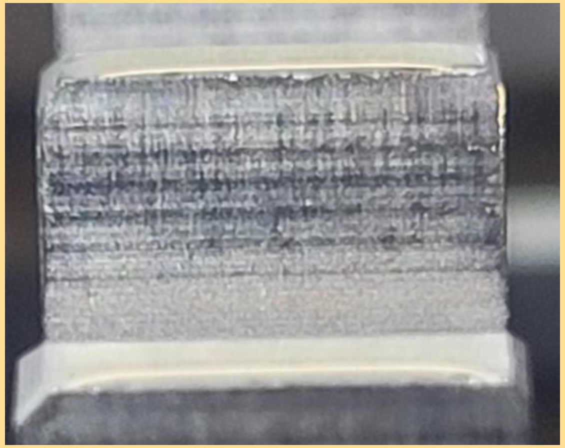
High-speed back-to-back gear test rig



M_{start} = 80 Nm → Testing t = 7 min → Visual inspection → scuffing → End

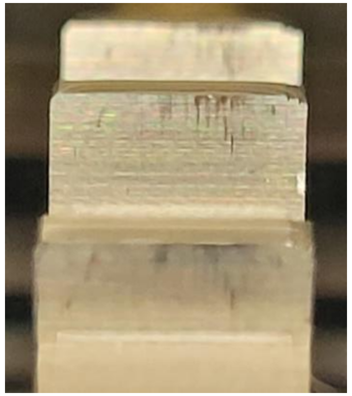
Visual inspection → No damage +10 Nm → Testing t = 7 min

Testing Mini M4T Test Rig
27MnCr5 Scuffing Geometry / 40CrMoBi4 Scuffing Geometry

150 Nm	160 Nm	170 Nm	180 Nm (Test rig max)
			
			

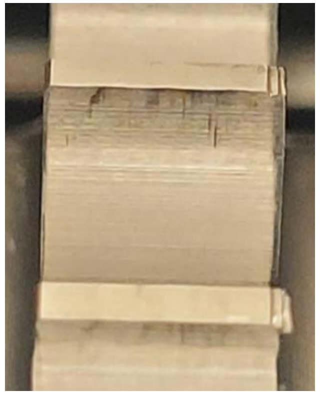
Testing Mini M4T Test Rig
Scuffing test 27MnCr5 gears at n = 12000 rpm

80 Nm

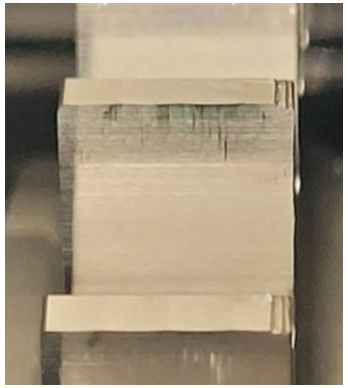


90 Nm

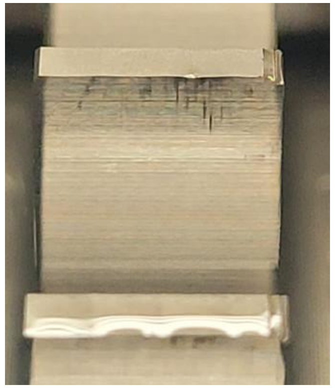
100 Nm



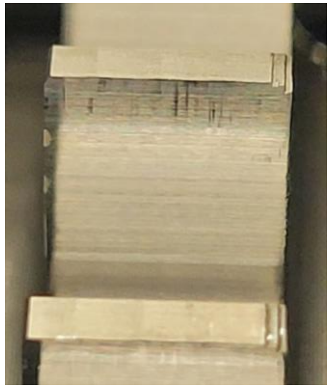
110 Nm



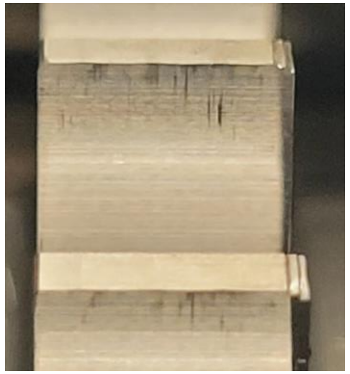
120 Nm



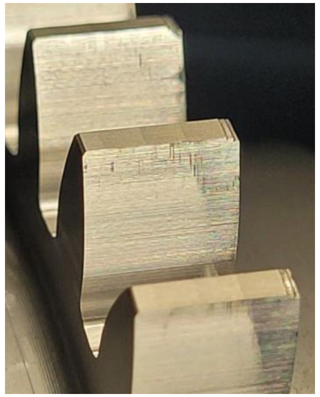
130 Nm



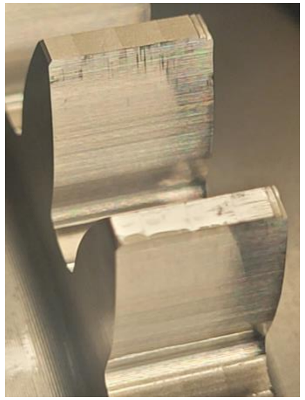
140 Nm



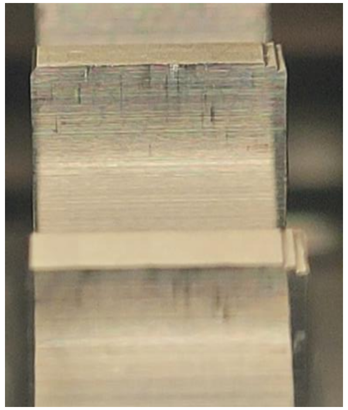
150 Nm



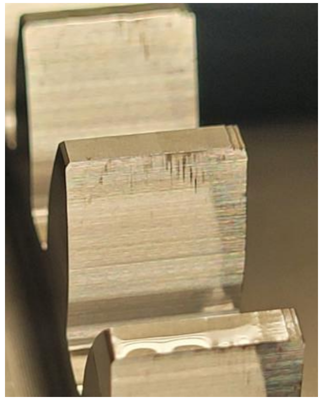
160 Nm



170 Nm

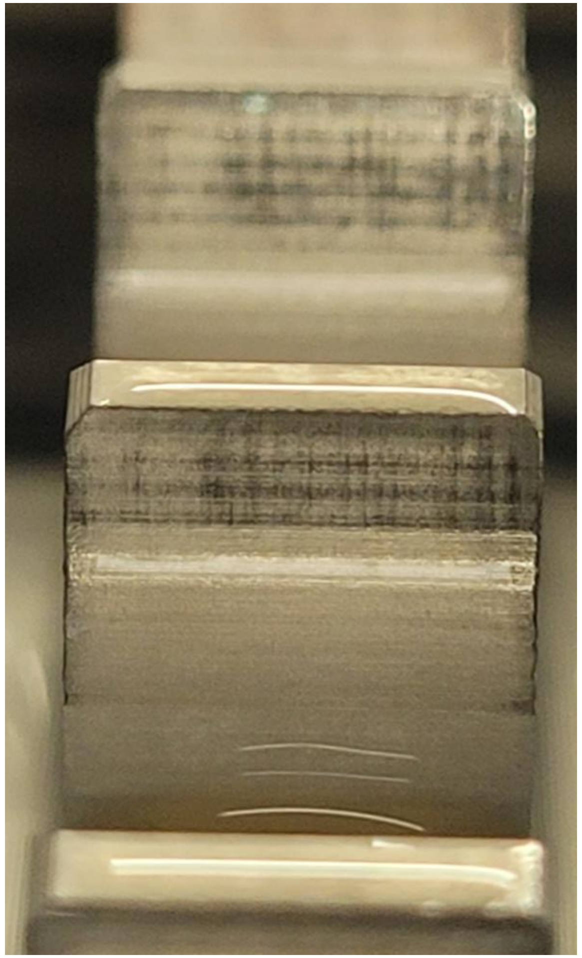


180 Nm

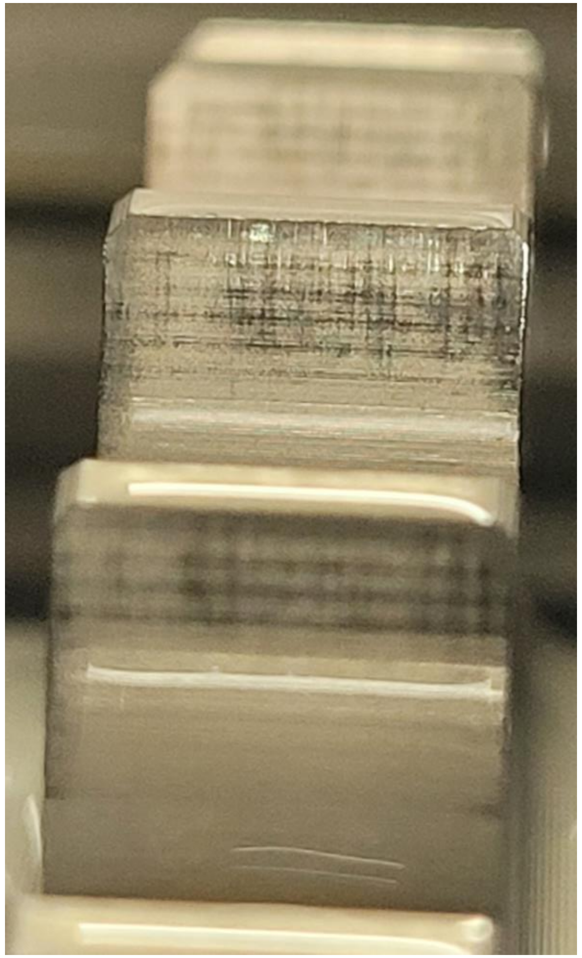


Testing Mini M4T Test Rig
Scuffing test 40CrMoBi4 gears at n = 12000 rpm

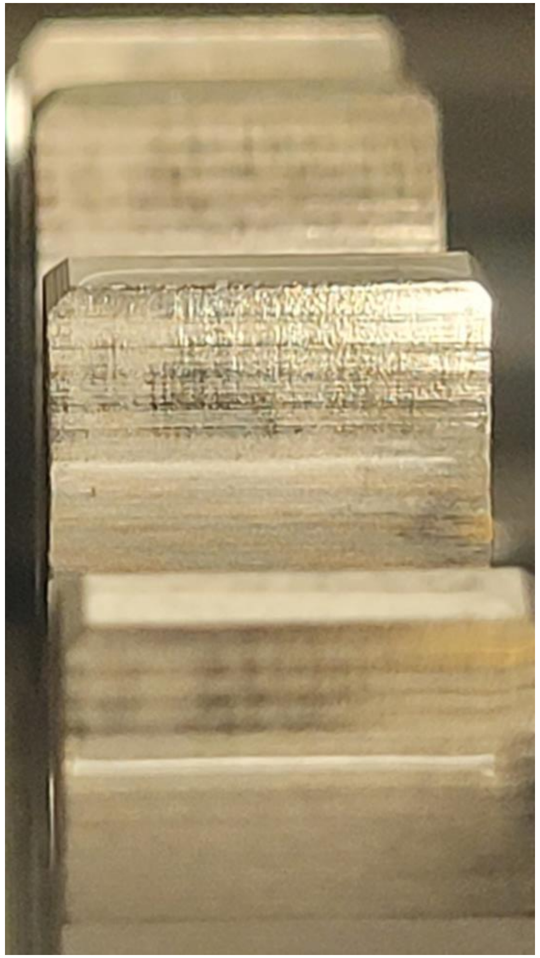
150 Nm



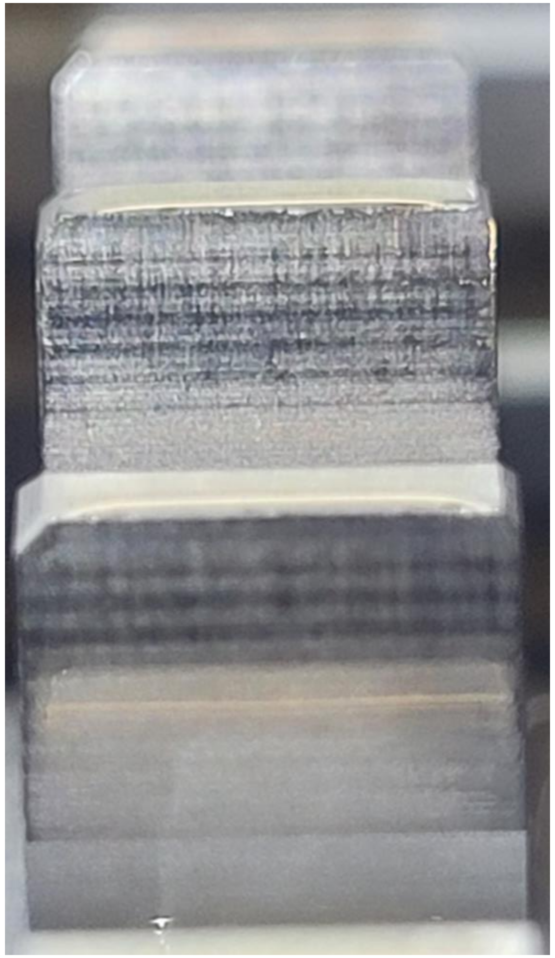
160 Nm



170 Nm



180 Nm



Agenda

Conclusions for Future EV Gears at High Speeds

Project results Topgear and general advices at highspeeds

Bending Strength

- 27MnCr5 case-hardened has a higher tooth root bending strength than 40crMoBi4 nitrided steel
- The tooth root load capacity increases at an increased speed of 12000 rpm compared to the standard test at 3000 rpm (ZALFEN)

Flank Load Capacity

- 27MnCr5 case-hardened and 40crMoBi4 nitrided steel show different damage types (Pitting & Micropitting)
- At increased speed, there appears to be an increased risk of micropitting despite good roughness values for case-hardening steel and better lubrication with high tangential velocities in theory
- The initial results show that the pitting load capacity could also increase at higher speeds. This must be investigated further

Scuffing Load Capacity

- The Aerospace 555 oil used does not lead to scuffing regardless of the material variant
- It is known from the state of the art that the scuffing load capacity increases with high circumferential speeds
- Low-viscosity oils with high scuffing load capacity are recommended for high-speed applications