

Robustness and thermal behavior evaluation of MD H₂ internal combustion engine components

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für Wirtschaft
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aufgrund eines Beschlusses
des Deutschen Bundestages



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Robustness for NRMM



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PoWer

Potenzial von Wasserstoffmotoren für effiziente und robuste Off-Road Anwendungen



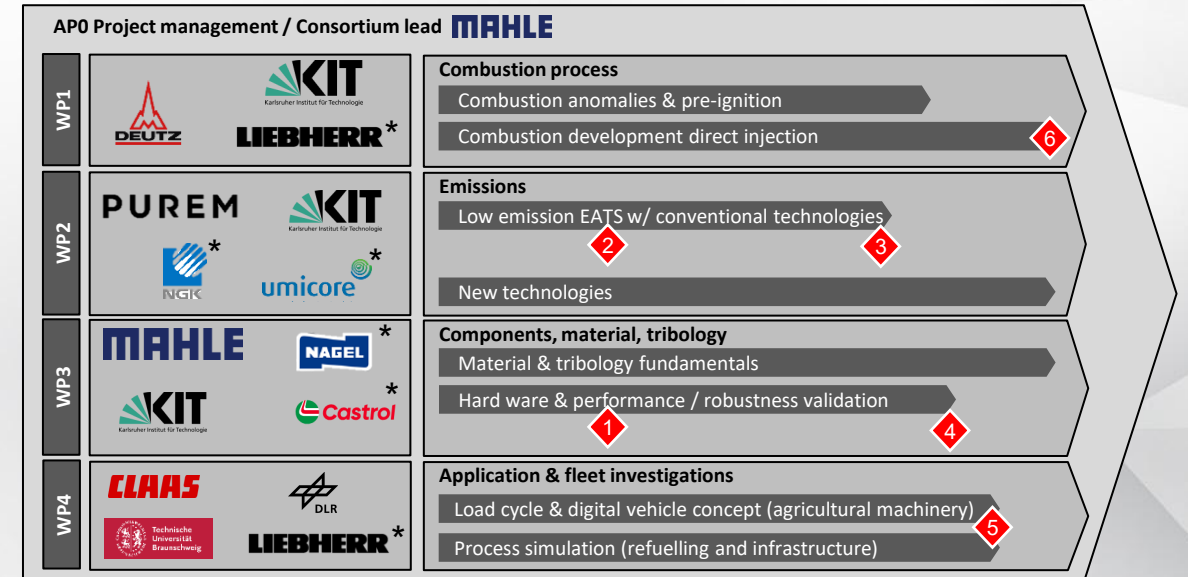
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Project profile

- Funded by the Federal Ministry for Economic Affairs and Energy with 5.1 mio. €
- Duration: 08/2024 – 07/2027

Objectives reflected in the work packages

- Combustion process
- Emissions
- Components, material and tribology
- Application and fleet investigations



M1: DEUTZ engine available

M2: Low emission EATS** available

M3: Low emission demonstrated (NOx & PN)

M4: Robustness engine & EATS demonstrated

M5: Wide range of H₂-ICE application demonstrated

M6: Potential of DI-injection confirmed

Content and work package structure of the funded project “PoWer”



The project “PoWer” aims to support the hydrogen-based powertrain concepts for construction and agricultural applications

Main Aspects of PCU Optimization



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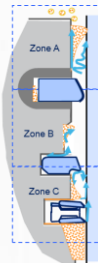
- **Safety** (H_2 concentration in the crankcase < 4%)
- **Lubricant degradation** (water content in the oil)
- **Components corrosion** (blow-by moisture)

Blow-by

Blow-by

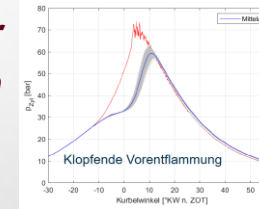
Oil droplets

- **CO₂ emissions** (single source of carbon)
- **Particle emissions** (single source of particles)
- **Abnormal combustion** (caused by oil droplets / oil formation)



Lube oil consumption

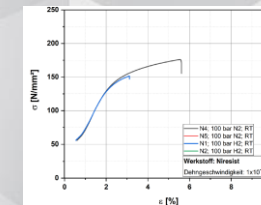
Irregular combustion



- **High peak cylinder pressures** (PCU damage)
- **Backfire** (intake manifold damage)
- **Hydrogen slip** (EATS damage)



H₂ material compatibility



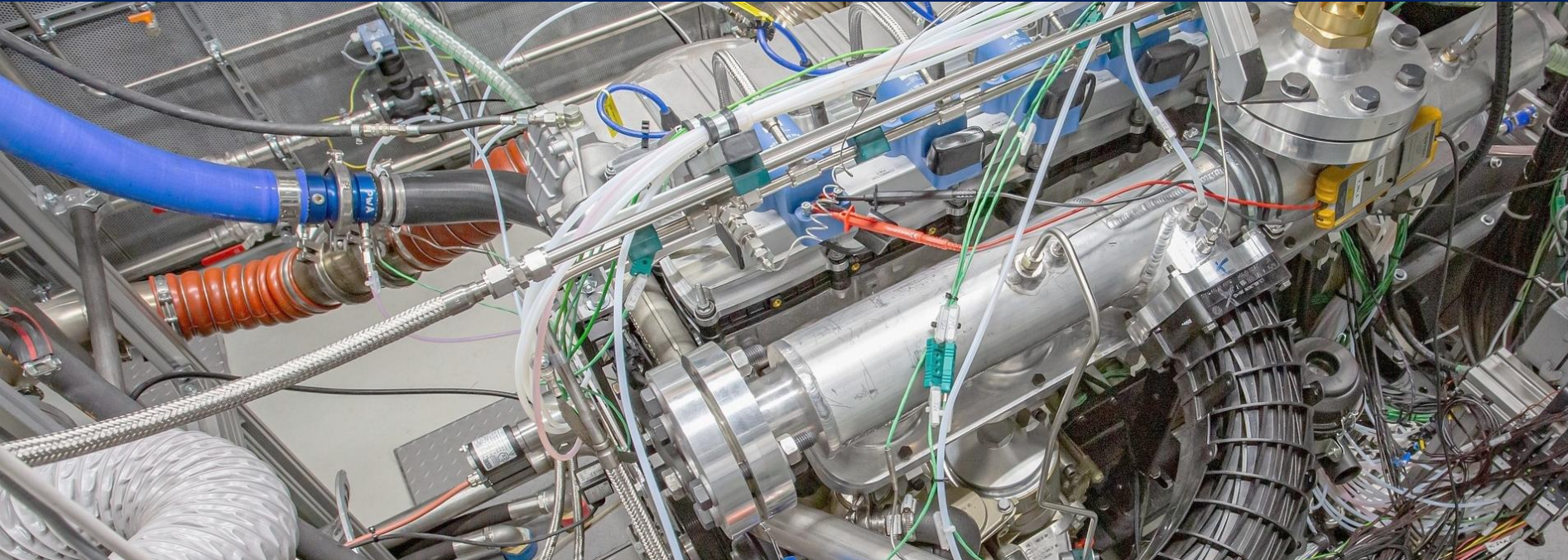
- **Hydrogen embrittlement**
- **Wear** (low and potentially polluted lubricant availability)
- **Corrosion** (blow-by moisture, condensation)



Holistic approach to robustness required – Measures and solutions are scope of the PoWer project

Engine Testing and System Approach

02



DEUTZ TCG 7.8 H2

Like a Diesel. Only without the Diesel.

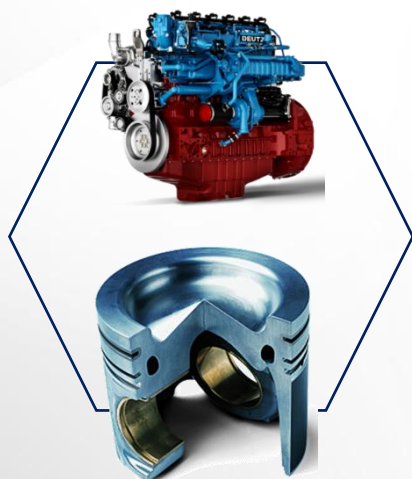
Specification	
Cylinder	6 inline
Displacement	7.755 l
Bore / stroke	110 / 136 mm
Max. power	220 kW @ 2,200 rpm
Max. torque	1,000 Nm (1,400 – 1,600 rpm)
Operation strategy	Lean-burn engine
H ₂ -injection	PFI (each cylinder)
Turbo charging technology	VTG
Consumption	~ 4 – 12 kg/h H ₂ depending on use
H ₂ purity	min. 98% or higher ISO 14687
Certification	EU Stage V - CO ₂ -free*



EU Stage V
certified

➤ Certified and robust DEUTZ TCG 7.8 H2 base engine

Piston Technologies



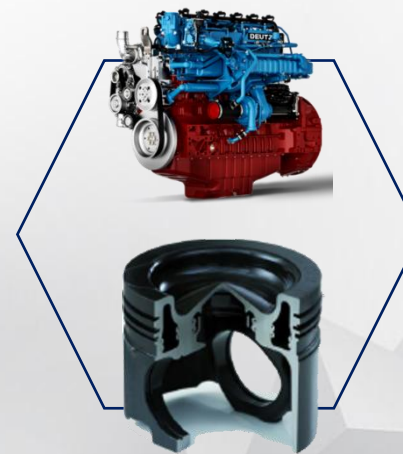
TopCast (Aluminium)



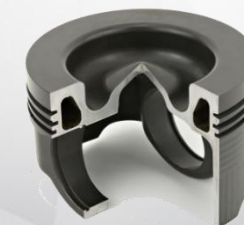
MonoCast (NCI)



MonoTherm (Steel)



MonoWeld (Steel)



MonoLite (Steel)

Robustness and performance potential

> Paving the way for high efficiency and high-power hydrogen engines

Steel Piston Approach

Approach

- Derive MonoWeld steel piston from series aluminium piston
 - Compensate differing thermal expansion to carry over ring pack
 - Maintain low blowby and LOC level

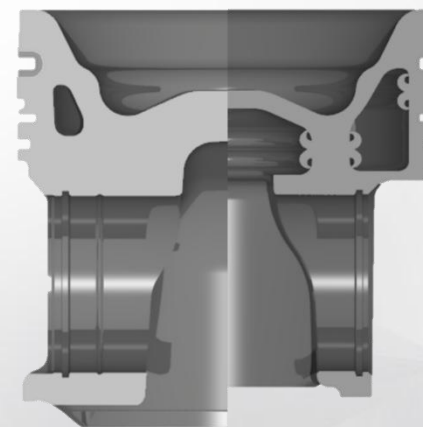
Results

- Ring pack for aluminium piston carried over to steel
- Max. overall piston temperature increase of ~70K
- Max. local piston temperature increase of ~100K at bowl center
- Steep temperature gradient on steel piston

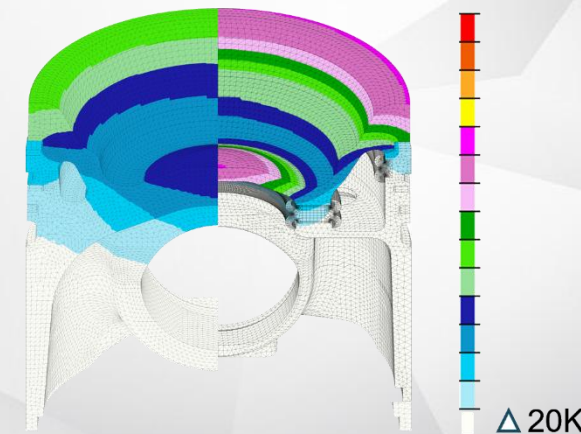
➤ Blowby/LOC maintained with increased piston peak temperature
→ Impact of piston temperature on combustion isolated



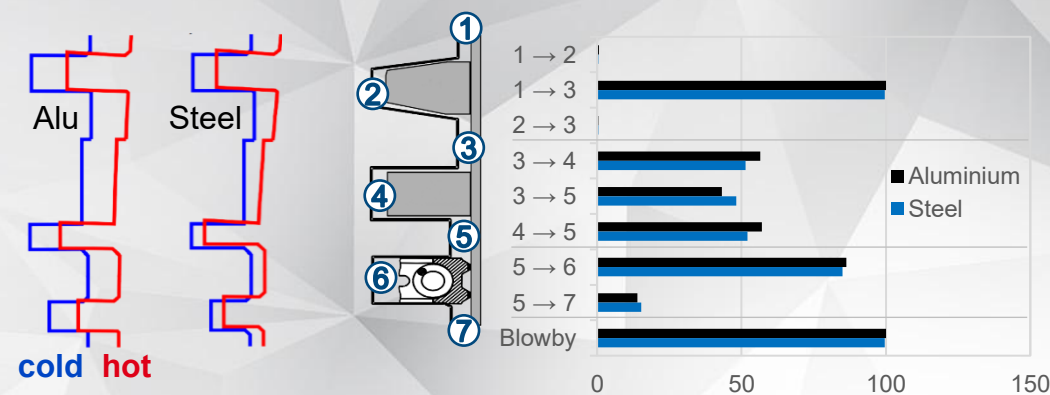
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Cross section of the aluminium piston (left) and steel piston (right)



Piston temperatures simulated at peak power 225kW



Thermal expansion and blowby comparison of aluminium and steel piston

RTM Methodology and Test Campaign



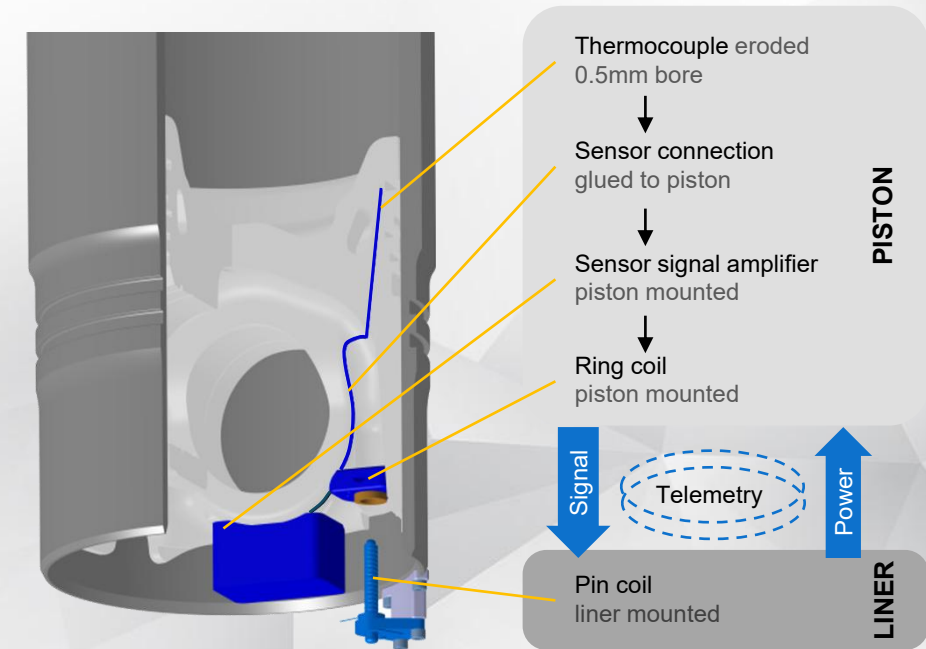
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Methodology

- Aluminium and steel piston equipped with Real Time Telemetry (RTM) to measure component temperatures
- Measurement position on comparable locations for aluminium and steel

Test campaign

- Engine map
- Full load curve
- Spark sweep
- EGR sweep
- Coolant sweep
- Transient load steps



RTM setup and signal processing schematics



RTM measurement to understand the impact of aluminium and steel material on piston temperature and combustion anomalies

Aluminium vs. Steel Piston: Piston Temperatures



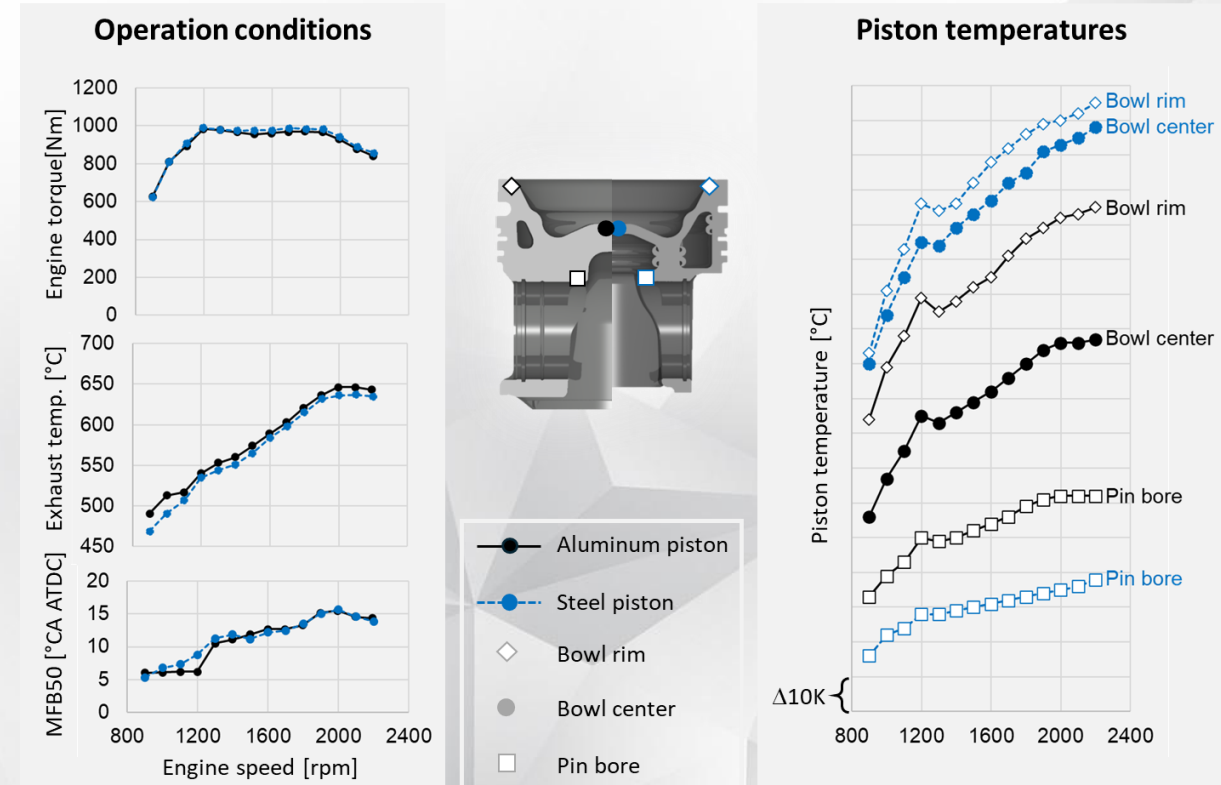
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Methodology

- Full load piston temperature comparison
- Engine calibration not adapted

Results: steel piston vs. aluminium

- No apparent impact on performance and combustion
- Max. piston temperature ~30K hotter
- Bowl rim and bowl center on comparable level – hot surface toward combustion bowl increased
- Increased temperature gradient (combustion chamber to pin bore)



Steel piston temperature significantly higher, but engine performance & combustion process not affected

Aluminium vs. Steel Piston: Piston Temperatures



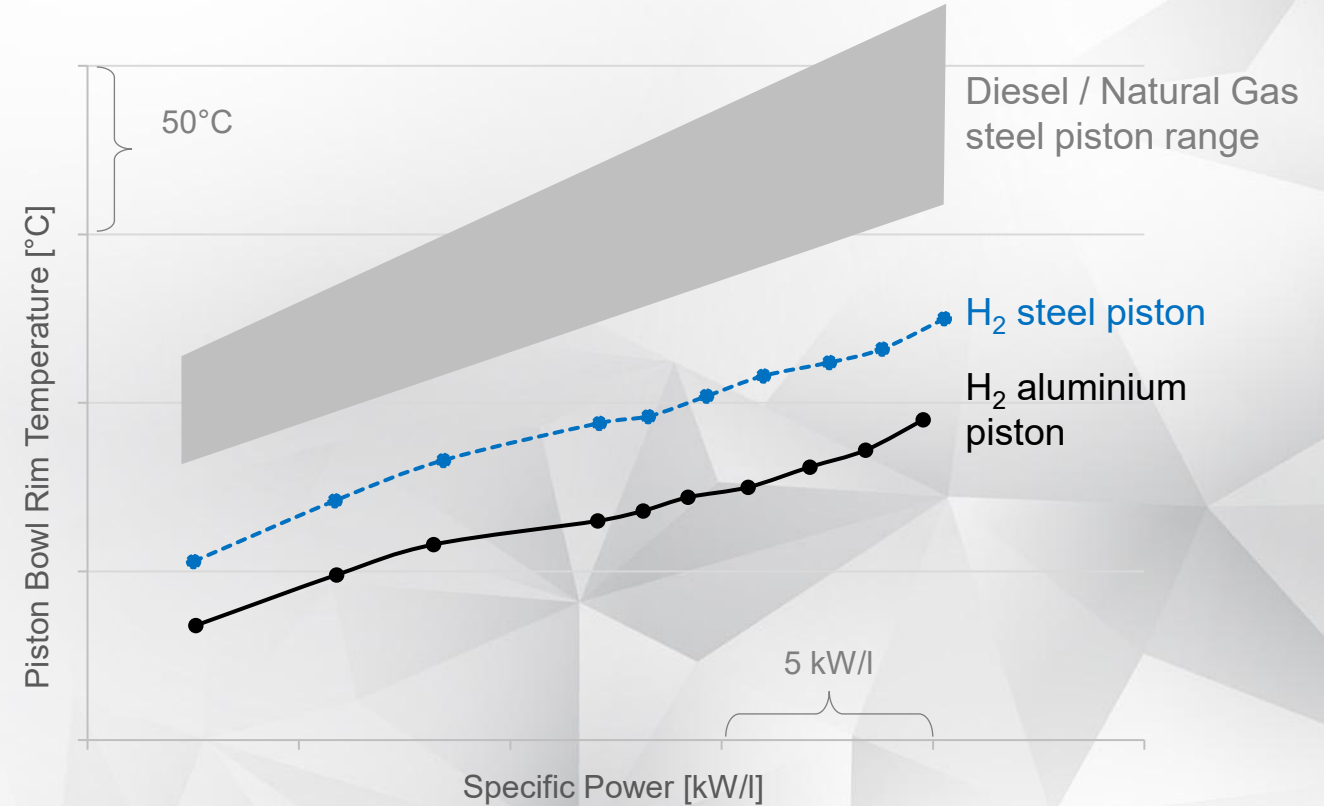
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Piston temperature level

- Piston temperature over engine platforms can be compared when plotted over specific engine power
- Almost linear temperature behaviour
- Significant temperature gap between Diesel and H₂ steel piston temperature



Temperature level significantly below Diesel and Natural Gas – wide piston technology portfolio to choose from

Aluminium vs. Steel Piston: Spark Sweep



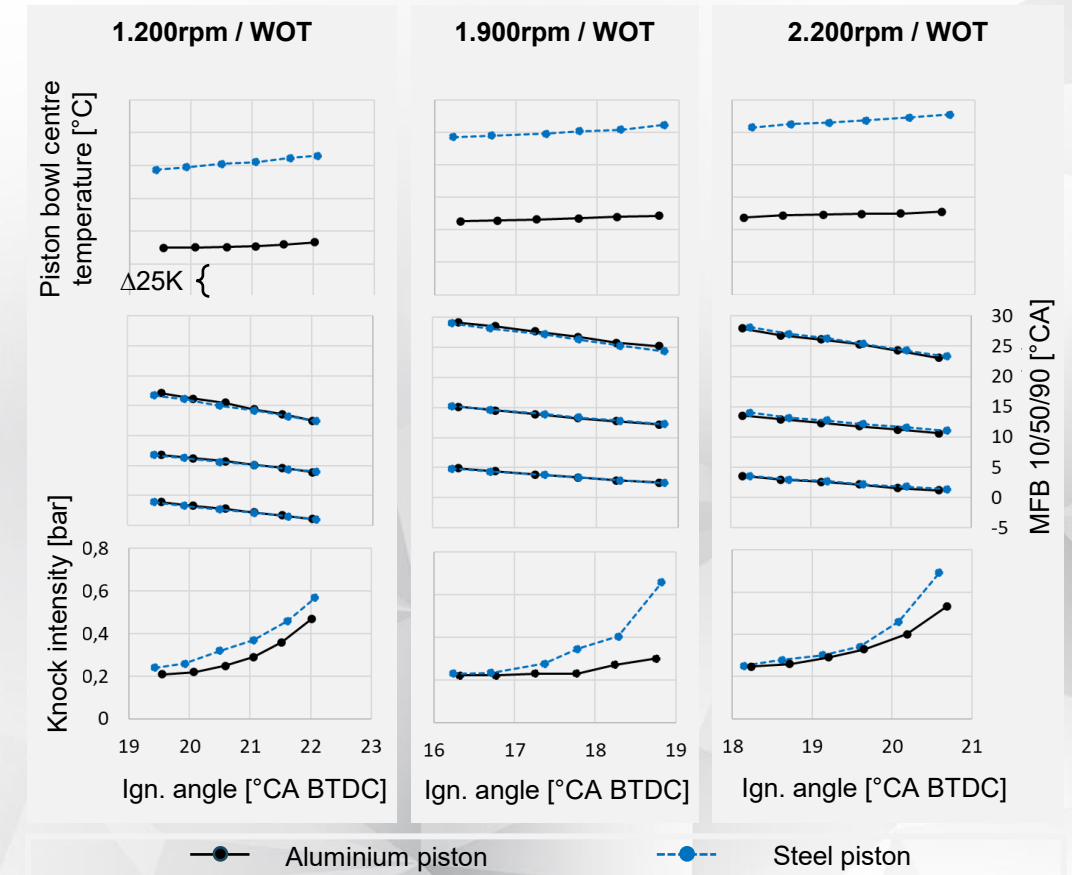
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Methodology

- Spark sweep at three full load operation points

Results

- Temperature increases with advanced spark timing
- Steel piston temperature on higher level and steeper gradient
- Knock intensity for both piston materials comparable at standard spark timing
- Similar knock intensity ramp-up with advanced spark timing
- Center of combustion comparable
 - Pre-ignition can be ruled out
 - Observed phenomenon is knock



Aluminium & steel piston lead to comparable combustion behaviour, however marginally higher knock intensity for steel with advanced spark

Aluminium vs. Steel Piston: Coolant Temperature Sweep



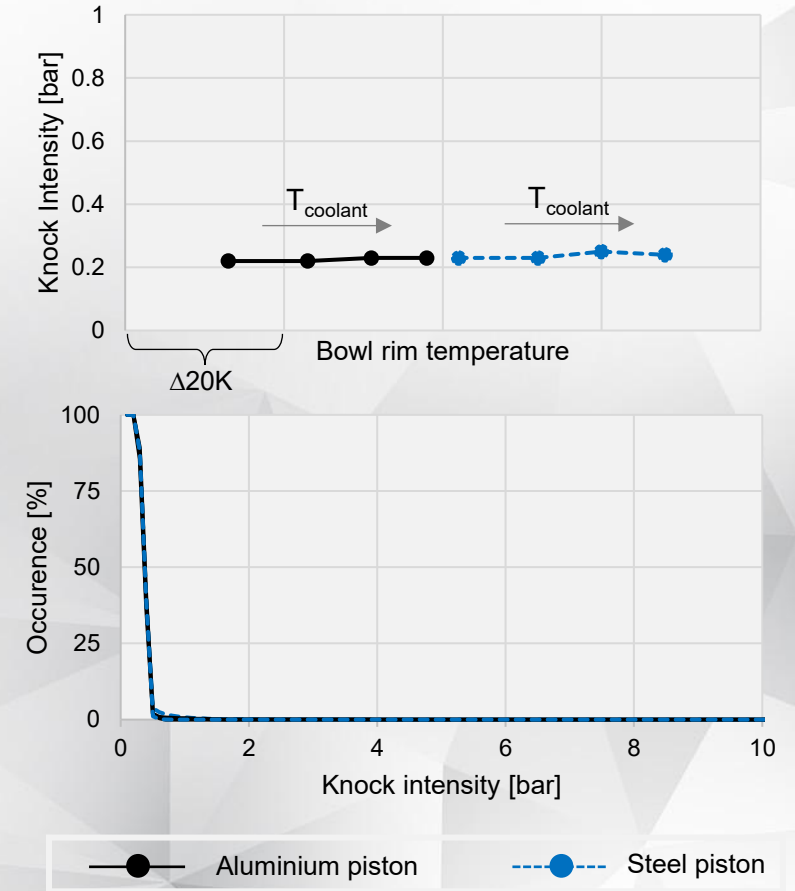
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Methodology

- Variation of engine coolant temperature from 70°C to 100°C
- Narrow down the root cause for marginally higher knock propensity of steel piston

Results

- Close to direct linearity between coolant temperature sweep and piston temperature (bowl rim)
- Impact on knock intensity negligible



> The piston temperature range for aluminium and steel pistons is below the threshold for combustion anomalies

Material

03



Hydrogen Embrittlement



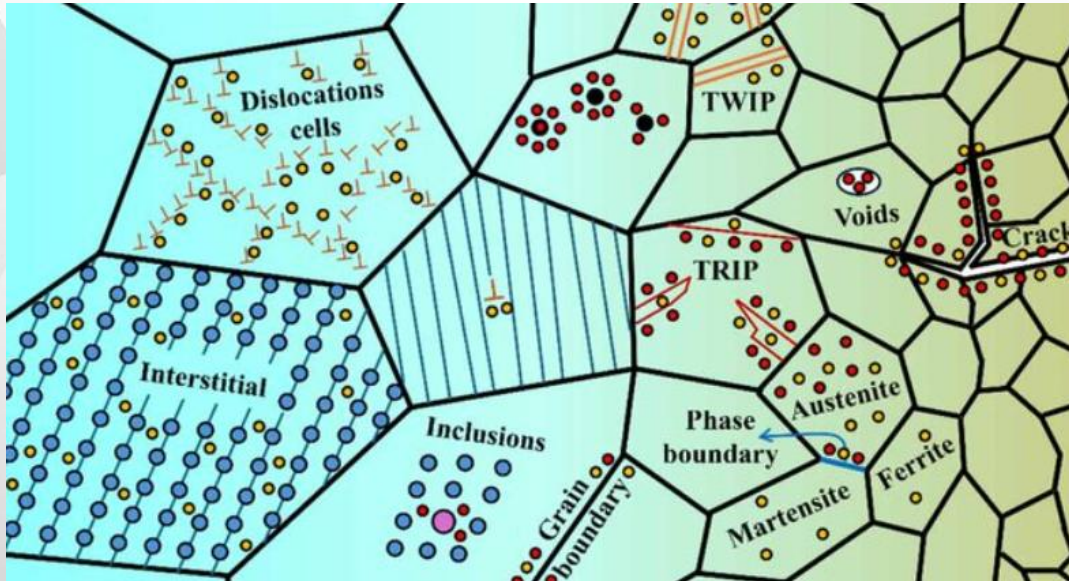
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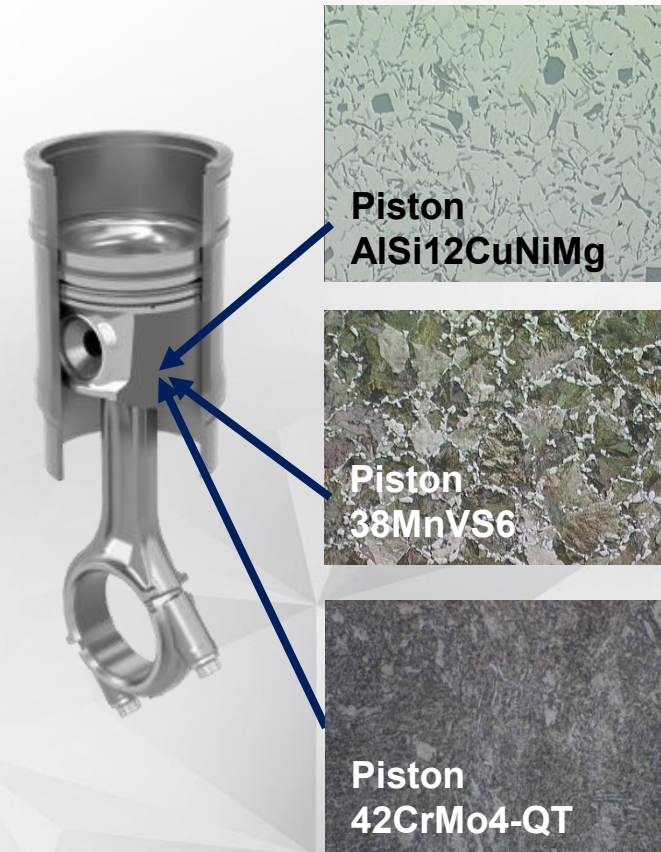
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● Diffusible hydrogen

● Trapped hydrogen



Source: Elucidating the influence of alloying elements on hydrogen embrittlement in steels through machine learning-aided property prediction



➤ Diffusible und reversible trapped hydrogen plays the major role for material embrittlement

Slow Strain Rate Tests (SSRT)



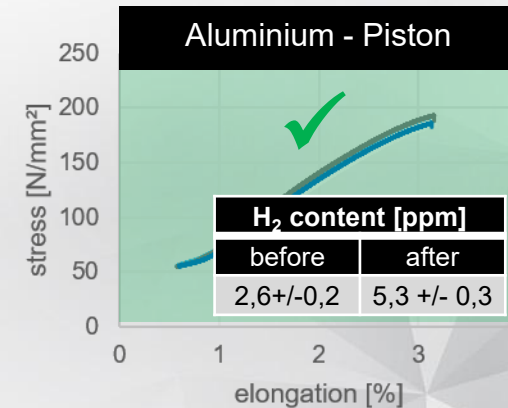
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Approach

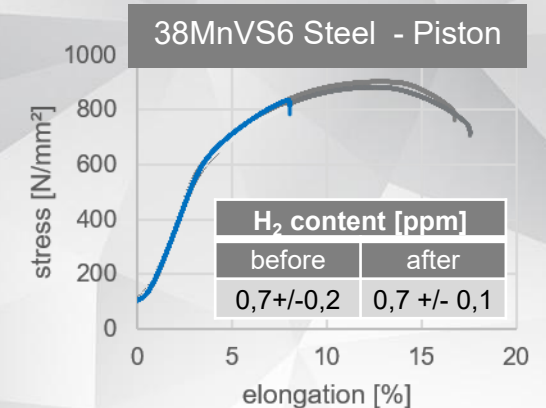
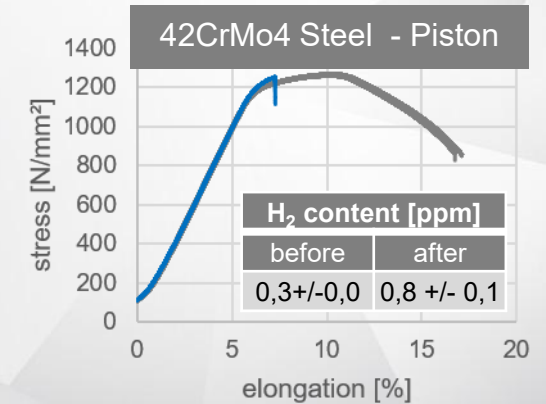
- SSRT to evaluate the impact of hydrogen on material properties
- Test procedure
 - Loading: H_2 or air at 250°C / 100bar / 100h
 - SSRT: H_2 at 20°C / 100bar / $1 \times 10^{-6}/\text{s}$ - $1 \times 10^{-5}/\text{s}$

Results

- All materials showed severe hydrogen impact – apart from aluminium
- Up to 88% reduction in ductility
- Hydrogen uptake observed in all materials
 - Higher for aluminum and Cast Iron
 - Smaller for steel alloys



— H_2 at 250°C / 100bar / 100h
— Air at 250°C / 100bar / 100h



➤ H_2 impact on ferritic / martensitic steel despite low H_2 uptake

Hydrogen Uptake During Engine Operation



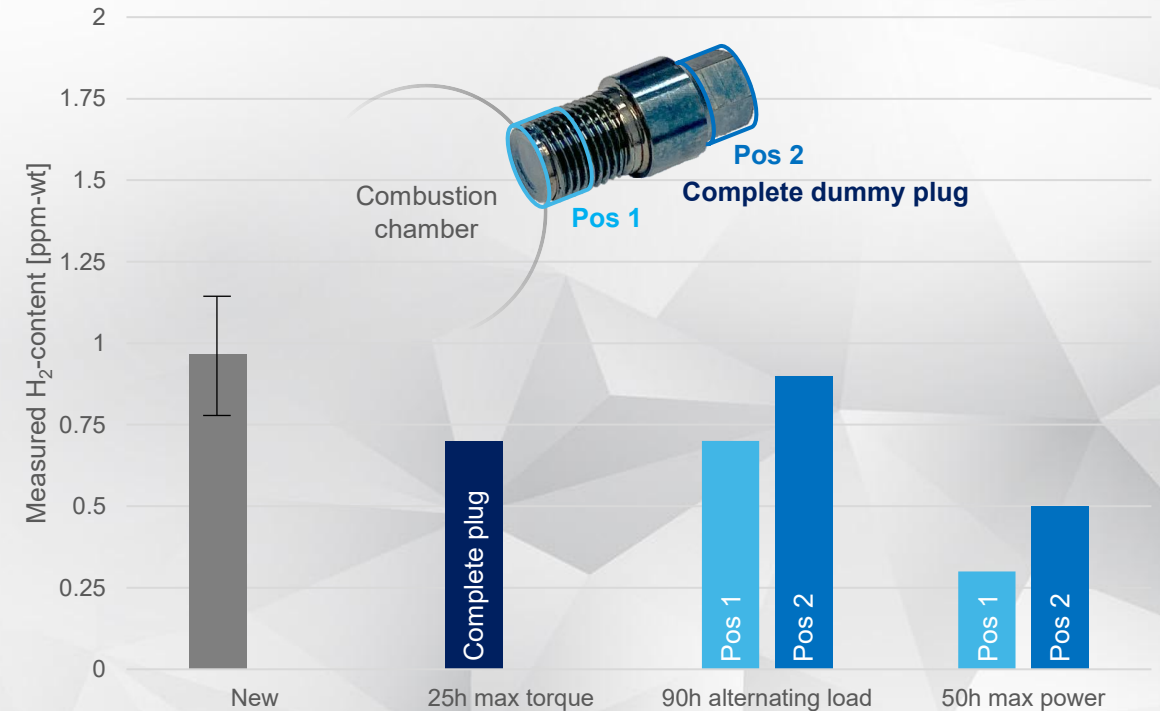
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Approach

- Pressure transduced of one cylinder replaced by dummy plug
- Material: Nireva - known for a high hydrogen uptake
- H₂ content measured after multiple engine tests via thermal desorption spectroscopy (TDS) at 780°C

Results

- Different trapping mechanisms can be seen in TDS as expected
- H₂ concentration in dummy plug after operation lower than parts w/o exposure to combustion atmosphere



H₂ content measurement suggest no hydrogen uptake during operation – simulation ongoing to show H₂ distribution close to surface

Summary

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No H₂ uptake in combustion atmosphere observed – confirmed by no H₂ related field failure

Temperature level for both – aluminium and steel - below Diesel and Natural Gas

Steel piston is preferred technology for high load applications

Impact on combustion anomalies is negligible

More robust against combustion anomalies

Enabler for higher peak cylinder pressures

Flexibility in geometry offers further thermodynamic potential

➤ Diesel-like robustness & performance can be achieved with improved PCUs



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