Ignition of hydrogen due to friction

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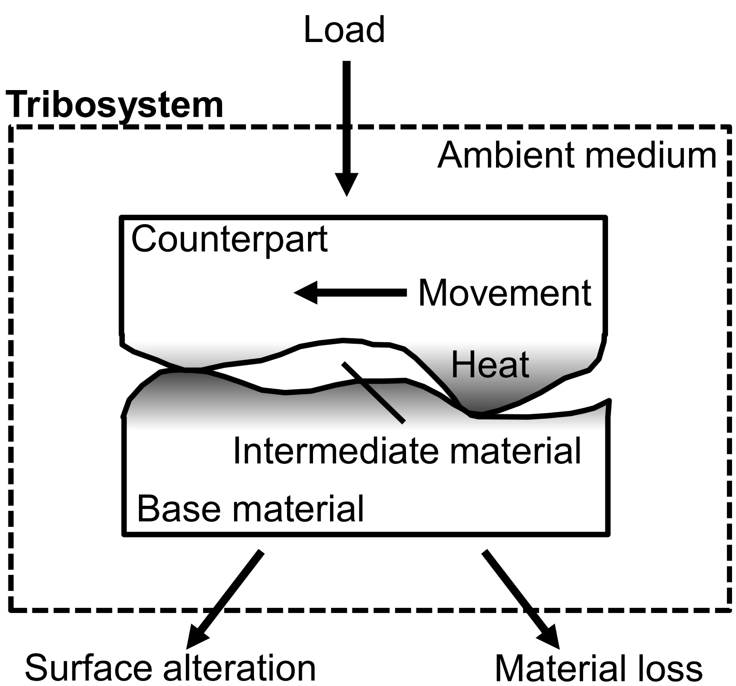
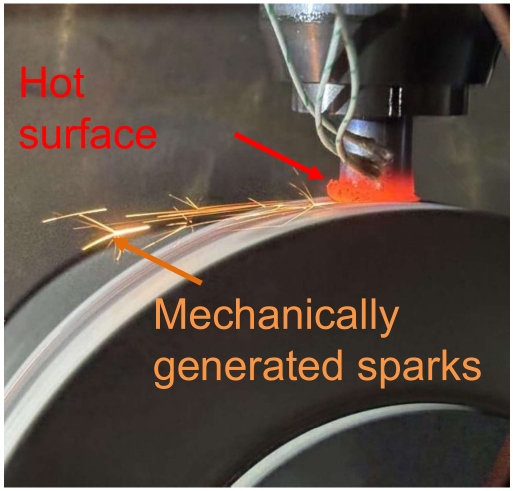
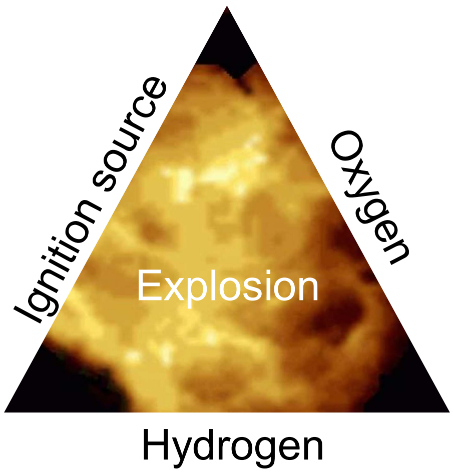
Introduction

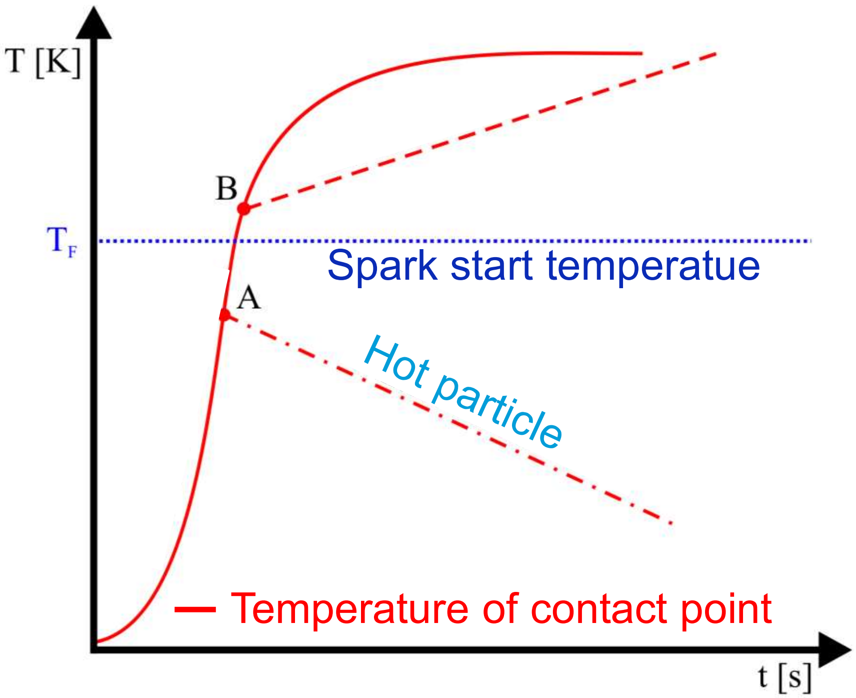






Mechanically generated sparks

Difference between „Hot particles“ and „Mechanically generated sparks“



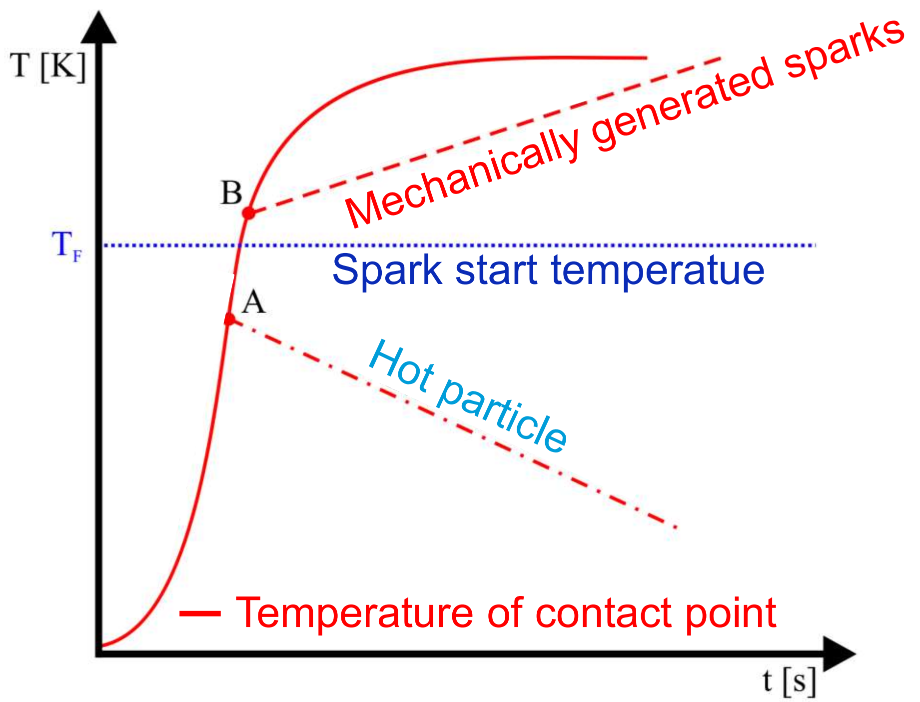
Reference: MEYER, L. Die Entstehung von heißen Oberflächen in metallischen Reibsituationen und ihre Zündwirksamkeit: PTB-Bericht PTB-Ex-9, Dissertation. Magdeburg, 2018

Hot paricle:
Temperature of contact point < T_F
→ no exothermic reaction
→ cools down during flight
→ no ignition known due to hot particles

Below T_F:
Ignitions are only possible due to hot surfaces

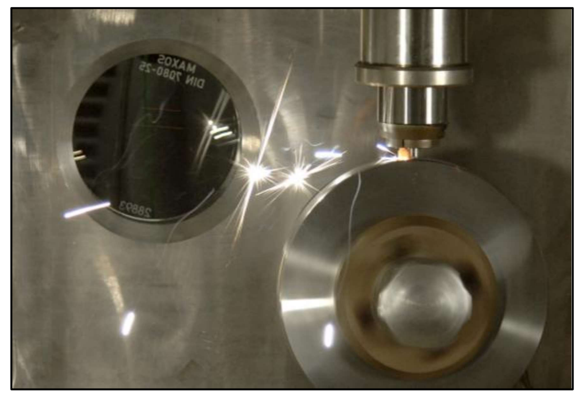
Mechanically generated sparks

Difference between „Hot particles“ and „Mechanically generated sparks“

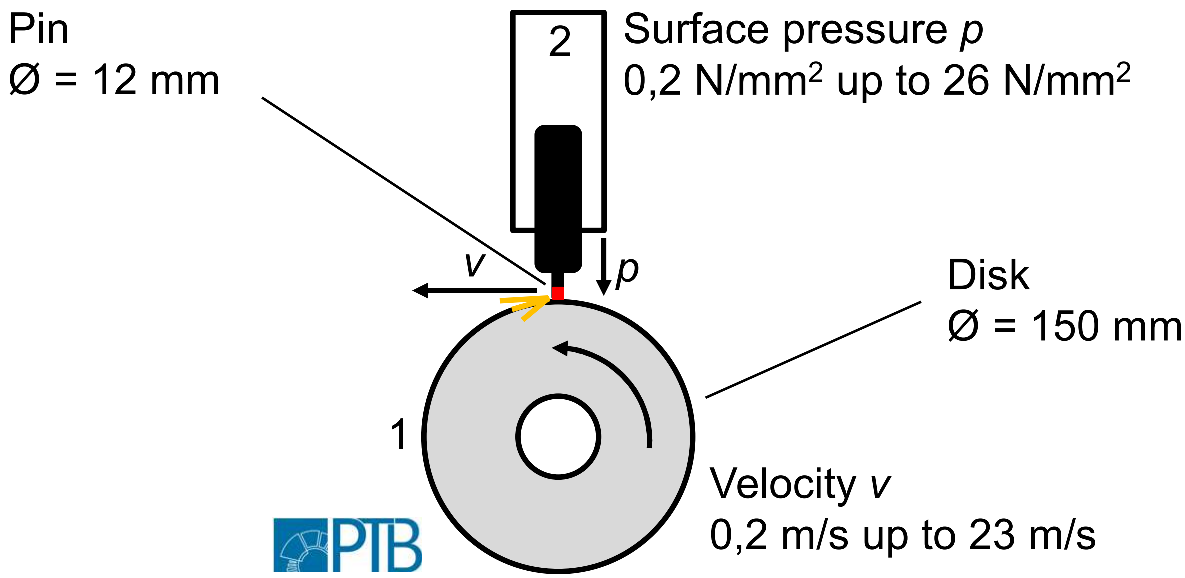


Reference : MEYER, L. Die Entstehung von heißen Oberflächen in metallischen Reibsituationen und ihre Zündwirksamkeit: PTB-Bericht PTB-Ex-9, Dissertation. Magdeburg, 2018

Mechanically generated sparks :
Temperature of contact point > T_F
→ Sufficient energy for an exothermic reaction
→ Rise in temperature up to over 900 °C
→ Ignition

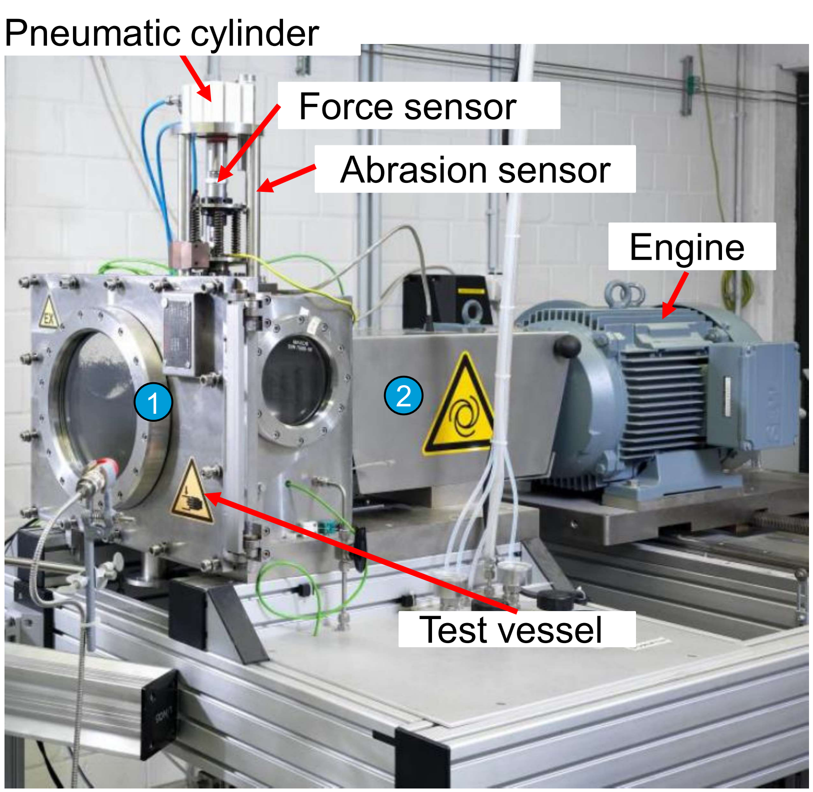


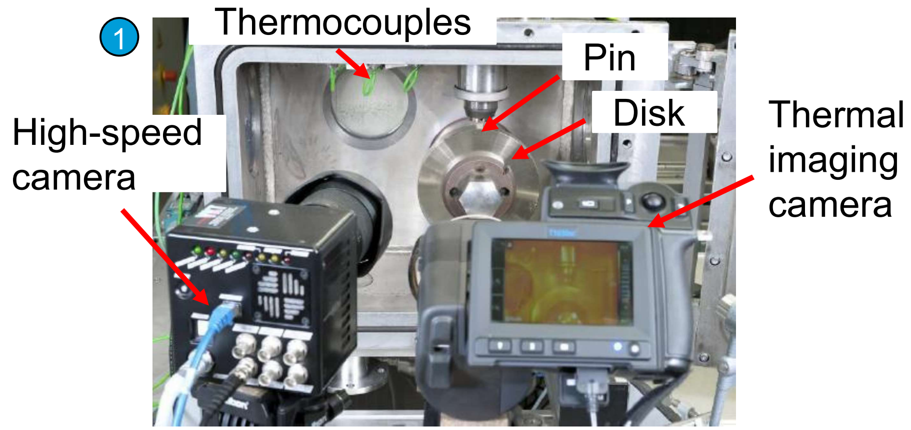
Set up for experiments

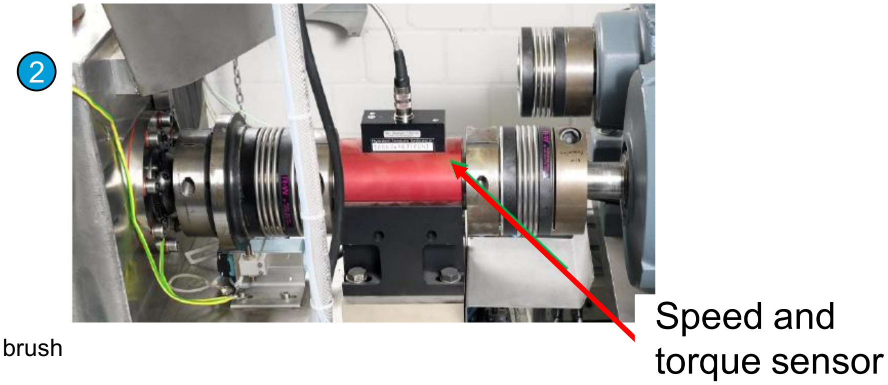


1: Rotating disk mounted on a shaft
2: Cylinder for applying contact pressure

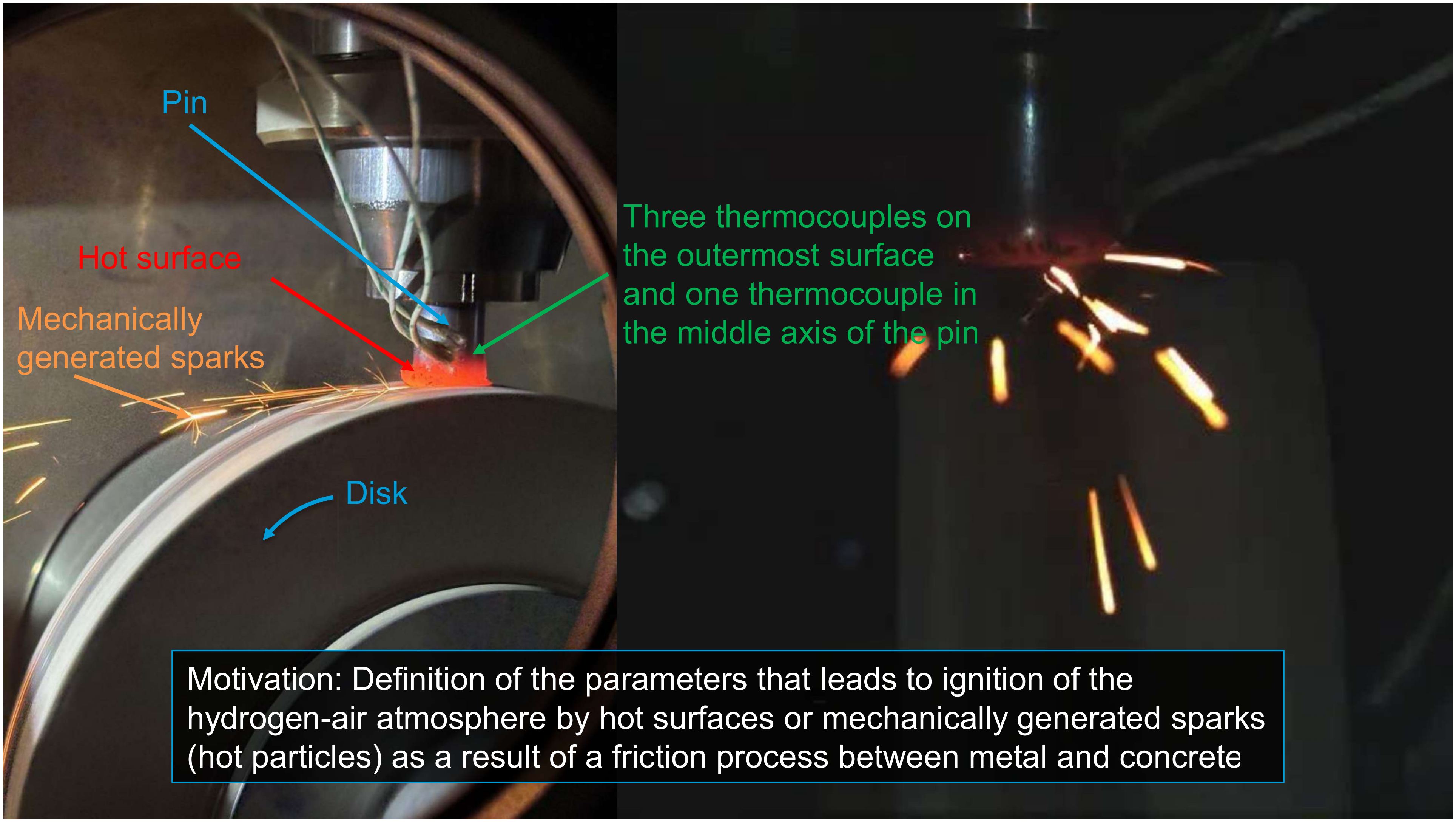
Set up for experiments







Reference: Aguilera Cabezas, F. J. (2022): Non-spark and conventional metarials for brush cutters: mechanical and thermal behavior. Master-Thesis PTB/Universidad Se Sevilla



Motivation: Definition of the parameters that leads to ignition of the hydrogen-air atmosphere by hot surfaces or mechanically generated sparks (hot particles) as a result of a friction process between metal and concrete

Material combinations

PTB - Concrete

Cut from paving slabs using a water jet cutter

BAM - Concrete

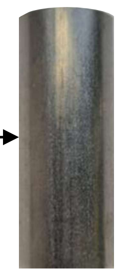
Additive 81% (Okrilla quartz sand, various grain sizes)
12% Cement
6,8 % Water
0,2 % Flow agent

BAM - Concrete

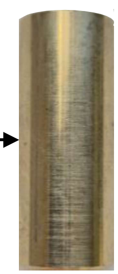
With 5% Corundum

vs.

Mild Steel
1.0038



Stainless Steel
1.4541



Aluminium Bronze
(AMPCO 45)

Challenges - Concrete

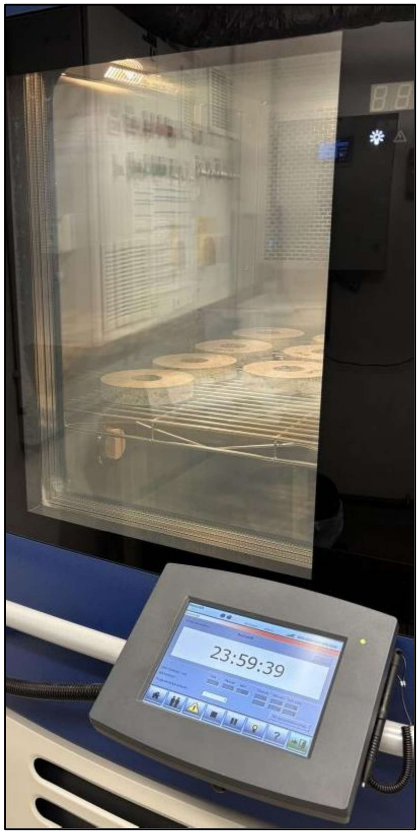
Aim:
Constant start conditions

Problems:
- High humidity and condensation in the test vessel due to the release of pore water from the concrete disks
  (experiment without hydrogen)

Solutions:
- Drying the concrete disks (24 h at 120 °C)

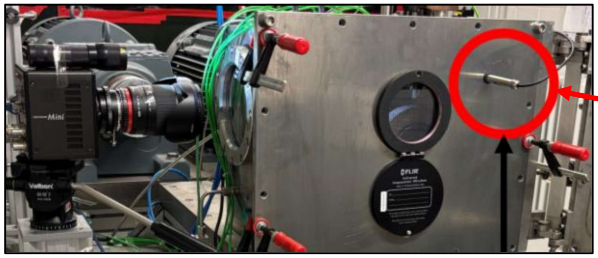
→ Weight loss up to 24 g

Note: Another drying cycle will not result in any further weight loss



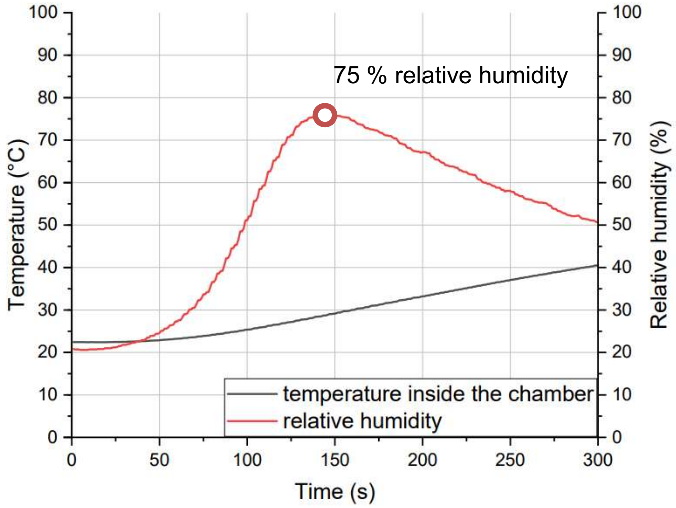
Challenges - Concrete

Experiment with mild steel (1.0038),
v = 5 m/s, *p* = 2 N/mm²

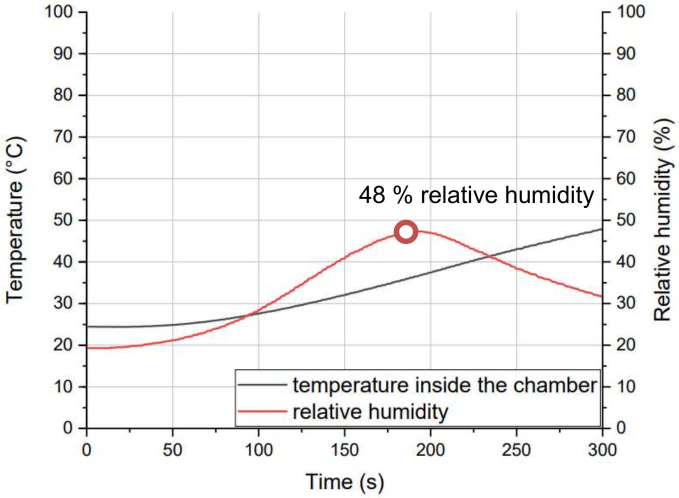


Sensor for
humidity and temperature

Not dried PTB-Concrete-Disk

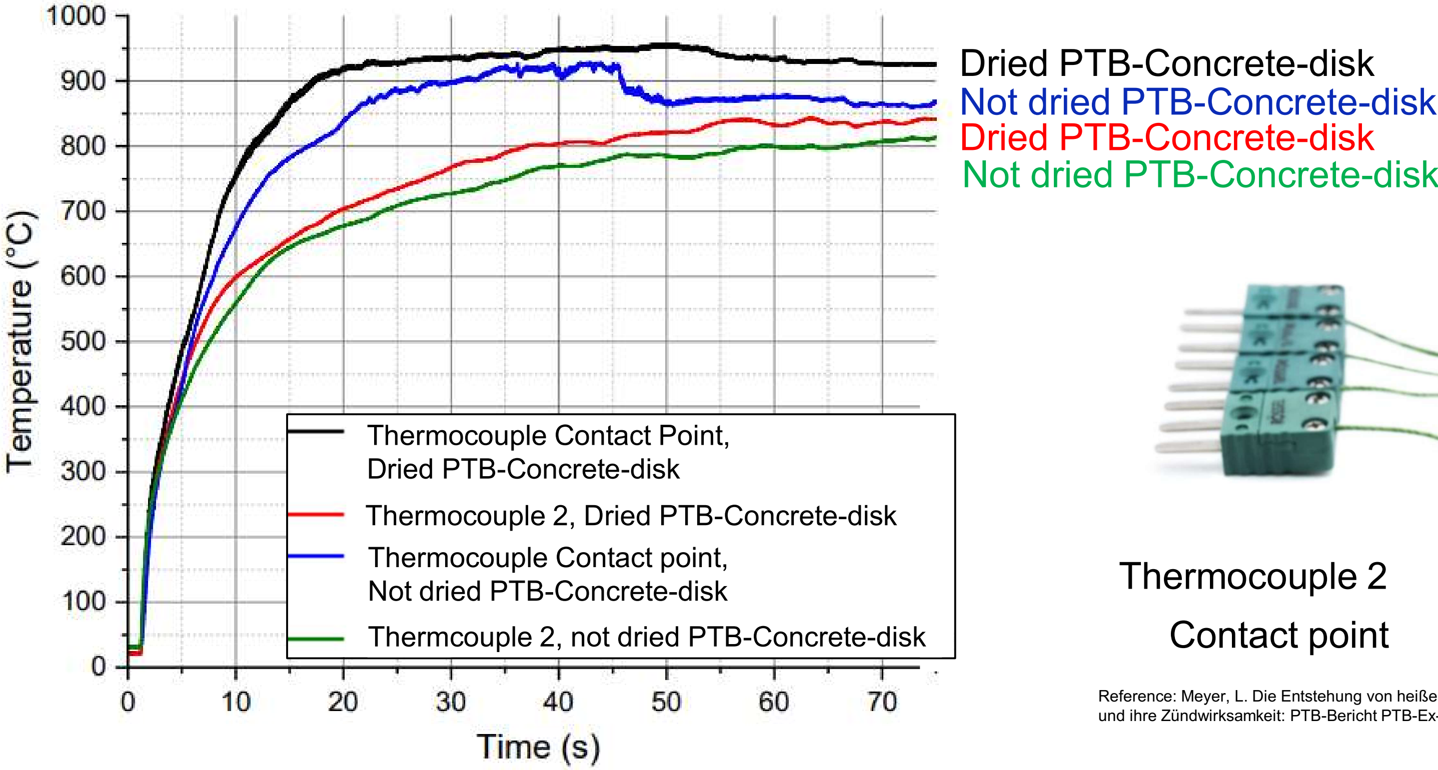


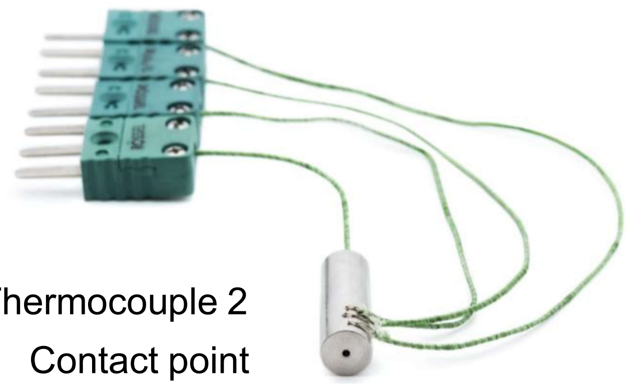
dried PTB-Concrete-Disk



Challenges - Concrete

Experiment with PTB-Concrete (disk) and mild steel 1.0038 (pin), v = 5 m/s, p = 5 N/mm²





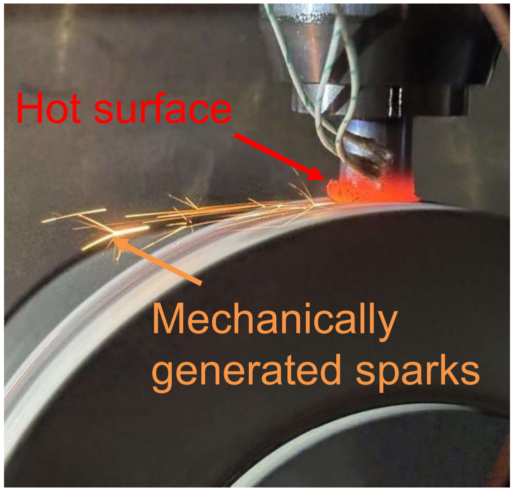
Thermocouple 2

Contact point

Reference: Meyer, L. Die Entstehung von heißen Oberflächen in metallischen Reibsituationen und ihre Zündwirksamkeit: PTB-Bericht PTB-Ex-9, Dissertation. Magdeburg, 2018.

Hydrogen concentration

Why 10 Vol.-% of hydrogen in air, and not the stoichiometric mixture of 29.5Vol.-%?



Hot surface: Hydrogen has high heat conductivity (0.184 W/m·K at 20 °C) and can be used as a cooling medium
→ Concentrations below 29.5% Vol.-% result in earlier ignition

Mechanically generated sparks: The oxidation of the hot particles reduces the oxygen concentration and changes the mixture locally towards stoichiometric conditions

Verified by:

- Previous experiments using this test setup with 10 Vol.-%, 20 Vol.-% and 30 Vol.-% of hydrogen in air

Reference : - TITMAN, H.: The ignition of explosive gas mixtures by friction, 1954
- Welzel, F.: Die Entstehung von Zündquellen durch Reibvorgänge und deren Zündwirksamkeit in explosionsfähigen Gas/Luft-Atmosphären. 2014
- Meyer, L. Die Entstehung von heißen Oberflächen in metallischen Reibsituationen und ihre Zündwirksamkeit: PTB-Bericht PTB-Ex-9, Dissertation. Magdeburg, 2018

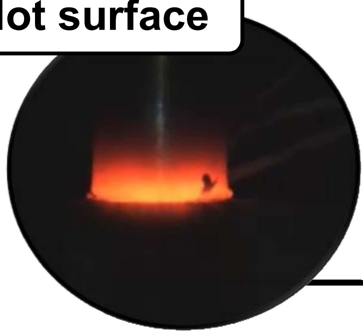
- Experiments on small hot surfaces

Reference : - Mevel, R.; Melguizo-Gavilanes, J.; Boeck, L. R.; Shepherd, J. E.: Experimental and numerical study of the ignition of hydrogen-air mixtures by a localized stationary hot surface. In: International Journal of Heat and Fluid Flow 76 (2019), pp. 154-169

Ignition source

The ignition source depends on the material:

Hot surface



PIN:
- Stainless Steel 1.4541
- Aluminium Bronze AMPCO45

vs.

DISK:
- PTB Concrete,
- BAM Concrete
- BAM Concrete with 5 % Corundum

Mechanically generated sparks

PIN:
- Mild Steel 1.0038

vs.

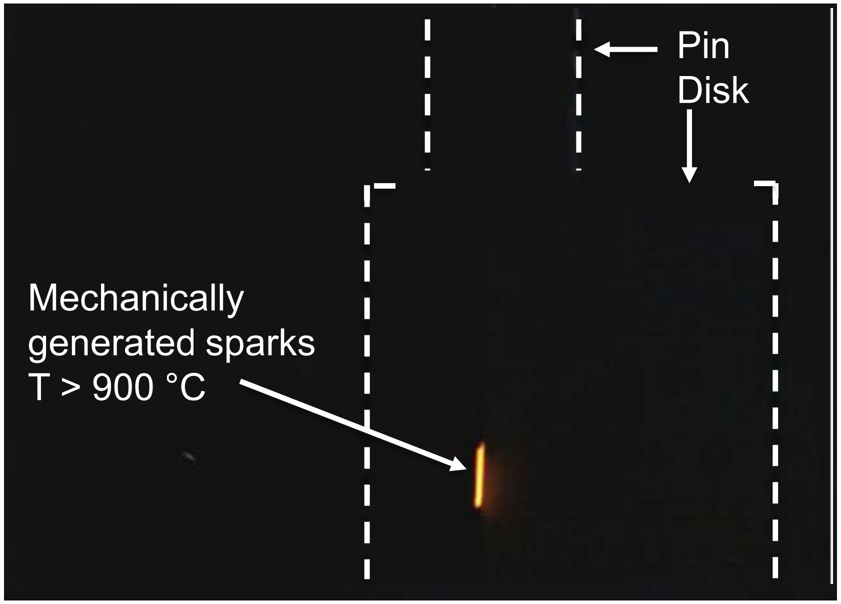
DISK:
- PTB Concrete,
- BAM Concrete
- BAM Concrete with 5 % Corundum

The corundum has no influence on the ignition source!

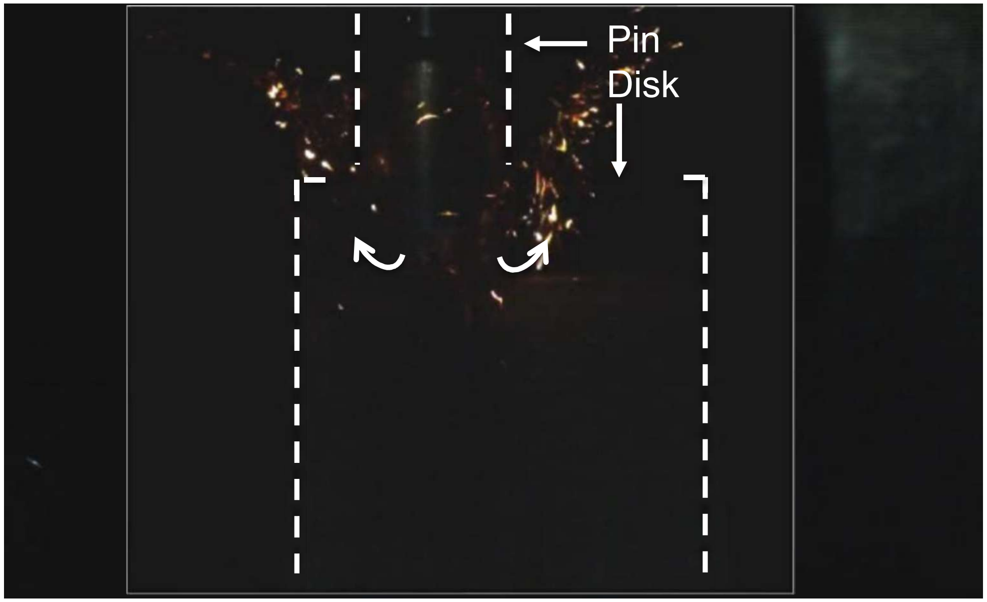
Ignition source

The ignition source depends on the material:

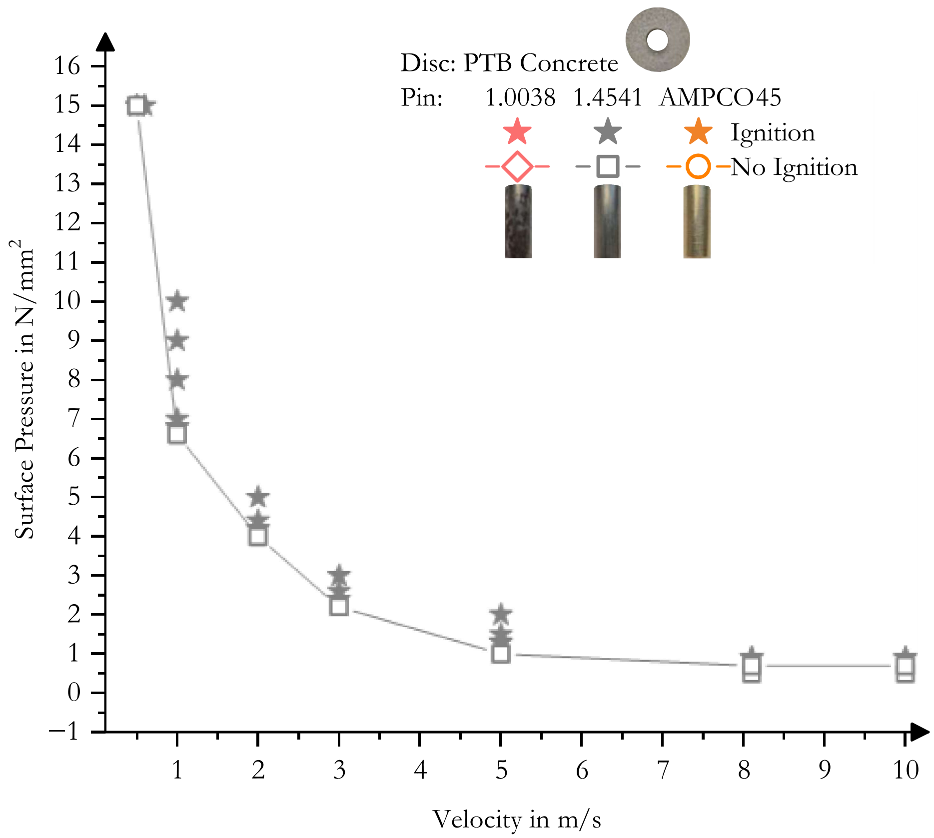
Mechanically generated sparks
and resulting explosion:
Concrete (disk) vs. Mild Steel 1.0038 (pin)



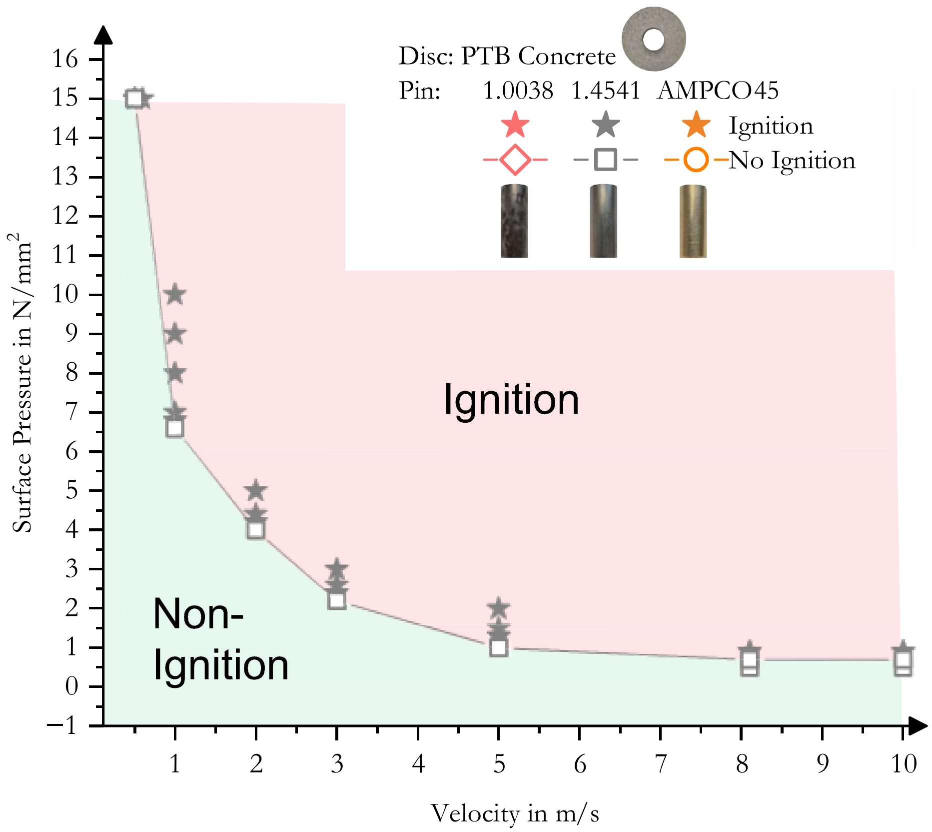
Explosion starts at the hot surface:
Concrete (disk) vs. Stainless Steel 1.4541 (pin) und
Concrete (disk) vs. Aluminium Bronze(pin)



Ignition limit curves

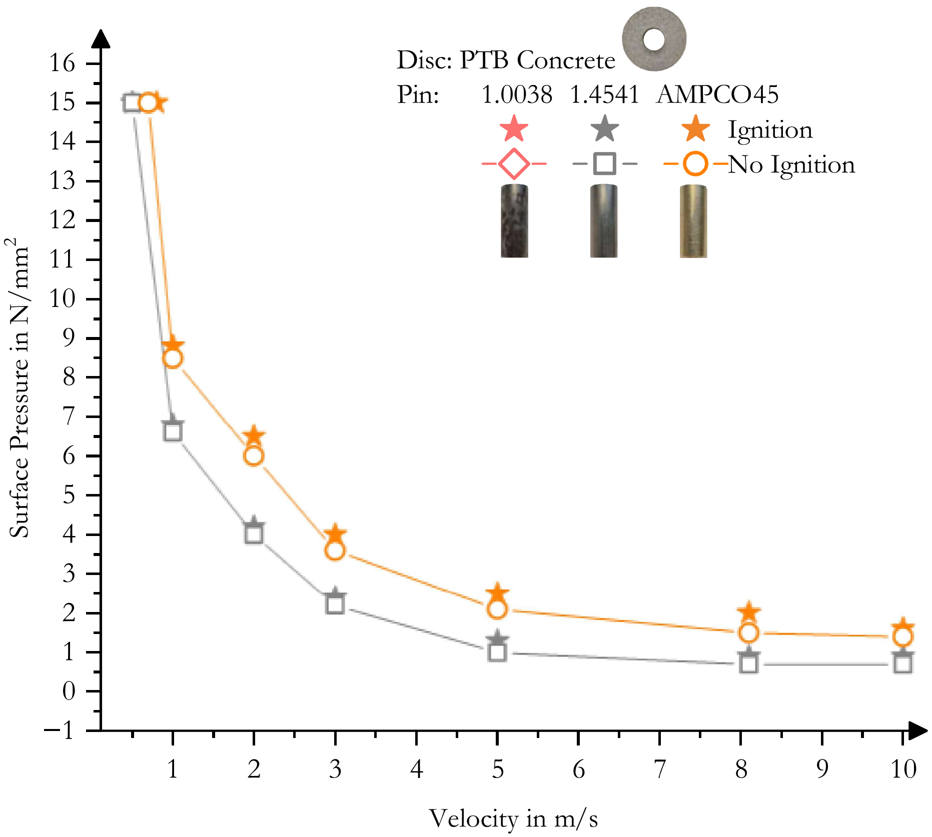


Ignition limit curves



Based on the Ignition limit curve, we can separate between an "Ignition" and "Non-Ignition" area

Ignition limit curves



Stainless Steel 1.4541 compared with Aluminium Bronze AMPCO 45:

Heat conductivity :

Stainless Steel 1.4541	15 W/m·K
Aluminium Bronze AMPCO 45	45 W/m·K

→ The lower heat conductivity of stainless steel causes ignition due to the hot surface at lower combinations of surface pressure and velocity.

Ignition source

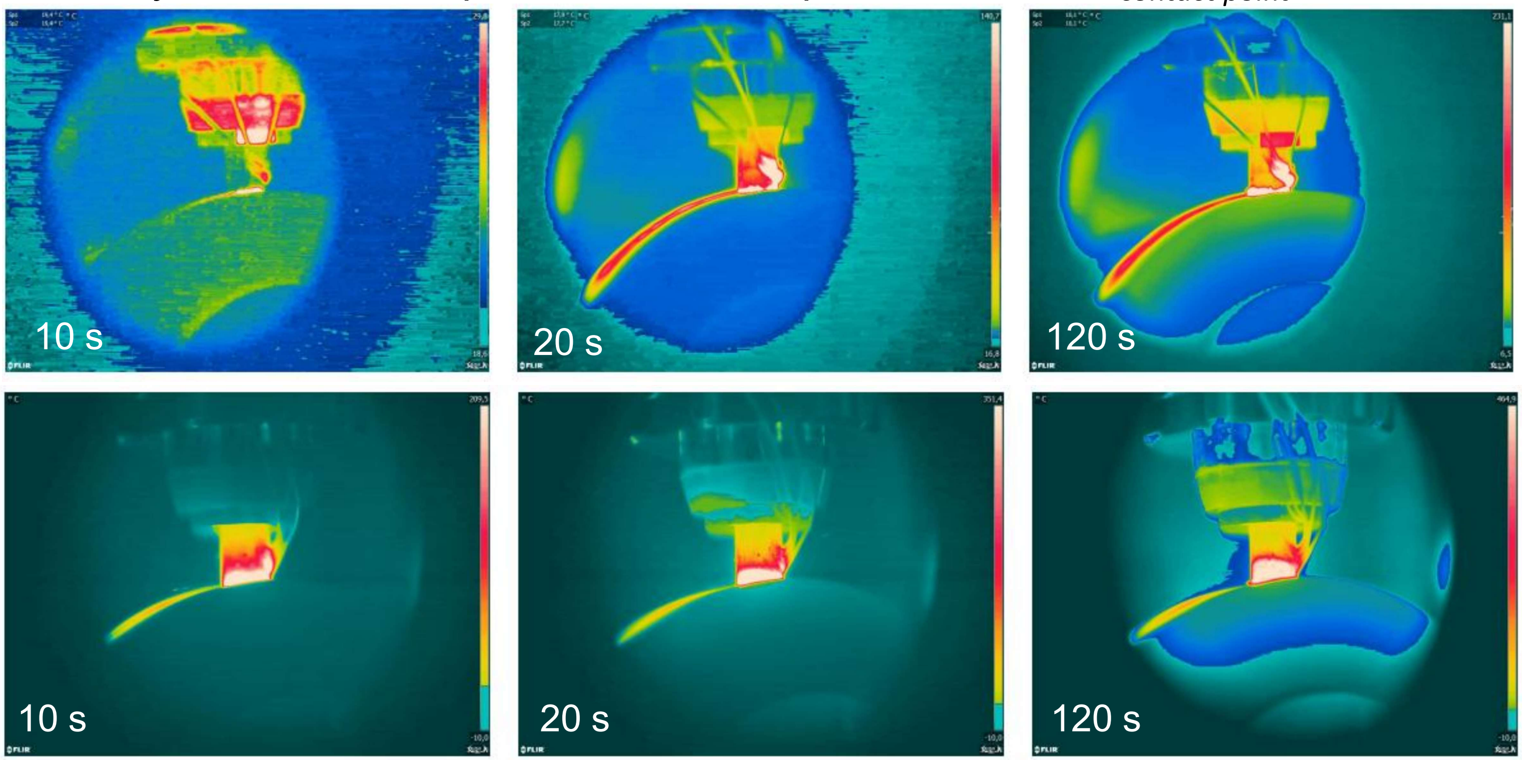
The temperature distribution depends on the material:

v = 5 m/s, p = 2 N/mm²

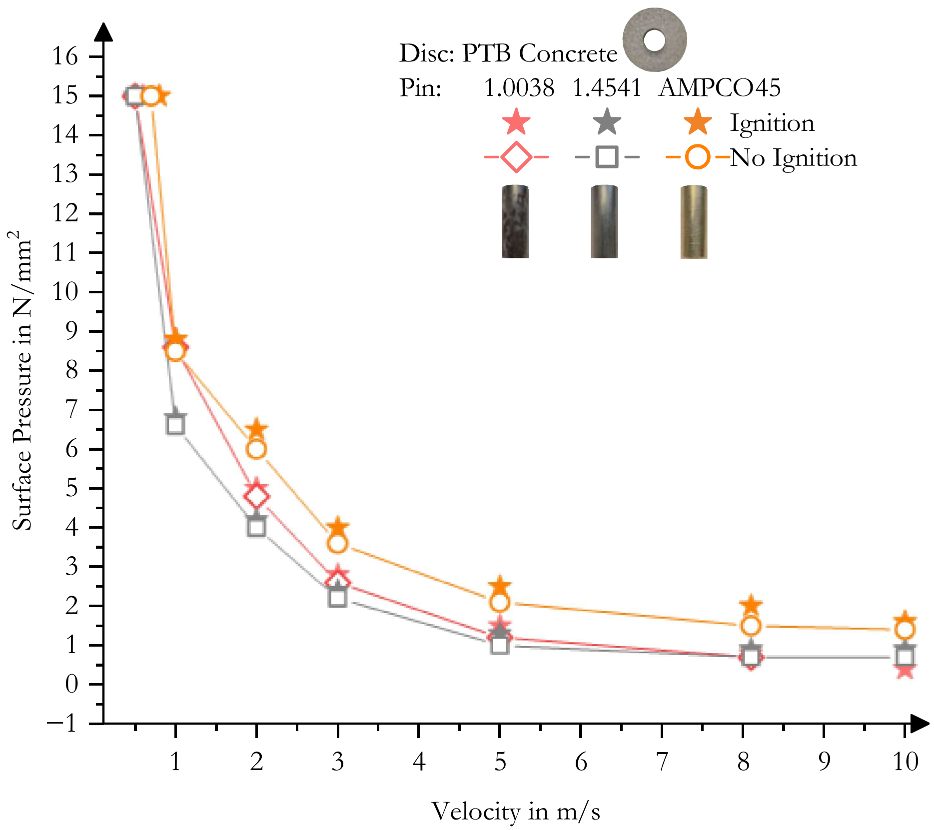
A lower heat conductivity leads to a hotspot at the contact point → $\lambda \downarrow = T_{contact\ point} \uparrow$

Aluminium Bronze AMPCO45
λ = 45 W/m·K

Stainless Steel 1.4541
λ = 15 W/m·K



Ignition limit curves



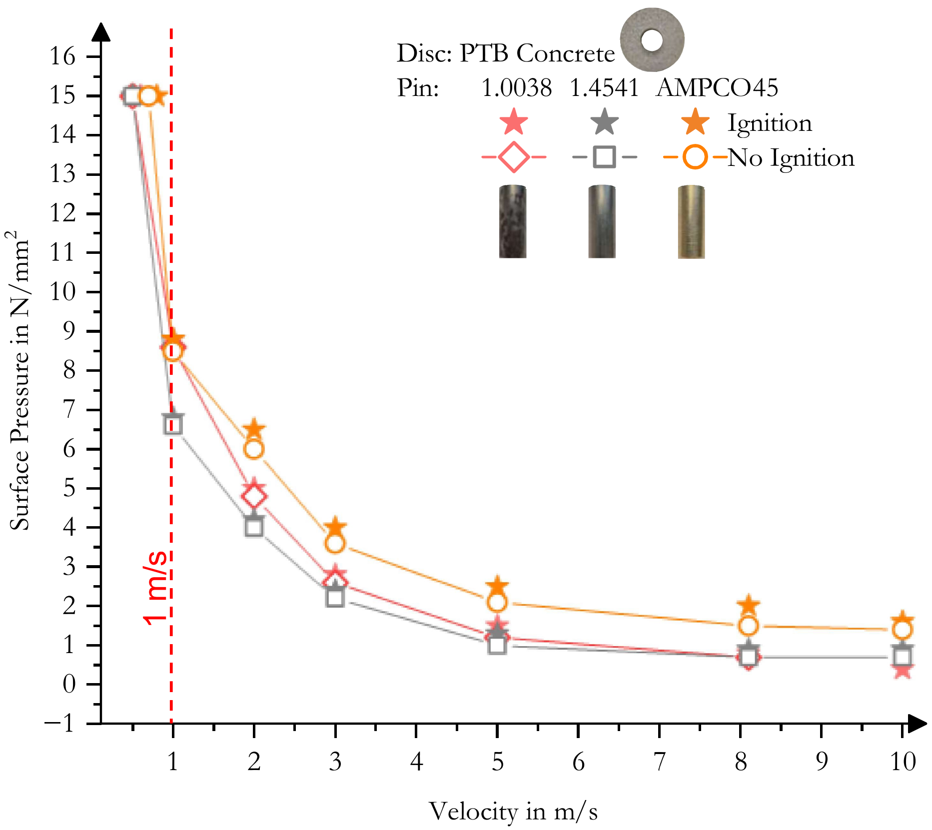
Stainless Steel 1.4541 and
Aluminium Bronze AMPCO 45
in comparison with Mild Steel 1.0038:

Heat conductivity :

Stainless Stell 1.4541	15 W/m·K
Aluminium Bronze AMPCO 45	45 W/m·K
Mild Steel 1.0038	60 W/ m·K

→ Mild Steel:
Due to its carbon content, it does not ignite from a hot surface, but rather from mechanically generated sparks

Ignition limit curves



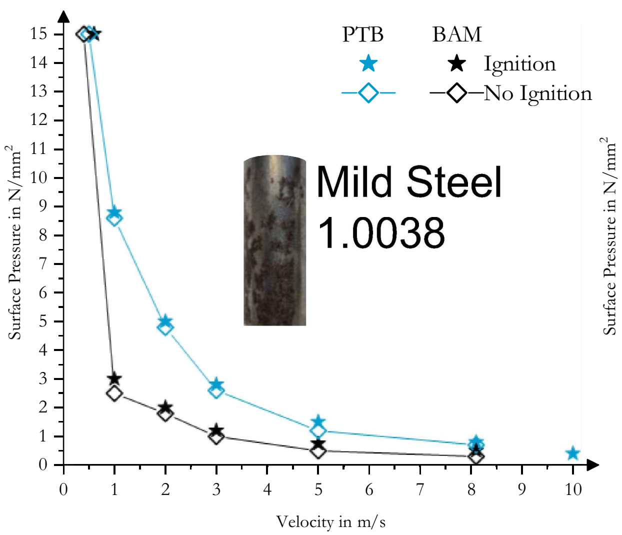
ISO 80079-36:2016:

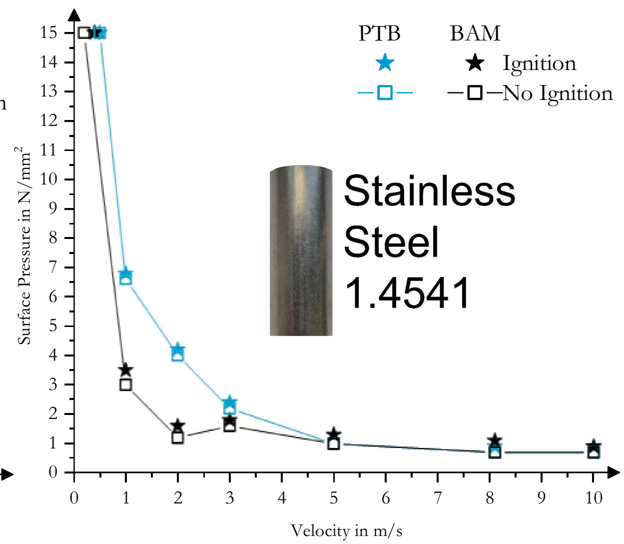
„A relative contact speed of 1 m/s is often used as the limit value below which friction ignition sources are not capable to ignite an explosive atmosphere. … There are a few exceptions, for example… explosive gas atmospheres such as hydrogen …, where there is a high contact load.„

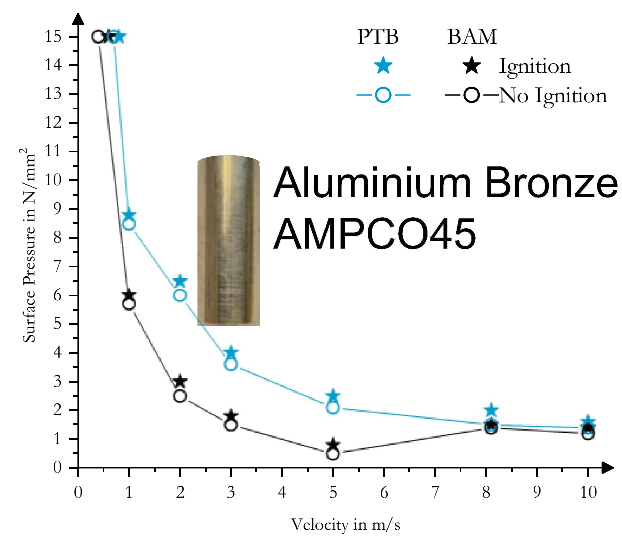
Ignition limit curves

PTB-Concrete

BAM- Concrete without Corundum



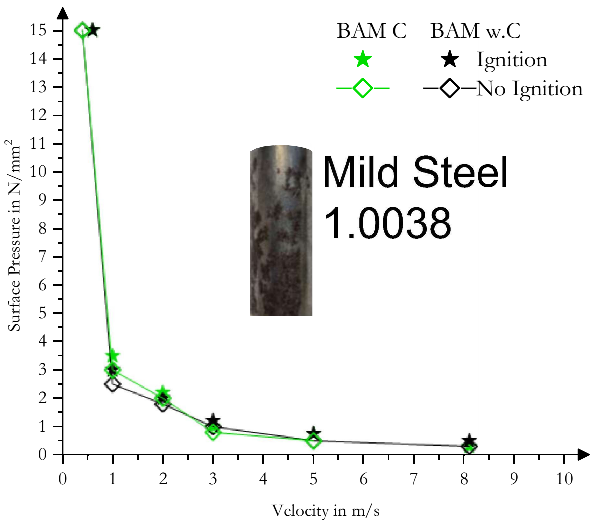


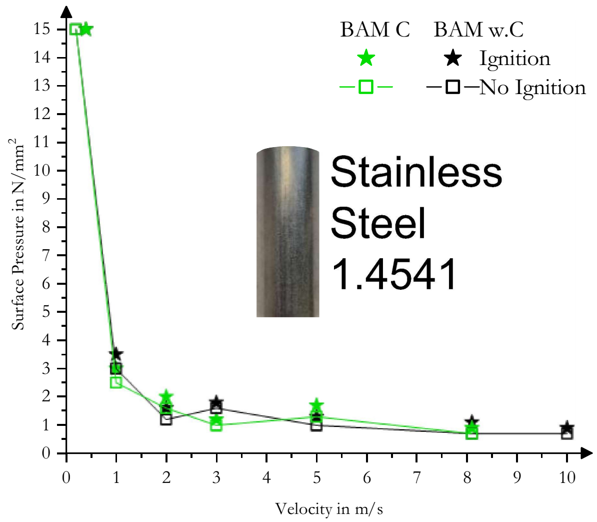


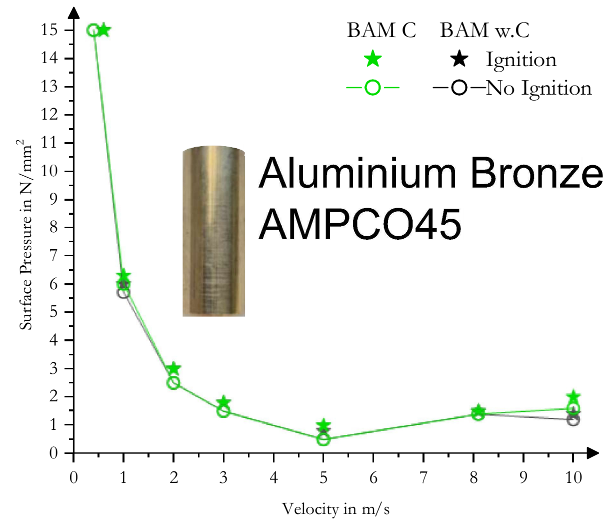
Ignition limit curves

BAM-Concrete
with 5% Corundum
(BAM C)

BAM-Concrete
without Corundum
(BAM w.C)





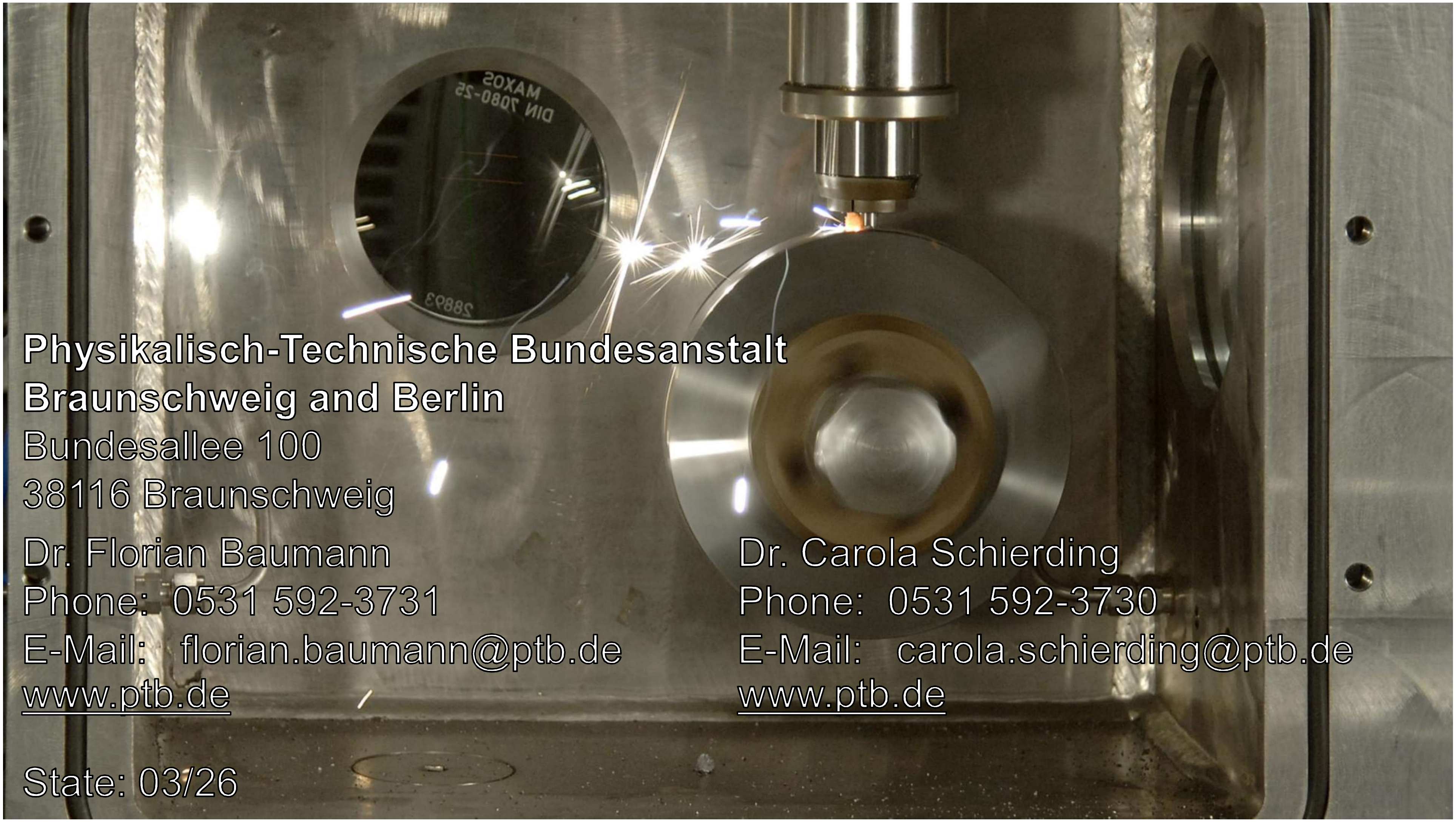


Conclusions


Applying concrete disks into the test setup:
- Pore water → Drying of the concrete disks (24 h at 120 °C)


The ignition source depends on the material:
- Mild Steel 1.0038 → Mechanically generated sparks
- Stainless Steel1.4541 & Aluminium Bronze AMPCO45 → Hot surface

Ignition limit curves (surface pressure over velocity):
- Determined for material combinations of Metal (pin) and Concrete (disk)
- Stainless steel has low heat conductivity (15 W/m·K) and is more inclined to form hot surfaces than Aluminium Bronze (45 W/m·K)
- Ignition is possible at velocities below 1 m/s with high surface pressures
- BAM-Concrete is more ignitable than PTB-Concrete! Why?
- 5% Corundum in the concrete has no effect on ignition source and ignition limit curve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