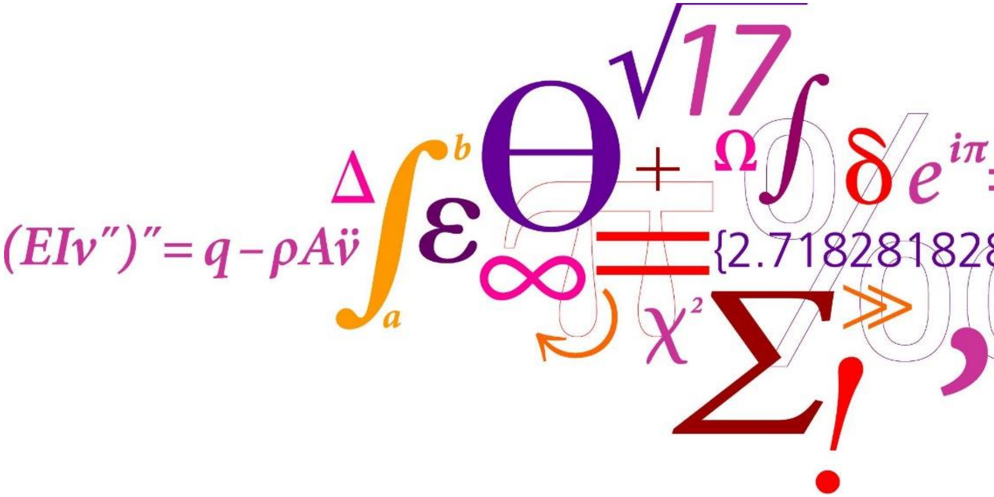
# Compressibility of liquid lubricants at high pressures

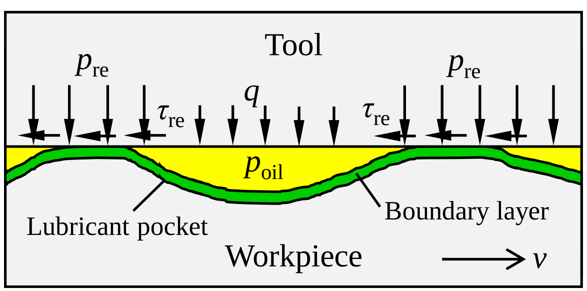
Mohd Hafis Sulaiman

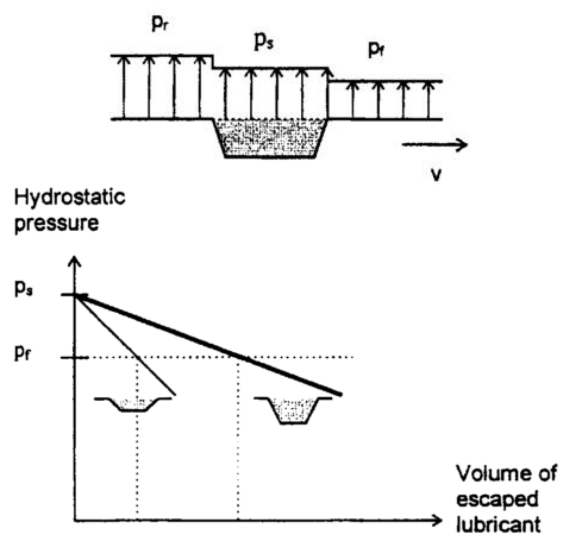



DTU Mechanical Engineering
Department of Mechanical Engineering

# Introduction

- When the pressure between surfaces increases, a confined lubricant in closed pockets will be a factor determining possible hydrodynamic and hydrostatic lubrication mechanism.
- How is the lubricant carry the load at different pressures?
- Are they any difference between a lubricant with and without boundary lubrication as the oil pressure increases in the pockets?
- Increased knowledge about the lubricant compressibility is required in order to design tailored surfaces for metal forming.

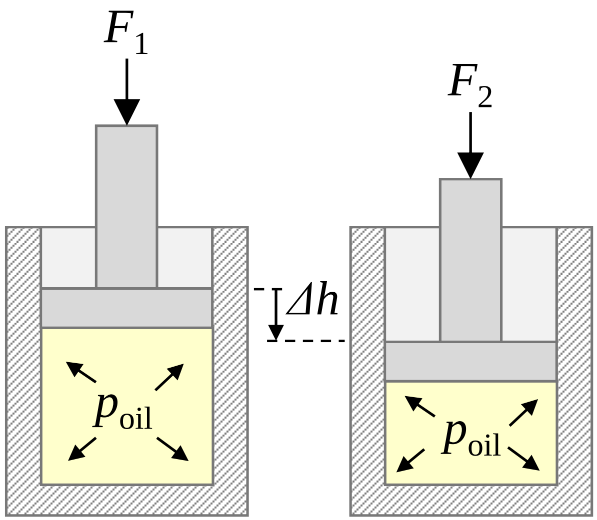


# Introduction

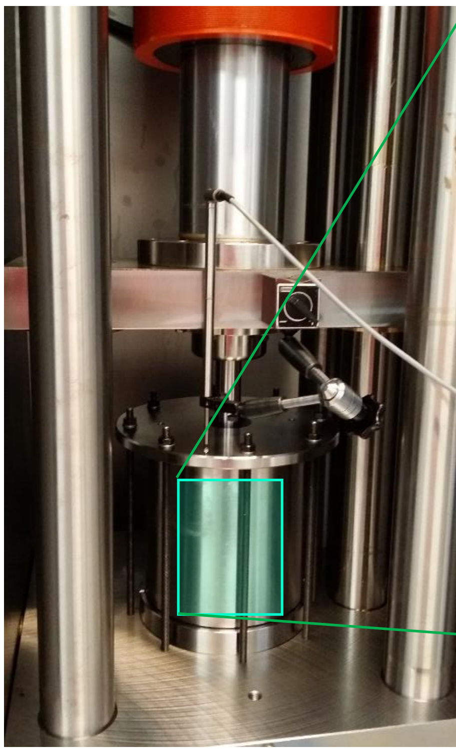
- Bulk modulus is a property that measures the compressibility of a fluid.
  - Bulk modulus
    - The product of fluid volume at any specified pressure.

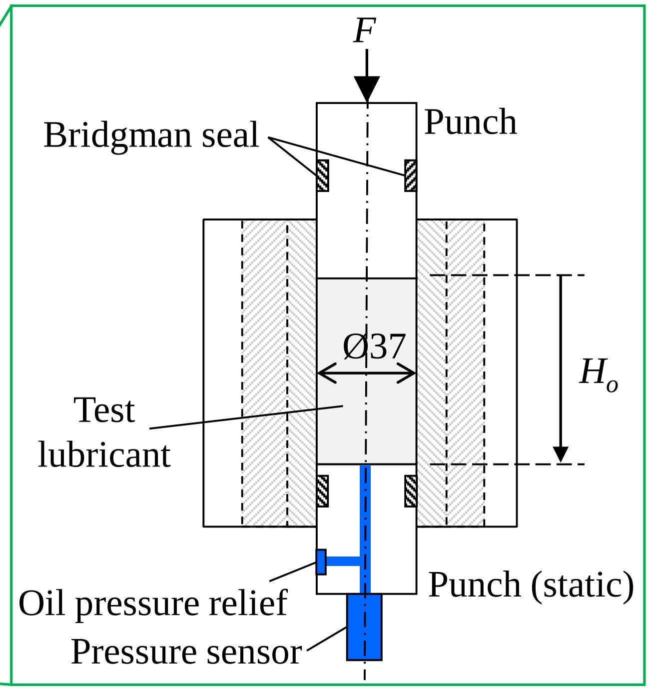
$$K_t = -V\frac{dP}{dV}$$

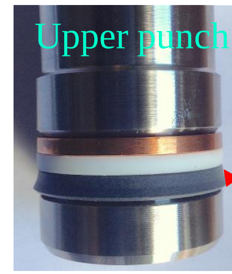


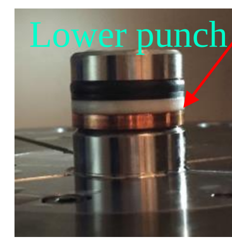
# High Pressure Equipment

- Built-in high pressure equipment at DTU-MEK.

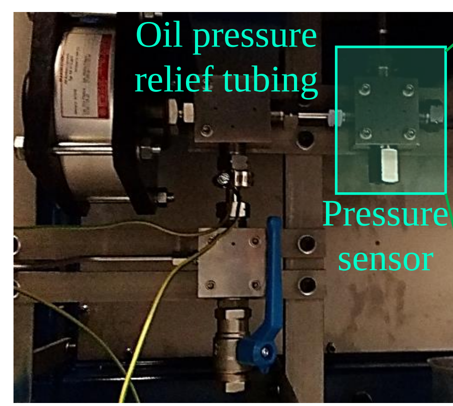




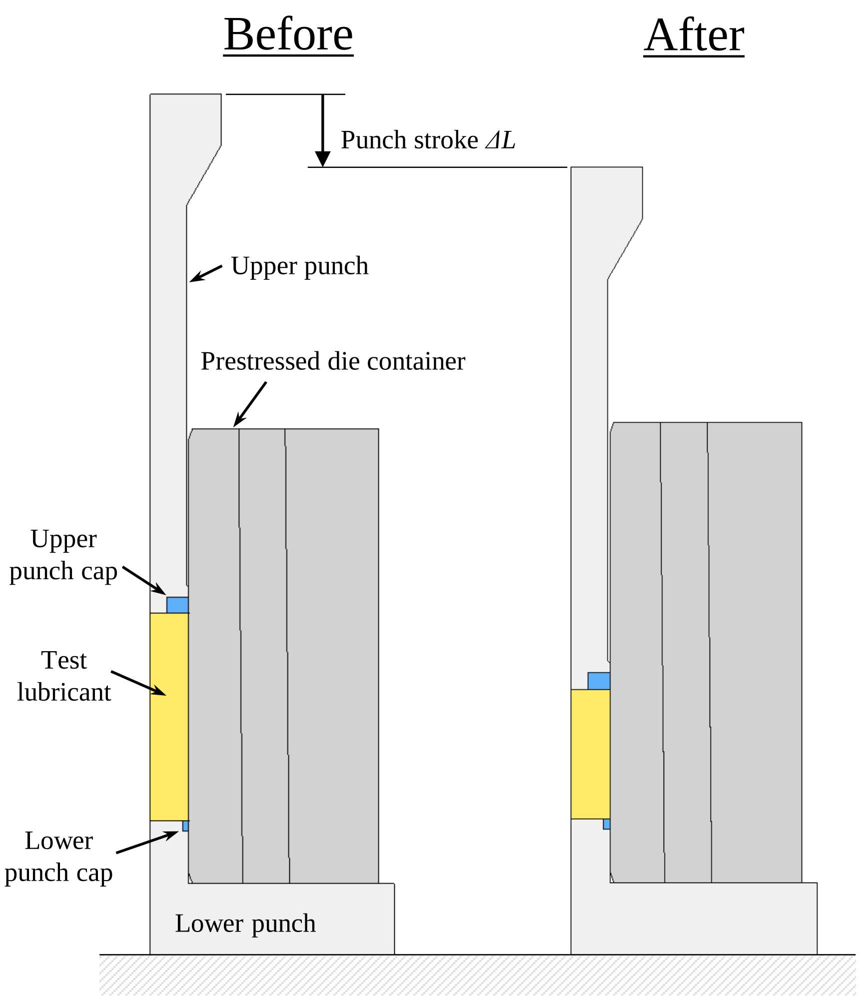




Bridgman seal (<500MPa):
- Copper (Brown)
- Teflon (White)
- Trelleborg (Black)


# Pressure limit check (by Numerical simulation)

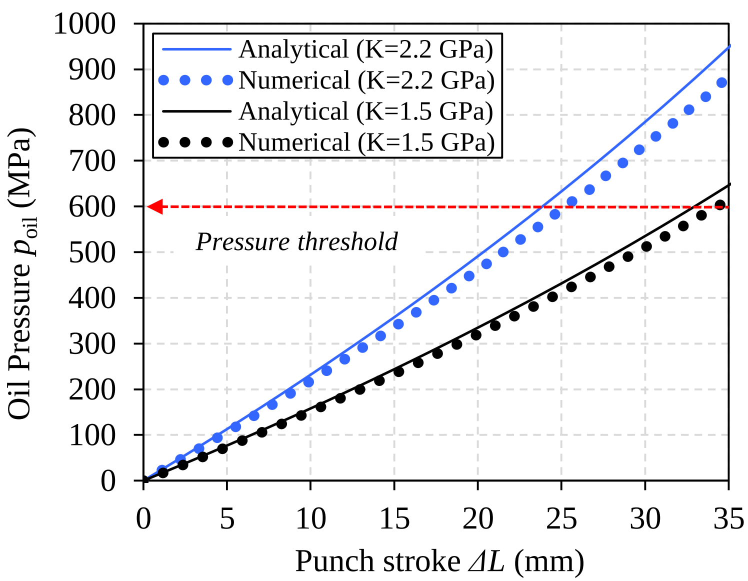



**Material properties**:

- Punches: Unimax, $E$ = 213 GPa.
- Punch cap: AISI 316, $E$ = 193 GPa.
- Prestressed die container: Vanadis 4E, $E$ = 206 GPa

**Lubricant properties**:

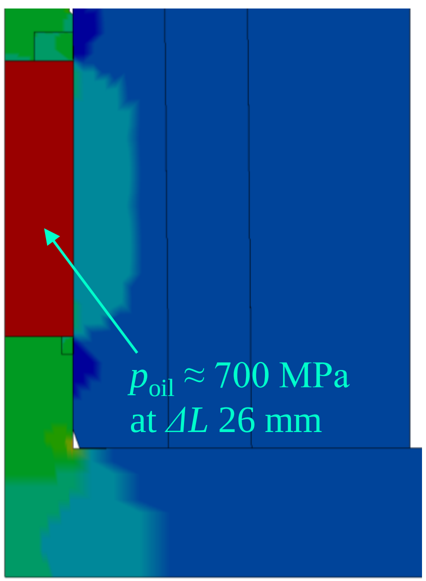
- Bulk modulus:
  - $K$ = 1500 MPa.
  - $K$ = 2200 MPa.



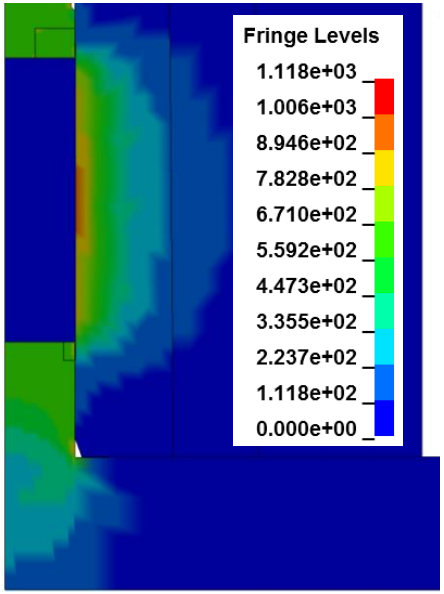
# Pressure limit check (by Numerical simulation)

- No marked expansion on the die and the punches.

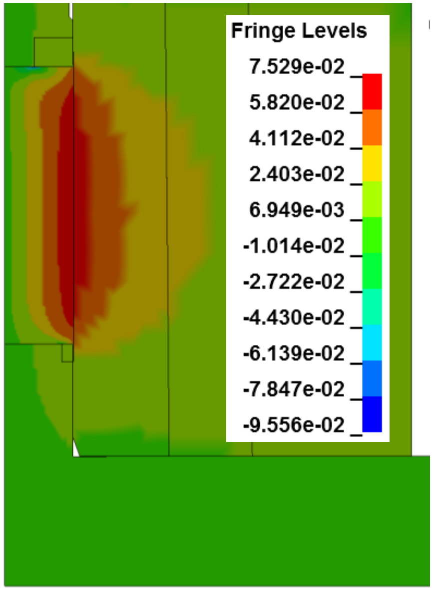
Oil Pressure



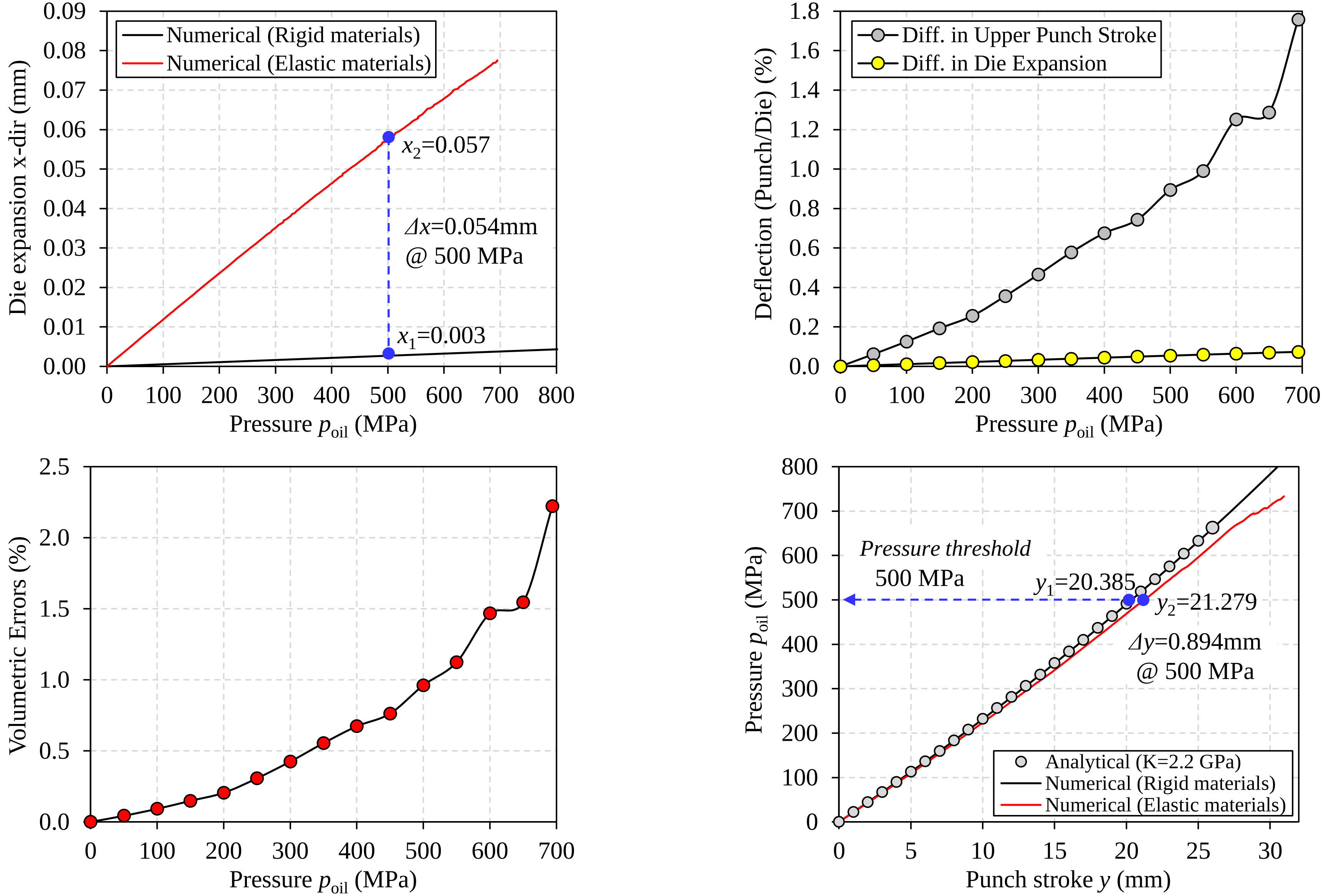

Von Misses Stress



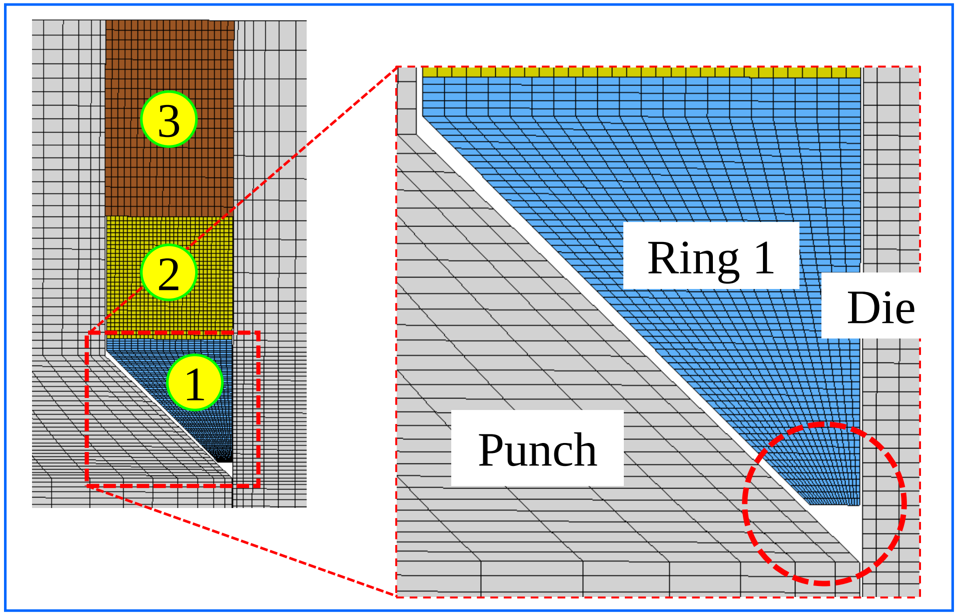

X-displacement



# Pressure limit check (by Numerical simulation)

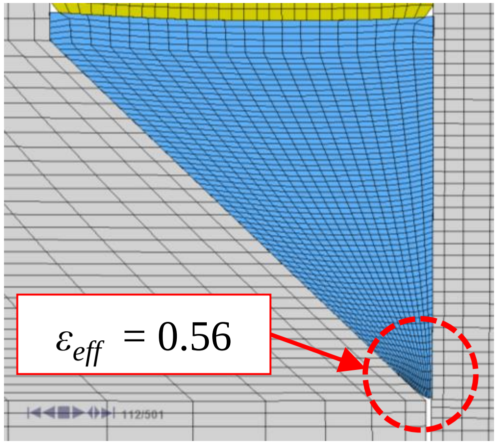


# Bridgman seal check (by Numerical simulation)

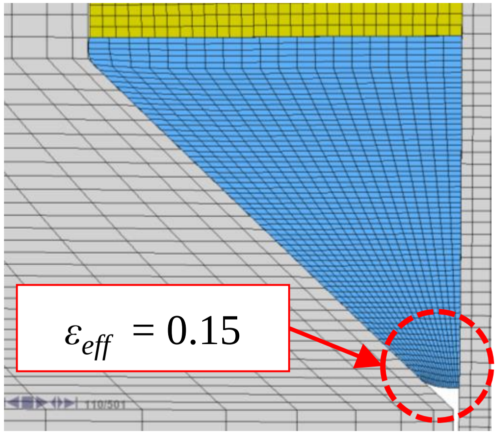



Pressing ring 3 down to 0.5mm

**Ring 1 (Copper)**



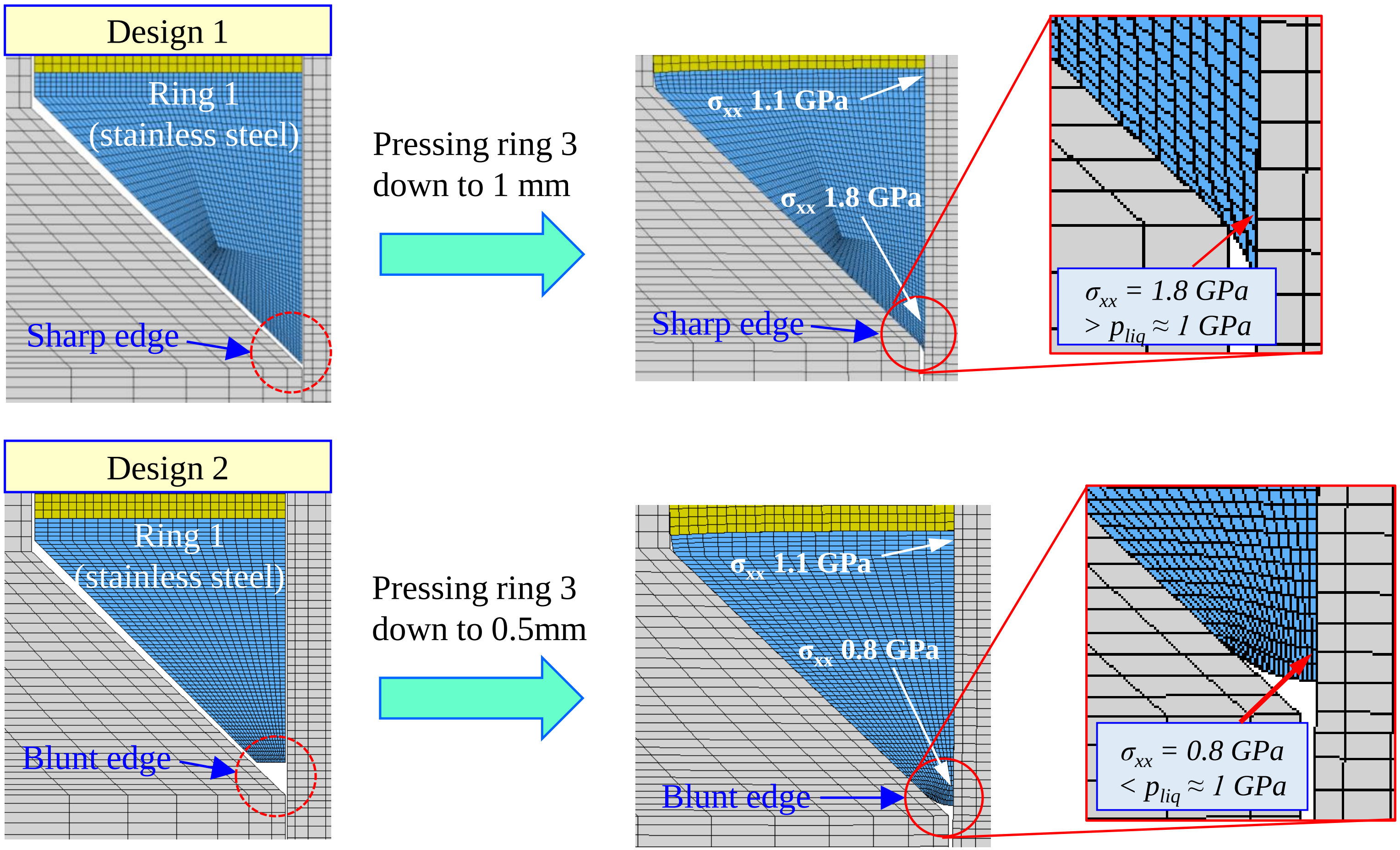

**Ring 1 (Stainless steel)**




| Part | Material | Mechanical Properties |
|---|---|---|
| Punch | Unimax | $E$ = 216 GPa |
| Die | Vanadis 4E | $E$ = 206 GPa |
| Ring 1 | Copper, or<br>Stainless steel 304 | $\sigma_o = 315.\varepsilon^{0.54}$<br>$\sigma_o = 1275.\varepsilon^{0.45}$ |
| Ring 2 | Steel Ma8 | $\sigma_o = 636.\varepsilon^{0.23}$ |
| Ring 3 | Stainless steel 304 | $\sigma_o = 1275.\varepsilon^{0.45}$ |

# Bridgman seal check (by Numerical simulation)

- Modified design of ring 1



# Test Lubricants

- There are 3 types:
  1) Water (for verification with the published data).
  2) Plain mineral oils (Thick and thin version).
  3) Good boundary lubricants (Thick and thin version).

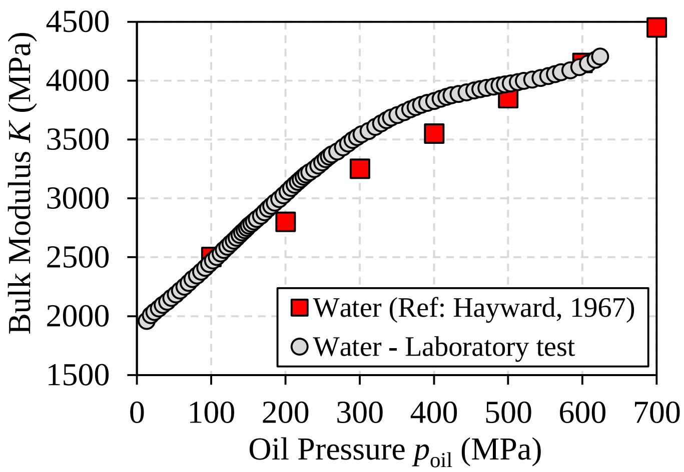
| Oil type | Product name | Kinematic Viscosity $\eta_V$ @ 40ºC [cSt] |
|---|---|---|
| - | Water | 0.658 |
| Naphthenic plain mineral oil | CR5 | 660 |
| Plain mineral oil* | CR5-Sun 60 | 60 |
| Mineral oil with additives | Rhenus LA 722086 | 800 |
| Mineral oil with additives | Rhenus LA 722083 | 300 |
| Chlorinated paraffin oil | TDN81 | 150 |

**50 wt. % mixture oil – Houghton Plunger CR5 ($\eta$=660 cSt) and Sunoco Sun 60 ($\eta$=10 cSt).*

# Results

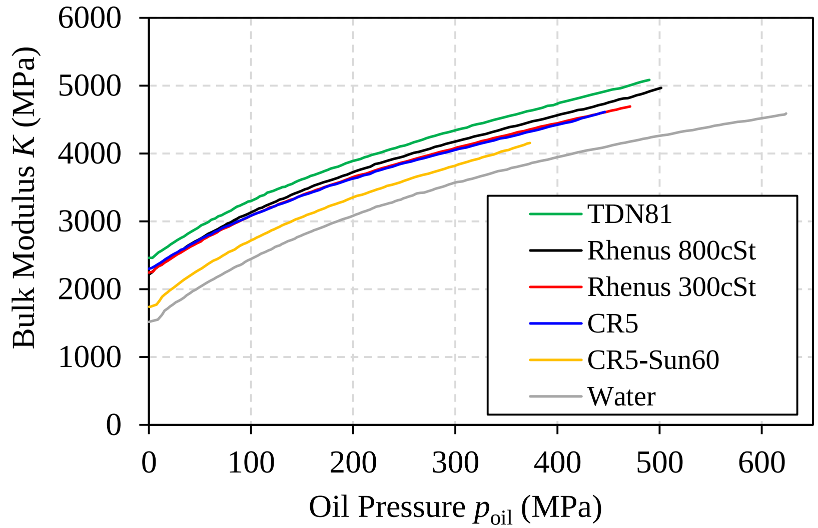
Verification of the built-in equipment at DTU-MEK

- Bulk modulus of water was compared with the established result.



# Results

- Bulk modulus at different pressures.

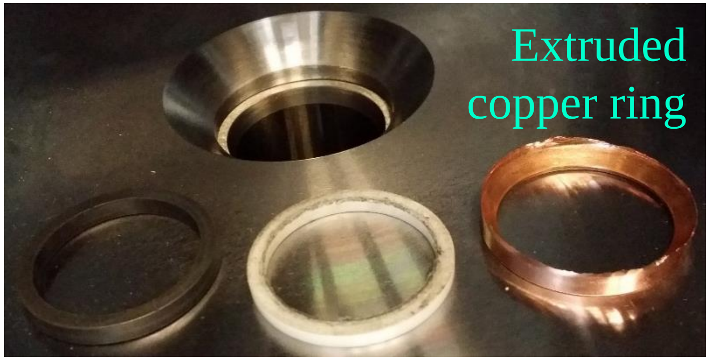



- The boundary lubricants has a marked influence on compressibility when compared to the thin plain mineral oil.
- Meanwhile, the thick plain mineral oil shown a good compressibility in comparison to that of the boundary lubricant (medium viscous version).

# Results

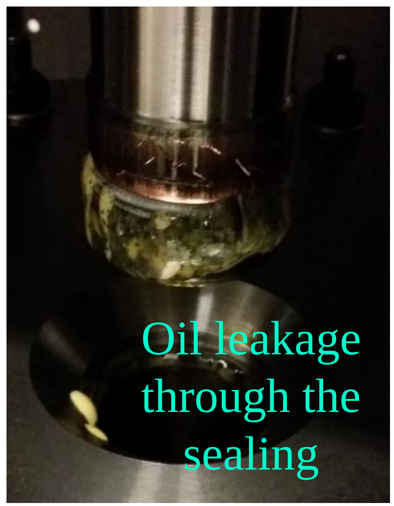
- A light damage on the seals caused by testing of plain mineral oil (a thin oil version).


After cleaning




# Results

- Heavy damage on the punch cap and the seals caused by testing of plain mineral oil (a thick oil version).


After cleaning

# Summary

- The compressibility test results shown a similar trend when evaluating the same oil types on textured tool surfaces in strip reduction testing.
- The compressibility of the lubricant may be an influential factor in determining possible hydrodynamic and hydrostatic lubrication mechanism.
- The influence of the lubricant compressibility need to take into account for a future work in modelling trapped lubricant behavior in metal forming operation.