Determination of lubricant bulk modulus in metal forming by means of a simple laboratory test and inverse FEM analysis

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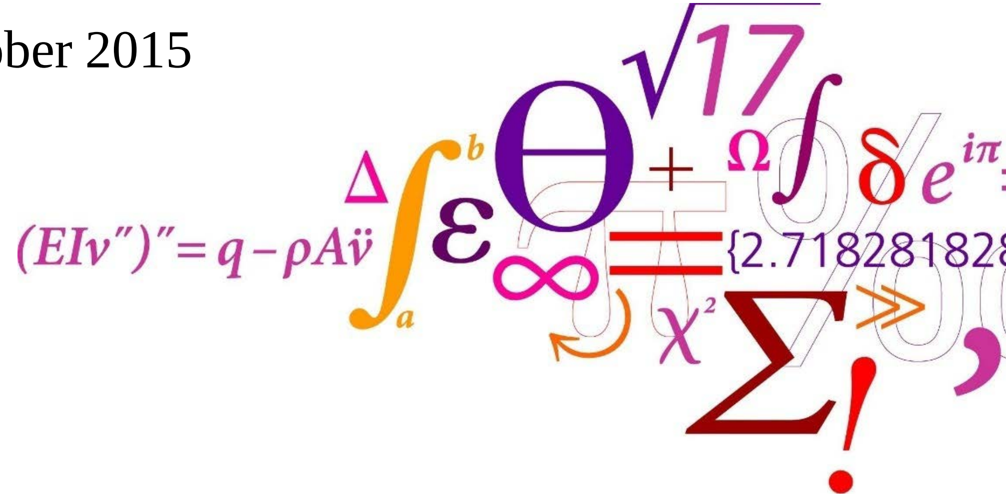
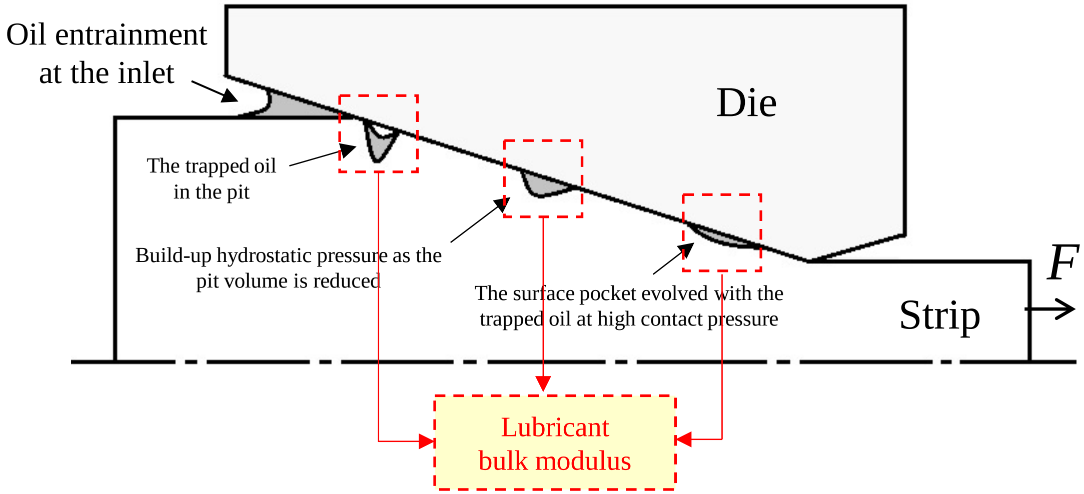


Introduction

- Increased surface roughness facilitates lubricant entrainment and mechanical entrapment.
- Surface characterization models of the trapped lubricant in closed pockets have been developed by many researchers.

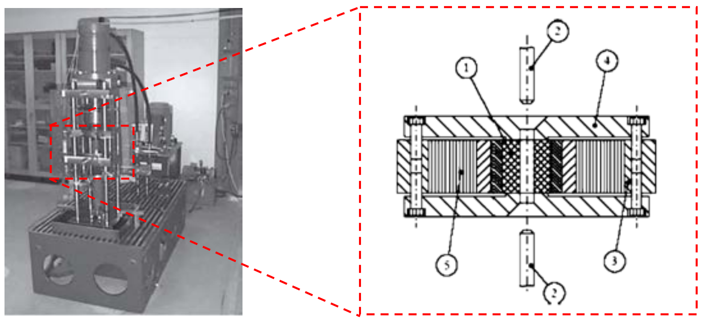


How do we typically determine the lubricant bulk modulus?

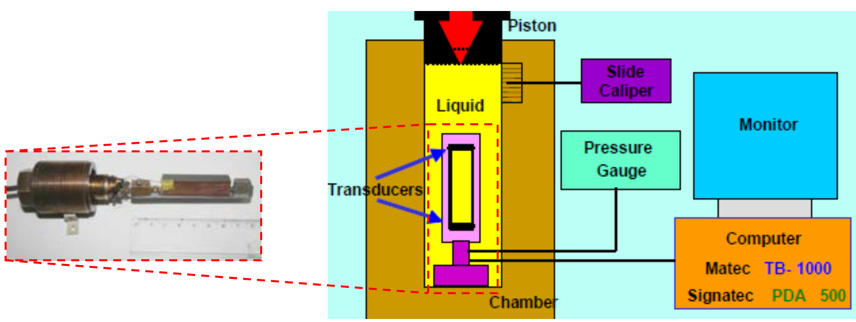
Introduction

Methods of obtaining lubricant bulk modulus:

1) Test methods - Advanced laboratory equipment:
   a) ASTM – Standard test method.
   b) High pressure chamber [1].



   c) Application of acoustic waves [2].

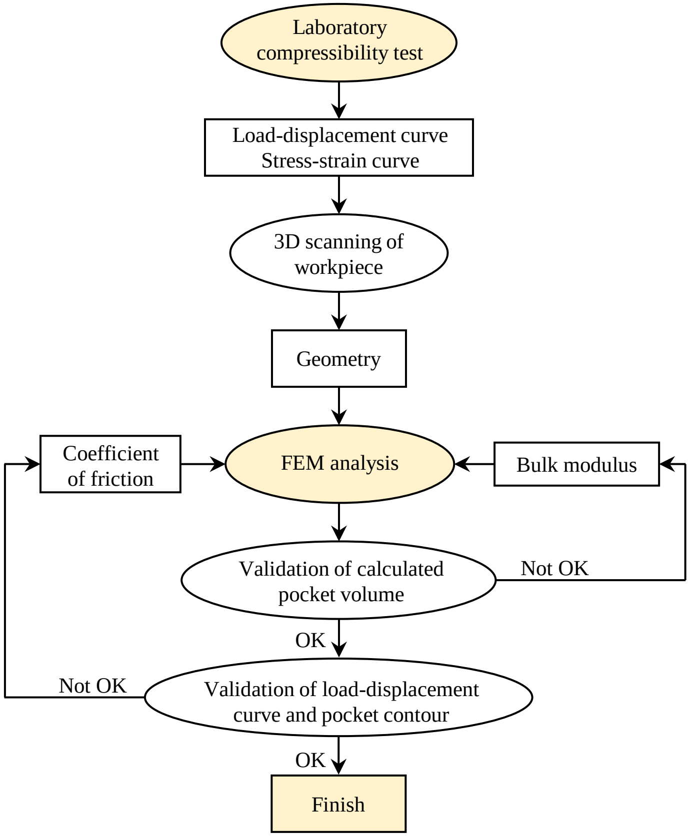


2) Literatures; journals, supplier catalogue, etc.

[1] J. Stahl, BO Jacobson, 2003. Compressibility of lubricants at high pressures. Tribology transactions, 46 (4), p. 592-599.
[2] Piotr Kiełczyński, 2010. Application of acoustic waves to investigate the physical properties of liquids at high pressure. Acoustic Waves, Don Dissanayake (Ed.), ISBN: 978-953-307-111-4, InTech, p. 317-340.

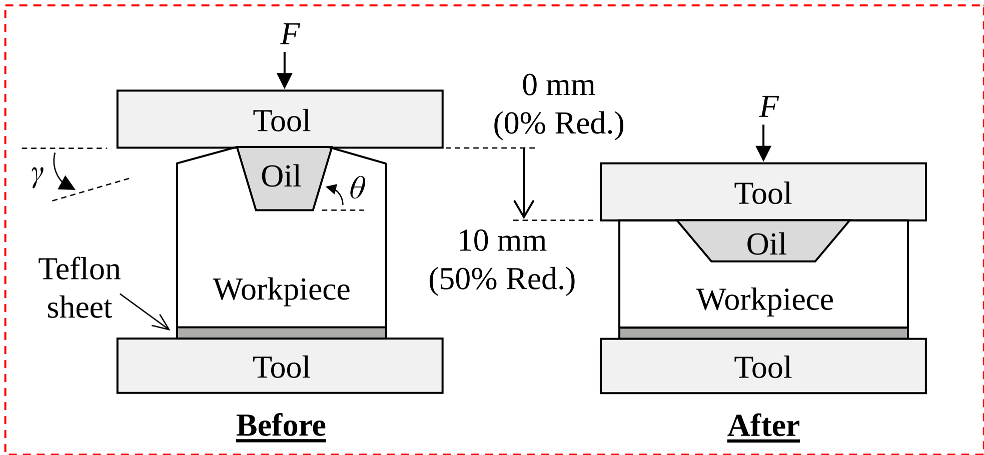
Proposed Method

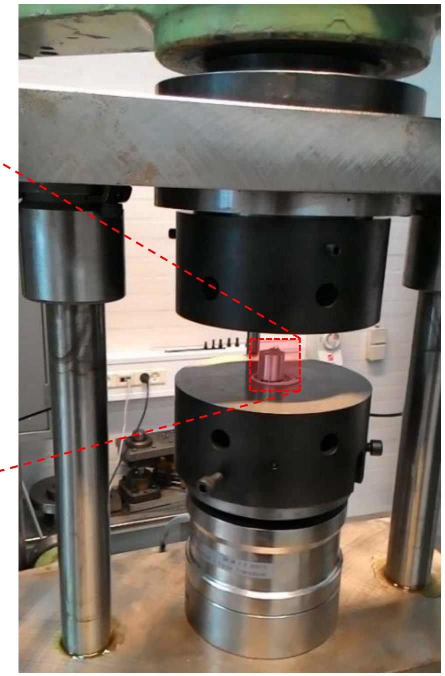
- A complete workflow for determination of the lubricant bulk modulus consists of:
  1) A simple laboratory test and,
  2) An inverse FEM analysis.



Laboratory Compressibility Test

- <u>Test Principle</u>





*<u>*Recommendations*</u>:

(1) A narrow surface angle to seal the lubricant completely from escape.
(2) An inclined pocket wall to avoid difficulty in measuring pocket volume.
(3) No lubricant applied on top tool-upset contact surface to prevent additional volume.

Item	Dimensions	
Workpiece	Height H_o	: 20 [mm]
	Diameter D_o	: 20 [mm]
	Slope γ of inclined top surface	: 2°
Surface Pocket	Height h_o	: 5 [mm]
	Top diameter d_o	: 6 [mm]
	Base diameter d_i	: 4 [mm]

Laboratory Compressibility Test

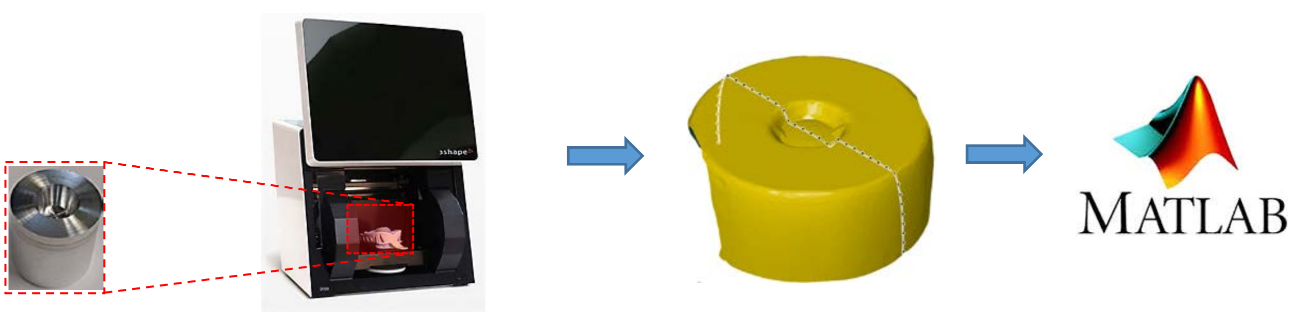
- Test Materials
  - Metal properties.

Properties	Values
Material	Al2S
Composition	Al 99.7%, Fe 0.2%, Si 0.1%
Hollomon flow curve expression $\sigma_o = C\varepsilon^n$	$\sigma_o = 135\varepsilon^{0.26}$ [N/mm^2]

  - Test lubricant.

Name of lubricant	Dynamic Viscosity η_o [Pa.s]	Kinematic Viscosity η_v @ 40ºC [cSt]	Density ρ @ 15ºC [g/cm^3]
CR5 Houghton Plunger	0.61	660	0.92

- 3D scanning of workpiece

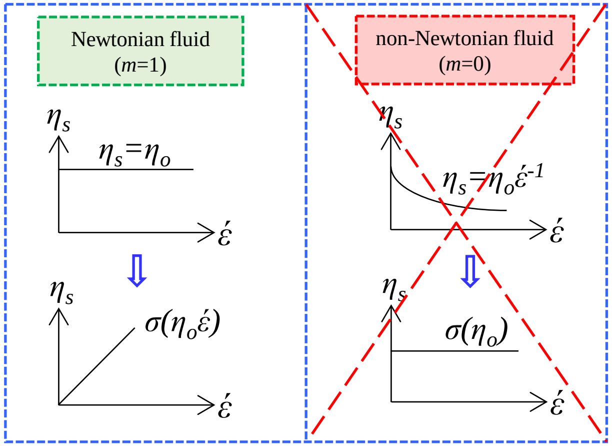


Finite Element Analysis

- The stress of the lubricant $\sigma_{lube,ij}$ is written in terms of deviatoric stress tensor and hydrostatic lubricant pressure as a function of strain rate $\dot{\varepsilon}$,

$$\sigma_{lube,ij} = \sigma'_{ij} - \sigma_{ii}$$

$$\sigma_{lube\,ij} = 2\eta_s \dot{\varepsilon}'_{ij} - K\dot{\varepsilon}_{ii}$$



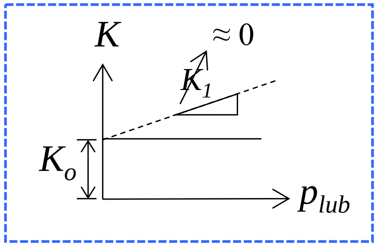
- The lubricant shear viscosity η_s,

$$\eta_s = \eta_o exp[\underbrace{\alpha}_{\approx 0}(p - p_o) - \underbrace{\beta}_{\approx 0}(T - T_o)]\dot{\varepsilon}^{\overbrace{m}^{\approx 1\ (Newtonian\ fluid)}-1}$$

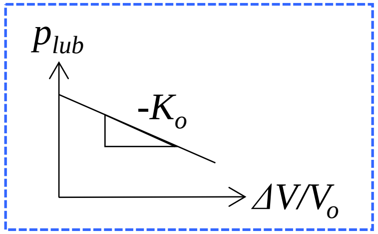
$$\eta_s = \eta_o$$

- The approximate lubricant bulk modulus K,

$$K = K_o + \underbrace{K_1}_{\approx 0} p_{lub}$$

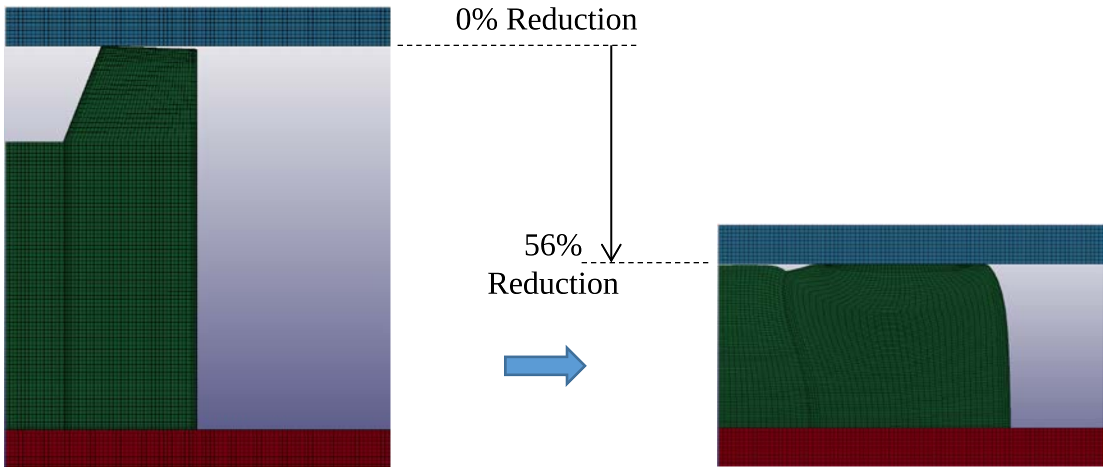


$$p_{lub} = -K_o \frac{\Delta V}{V_o}$$

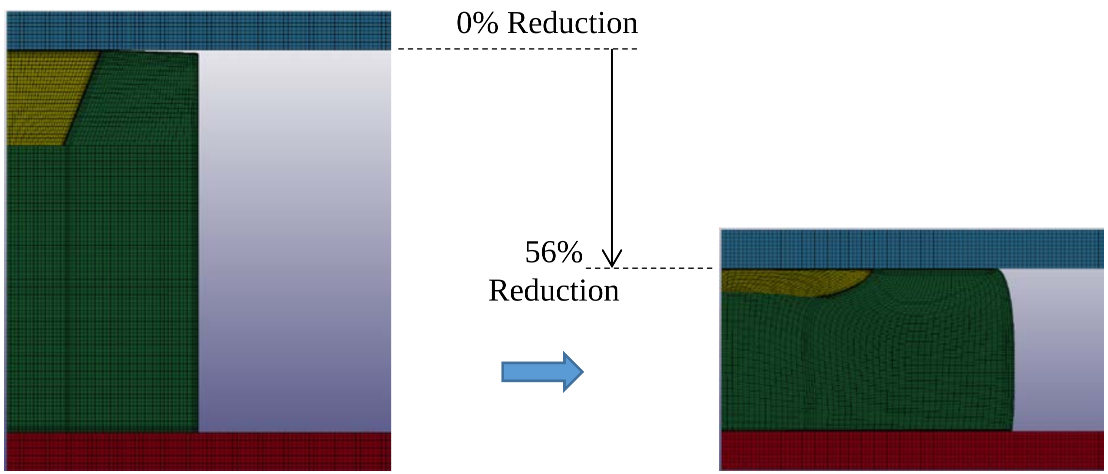


Finite Element Analysis

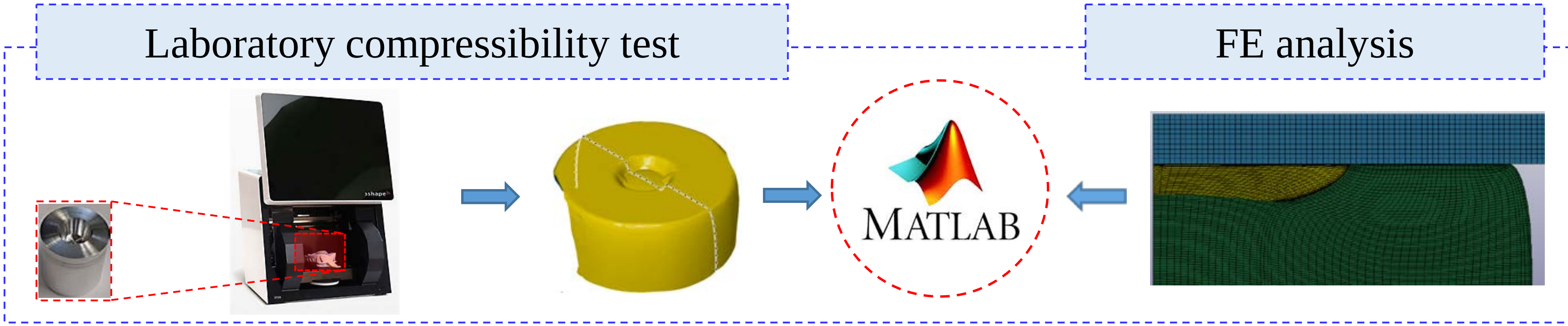
1) FE simulation of empty pocket.

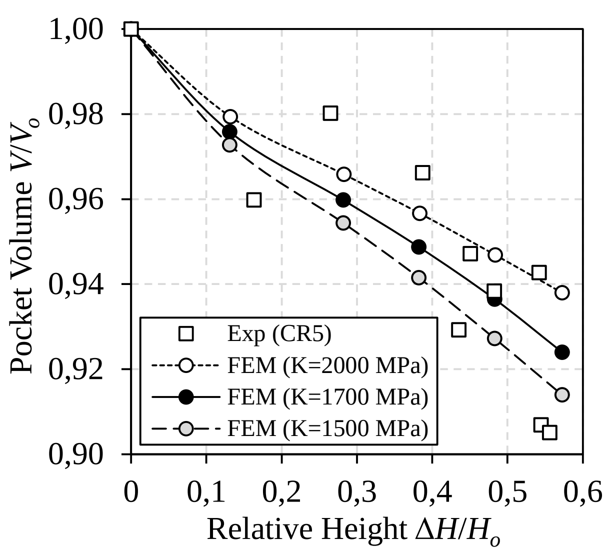


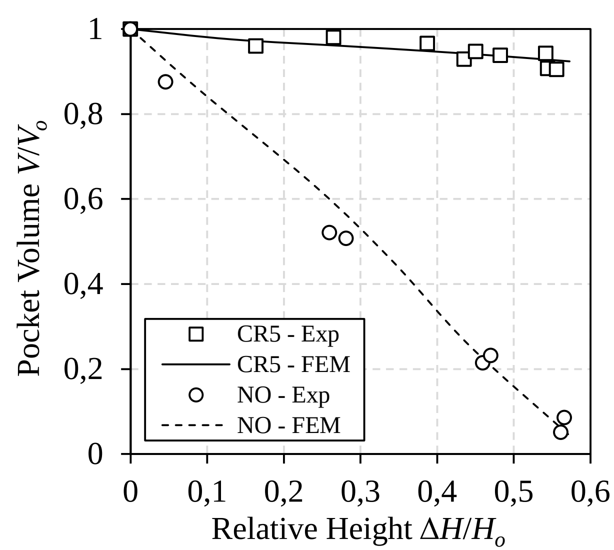
2) FE simulation of lubricated pocket.



FE & Exp. validation (Pocket volume)

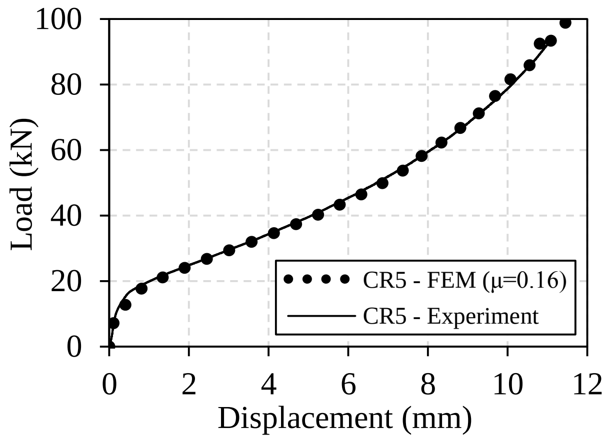


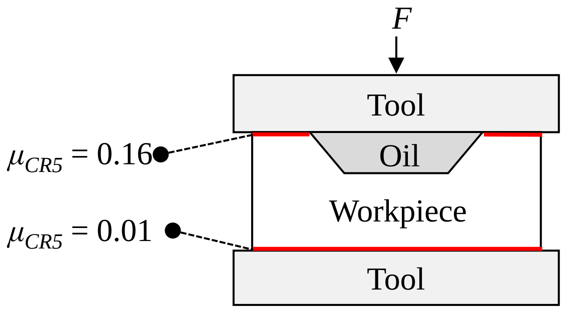




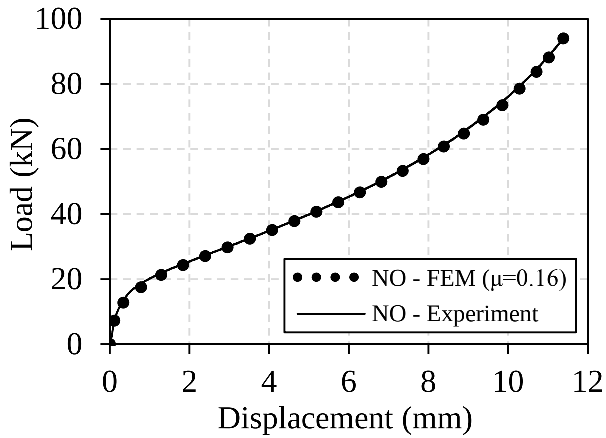
FE & Exp. validation (Load-disp. curve)

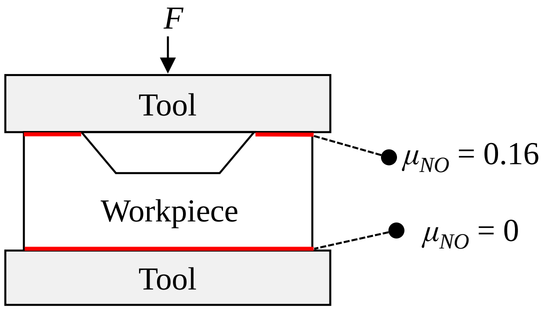
Lubricated pocket (CR5)



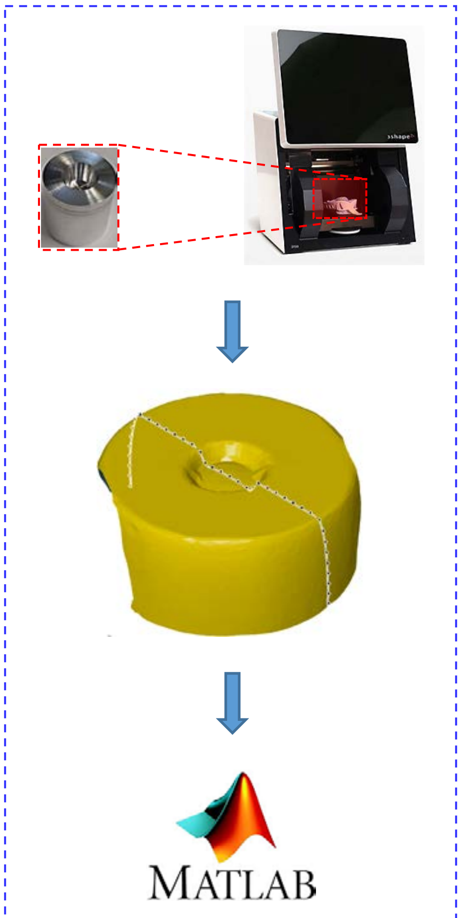


Empty pocket (NO)



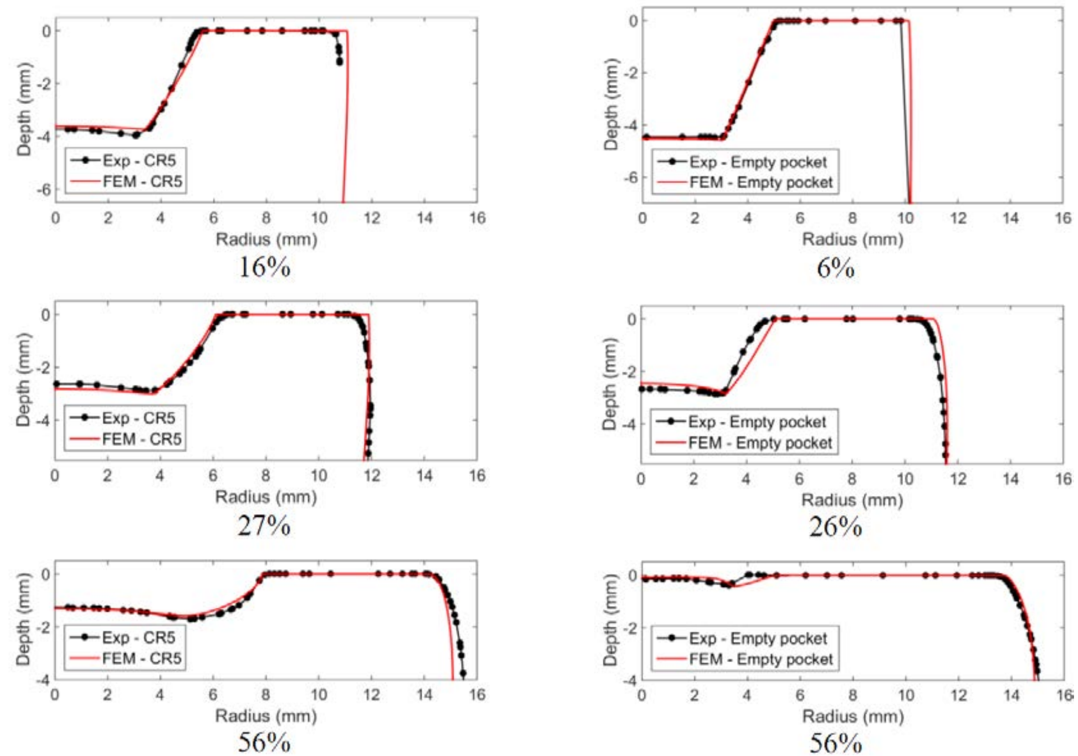


FE & Exp. validation (Pocket contour)



Lubricated pocket (CR5)

Empty pocket (NO)



Conclusion

The proposed method of determining liquid bulk modulus has proven to work satisfactory.

The method allows for determination of the bulk modulus without requirements for advanced experimental equipment.