Friction measurement

Ring test

Metal Forming (BMEGEMTAGE1)
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Introduction

Friction is a very complicated phenomenon, influenced by several hardly treatable parameters (including, but not limited to pressure, temperature, surface quality, air humidity etc.).

The **friction is hindering the displacement** of the surfaces, and **increases the temperature** of the contacted bodies. It can be characterized with the force hindering the motion.

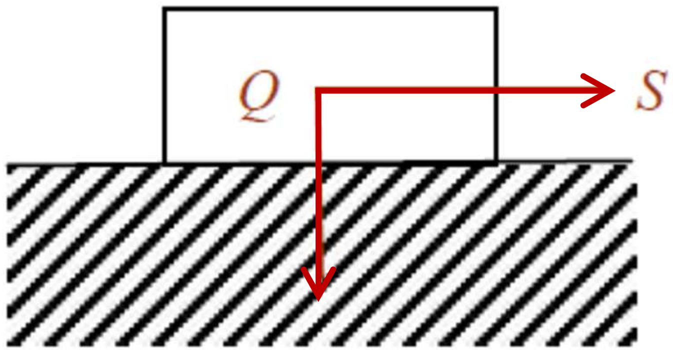
The **pressure between** the surfaces **in forming** technologies is much higher than in bearings, it can reach **2500 MPa** or even higher.

At machine parts the points of the contact surface **moving with equal velocity**, but at forming technologies the velocity of the contact surface can be different in different positions.

Friction models

Amonton-Coulomb friction (depends on the pressure)

If a body is pressed with a force **Q** to an other one, then:



$S = \mu \, Q$ force is needed to move it

$$\frac{S}{A} = \mu \, \frac{Q}{A} \;\longrightarrow\; \tau = \mu \, q \qquad \mu \geq 0$$

At metal forming the max. value at sticking: $\mu_{max} = \frac{1}{\sqrt{3}} = 0.577$

For this model:

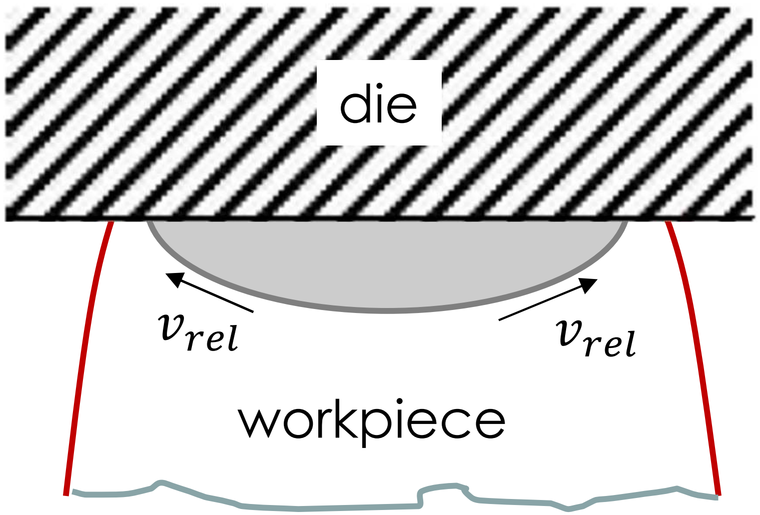
Friction is linearly proportional with the contact pressure.

Friction is independent on the relative velocity of the bodies and on the direction of movement.

Friction models

Kudo (shear) friction (depends on the material)

If a part of the body (grey volume) is „sticking" to the die because of the friction, the relative movement happens within the formed material. It happens when the shearing stress between the two bodies reaches the shearing flow stress:



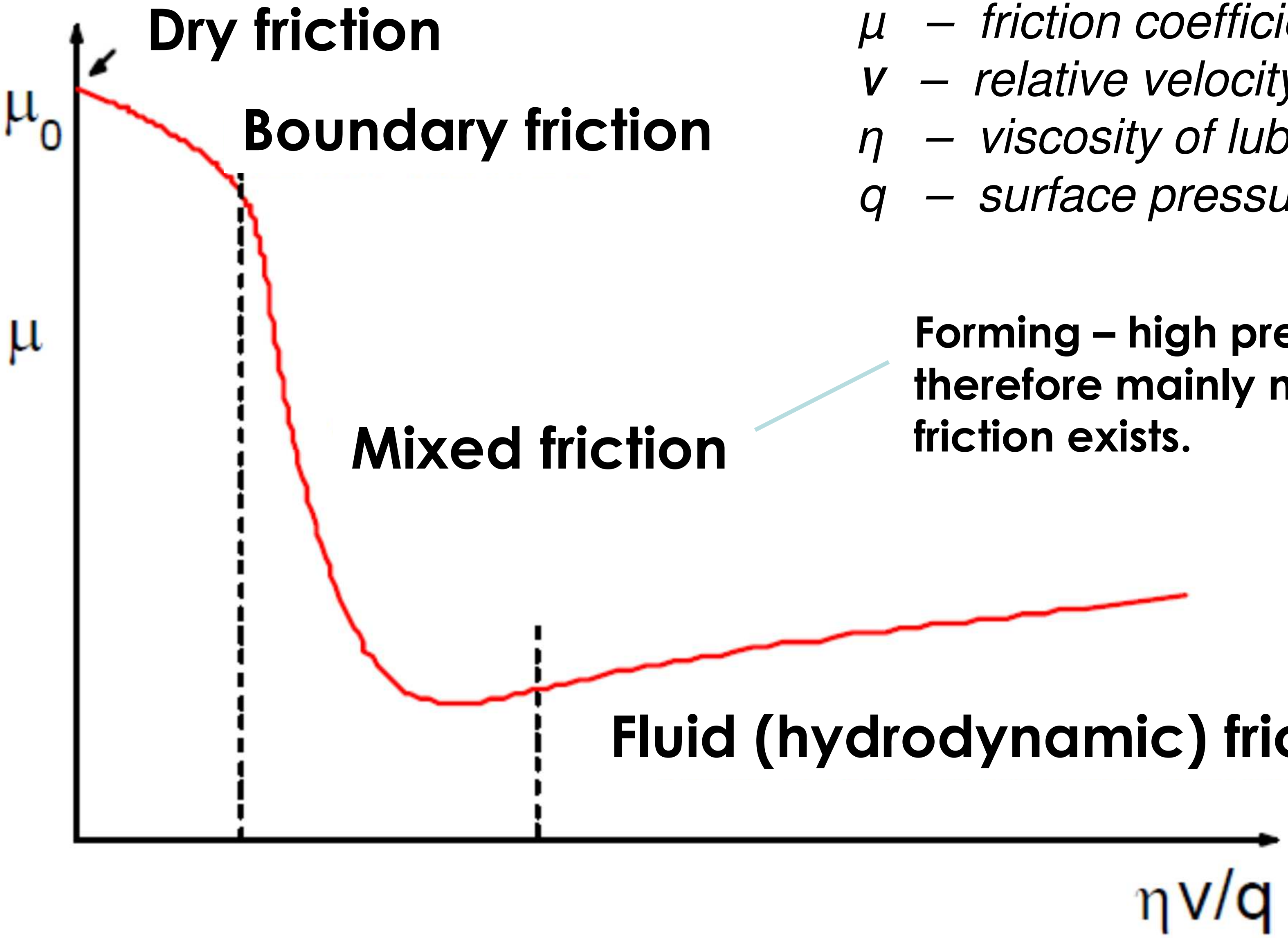
$$\tau = m\,\tau_{max} = m\,\tau_{flow}$$

$$\tau_{flow} = \frac{\sigma_{flow}}{\sqrt{3}}$$ (Mises theory)

$$\tau = m\frac{\sigma_{flow}}{\sqrt{3}} \qquad 0 \le m \le 1$$

Sticking happens at $m = 1$

Stribeck diagram



μ – *friction coefficient*
v – *relative velocity*
η – *viscosity of lubricant*
q – *surface pressure*

Forming – high pressure, therefore mainly mixed friction exists.

Measurement roles

In the practice the main role of friction measurements is to compare lubricants within given conditions.

Several measurement techniques were developed during the time, most of them **are rather complicated**.

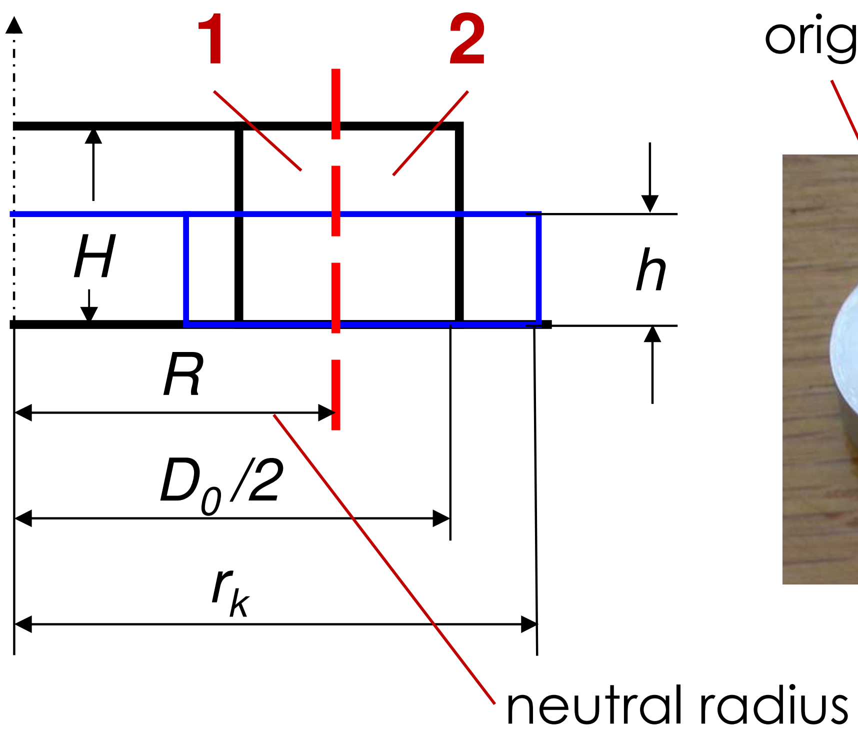
The simplest technique in **the ring test**, which does not require any special equipment.

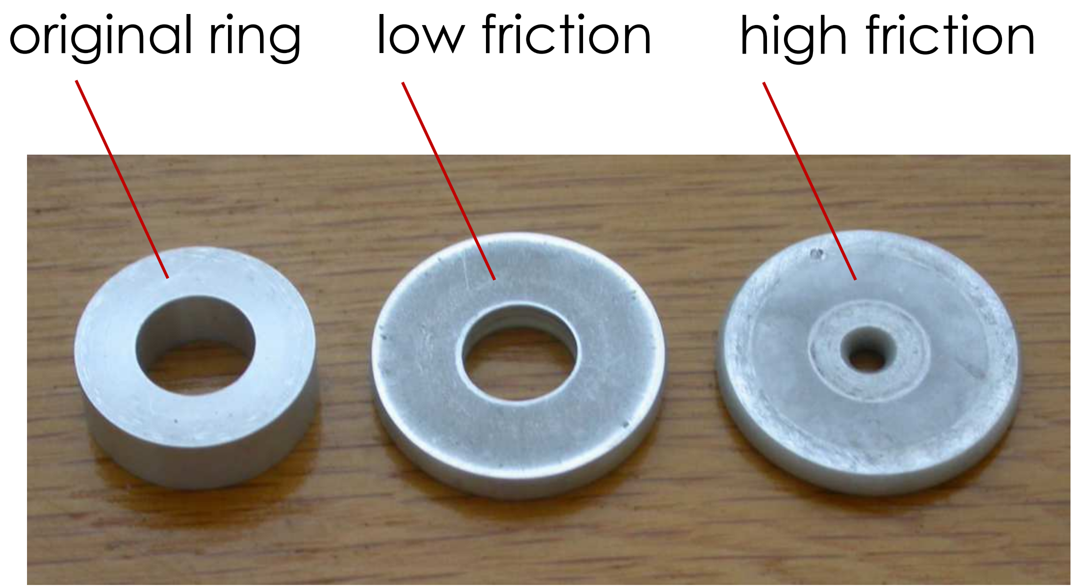
Only **simple tooling** (upsetting between parallel surfaces), **simple measuring device** (caliper) and simple specimen (cylindrical ring) are needed. These are available in any forming company. (No force measurement is needed.)

As the deviations of the measured values are rather big, statistical evaluation of the results are recommended.

Friction coefficient measurement

Ring upsetting

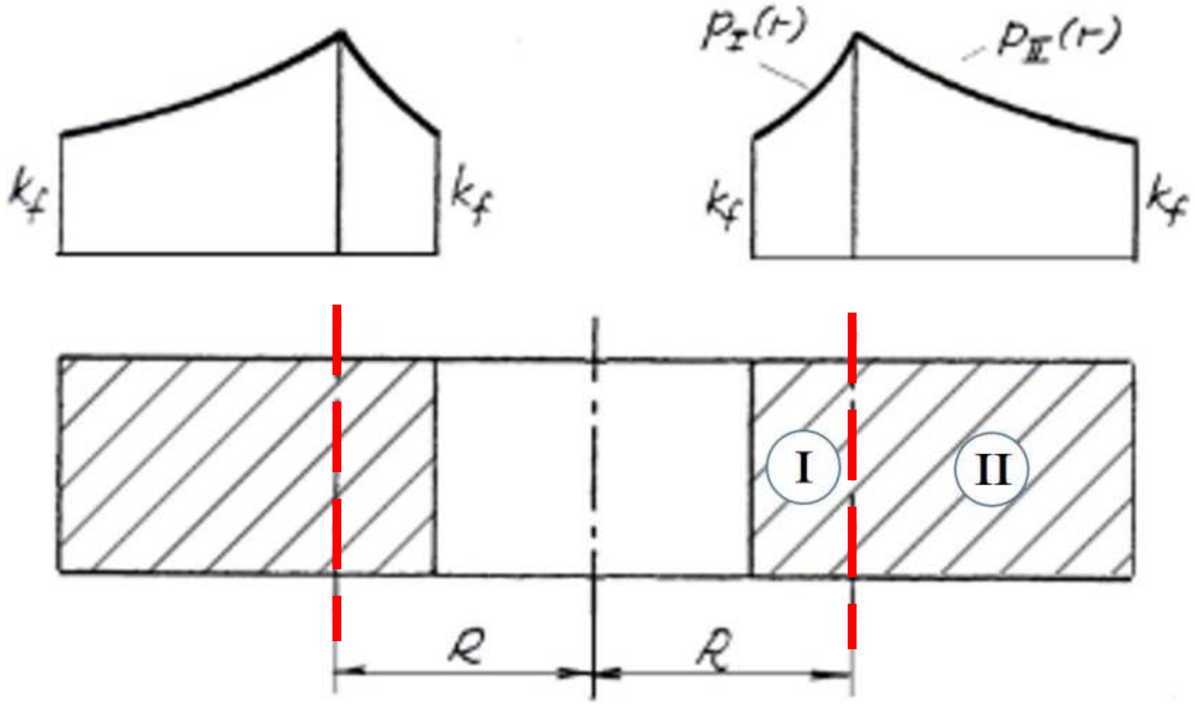




Volume 1 flows in, volume 2 flows out, no radial flow through the red line.

Friction coefficient measurement

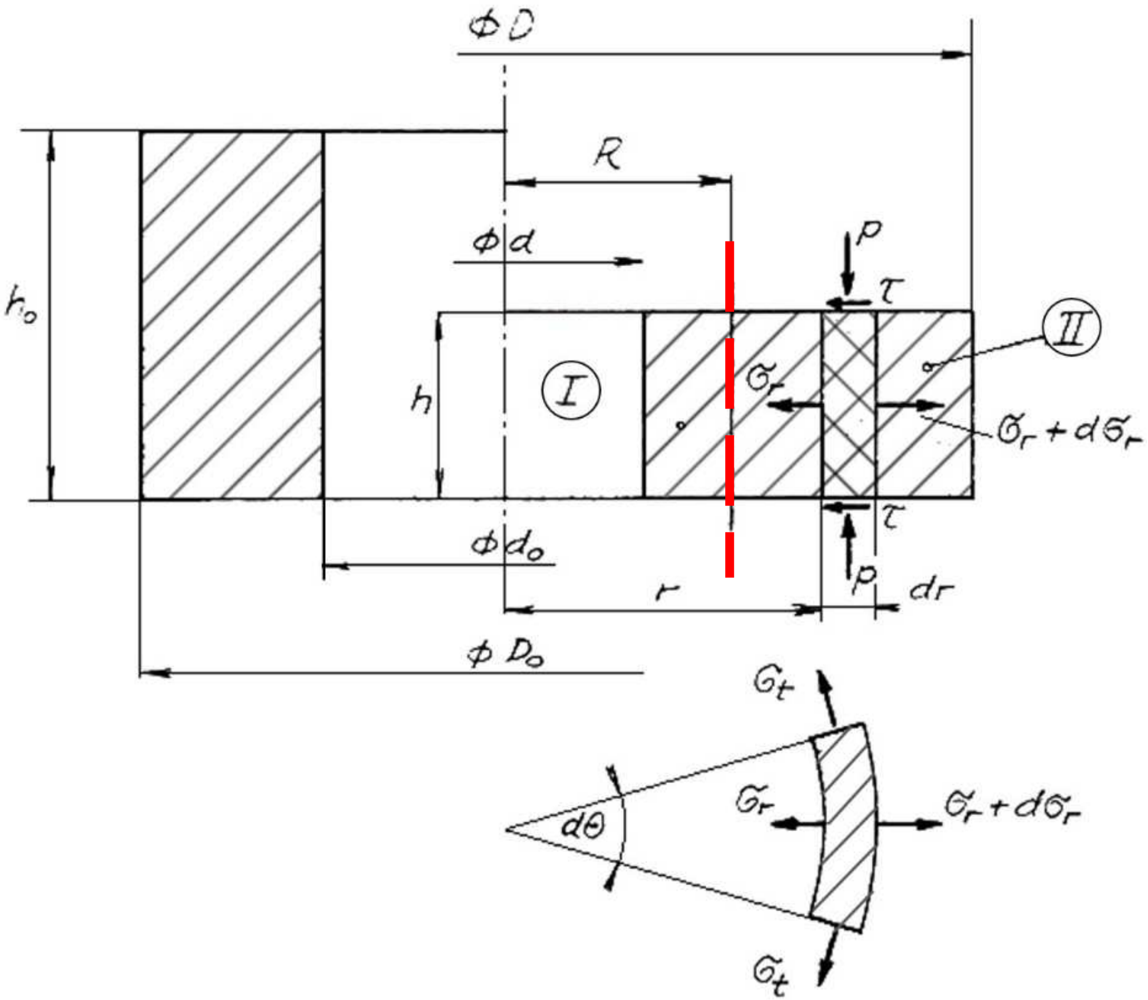
Ring upsetting



At the red line the axial pressure (p) for the two volume are equal.
This equilibrium can give an equation, from which the friction coefficient can be calculated. The equilibrium can be written on first for the radial stresses, which are also equal, but with opposite sign.
But these calculations are complicated → use nomograms.

Friction coefficient measurement

Ring upsetting
slab method



At the red line the radial stresses for the two volume are equal with opposite sign. This equilibrium gives an equation, from which the friction coefficient can be calculated.
But these calculations are complicated → use nomograms.

Friction coefficient measurement

Ring upsetting

slab method

The equilibrium equation of the signed elementary body leads a differential equation. Using the flow criteria for the solved equation the pressure in volume two (in symbolic form):

$$p_{II} = p_{II}\left(k_f,\ \text{geometry},\ \text{friction},\ r\right)$$

The same applies for volume one:

$$p_I = p_I\left(k_f,\ \text{geometry},\ \text{friction},\ r\right)$$

At the neutral radius **(r = R)** the two equation gives the same result, and the flow stress is removable:

$$k_f\, p_I\left(\text{geometry},\ \text{friction},\ R\right) = k_f\, p_{II}\left(\text{geometry},\ \text{friction},\ R\right)$$

This equation in even more simple symbolic form:

$$F\left(\text{geometry},\ \text{friction},\ R\right) = 0$$

Friction coefficient measurement

The obtained equation in even more simple symbolic form:

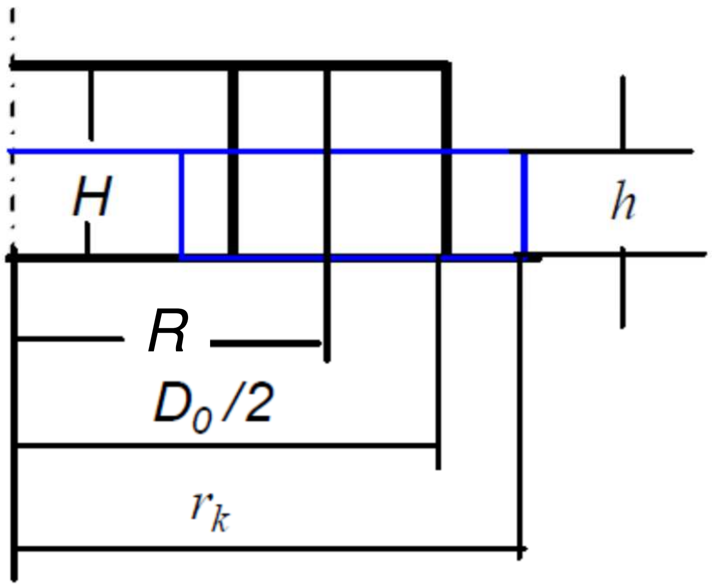
$$\mathrm{F}(\text{geometry},\ \text{friction},\ \mathrm{R}) = 0$$

In this equation:

The friction is represented by the Coulomb or Kudo coefficient, as appropriate.

The R neutral radius can be calculated from the volume constancy, written on one of the two volumes.

From the outer region:



$$\left(D_0^2 - 4\rho^2\right)\frac{\pi}{4}H = \left(r_k^2 - \rho^2\right)\pi h$$

$$R = \sqrt{\frac{D^2 H - 4r_k^2 h}{4(H-h)}}$$

Friction coefficient measurement

The equation for Kudo friction:

$\rho = R$

$$\ln \frac{r_k^2\left(\rho^2+\sqrt{3r_b^4+\rho^4}\right)}{r_b^2\left(\rho^2+\sqrt{3r_k^4+\rho^4}\right)} = \frac{2m}{h}\left(r_k + r_b - 2\rho\right)$$

This equation is **explicit for the Kudo** friction (but would be **implicit** if the solution was made **for Coulomb** friction).

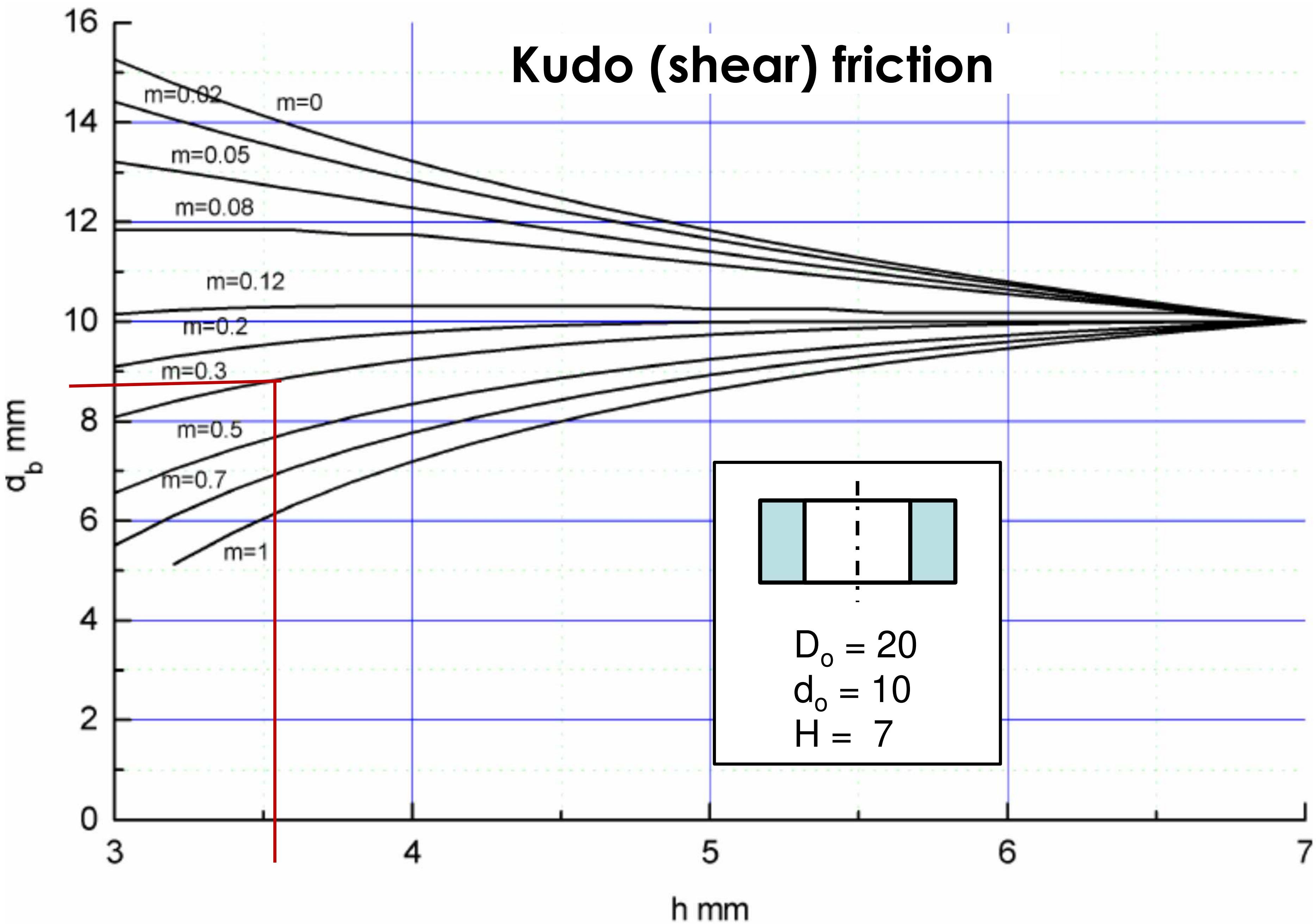
The equation is not nice, so nomograms **are** used in the practice.

The nomograms can be calculated by computer for any of the two friction models and for a given initial ring geometry.

The **height** and the **inner diameter** (it is much more sensitive for the friction than the outer) are measured.

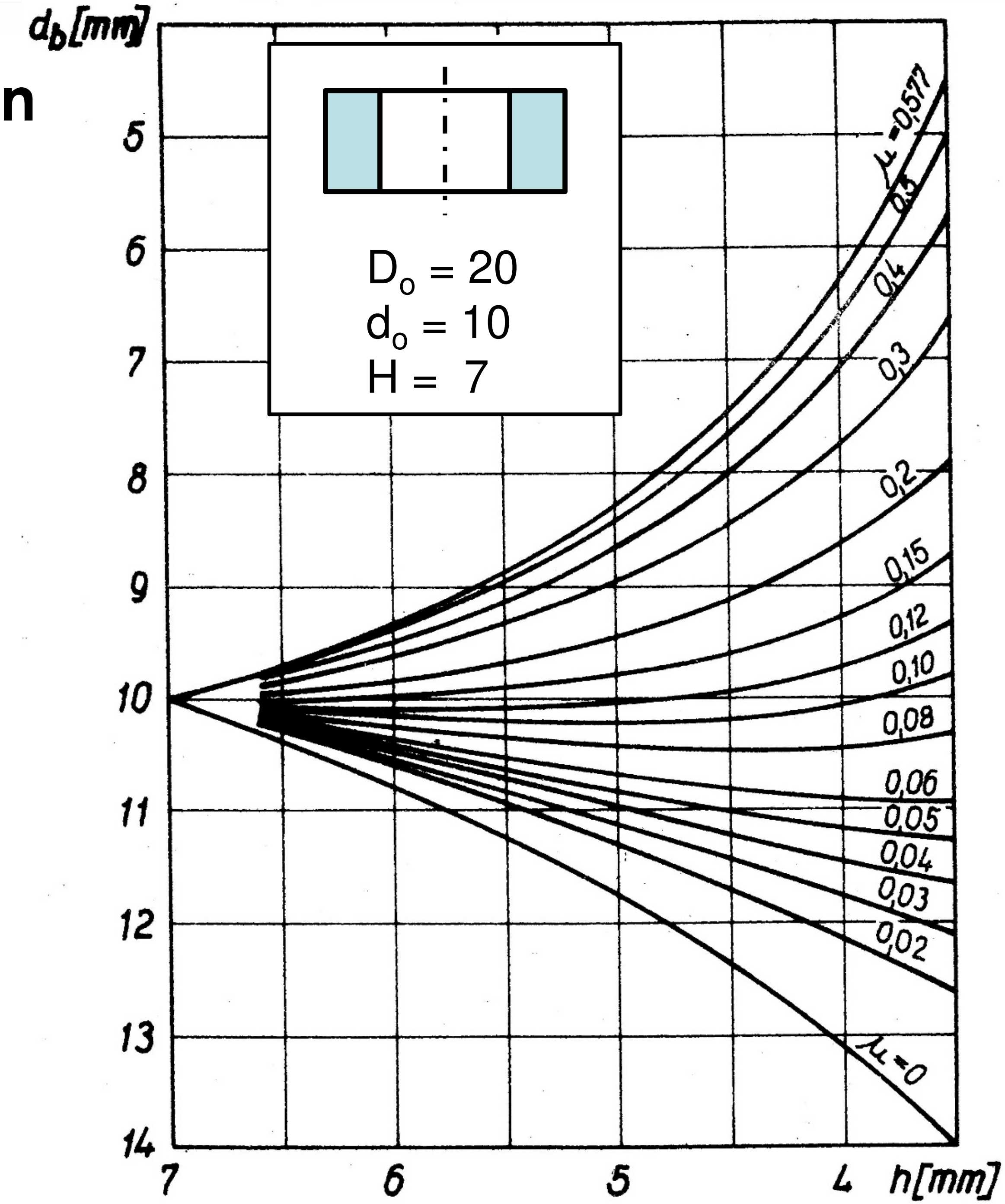
The most common ring size in the practice for **cold working** is the **20/10/7** (outer dia/inner dia/height) size. For higher temperature bigger size rings are recommended having higher heat capacity.

Friction coefficient measurement



Friction coefficient measurement

Coulomb friction



Measurement task

Measure the Kudo friction

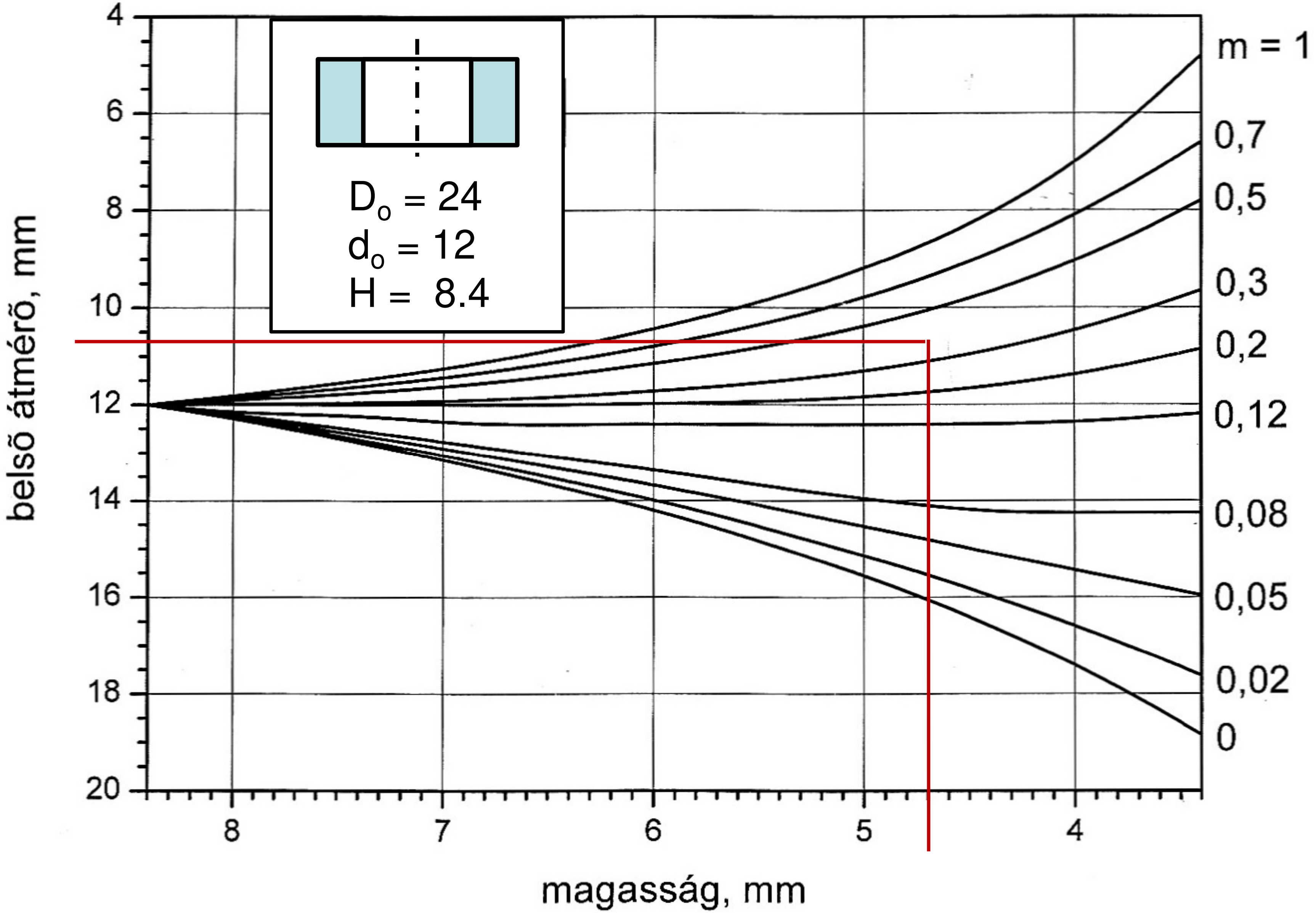
Ring size 24/12/8.4, made in AlMg3 material.

Conditions: room temperature and 400 °C
dry and lubricated by mineral oil.
(dry: cleaned by aceton)

630 MN Eccentric press

Friction coefficient measurement

Kudo (shear) friction



Measurement task

Measured results:

No.	Temp.	Lubr.	Height	Inner Φ	Kudo
1	20	No	4.7	10.7	0.38
2	400	No	3.81	6.2	1
3	20	Oil	4.62	11.8	0.18
4	400	Oil	3.75	8.9	0.47

No. 3 point is shown on the previous slide

Findings:

– applying lubrication decreases the friction

– increased temperature increased the friction (oxidising, burning the lubricant)

– the elastic deformation of the machine was well noticed from the height differences, caused by the changing of the material resistance against deformation constraint.

Thank you for your attention!