Metal Forming – BSc 2026/27-1

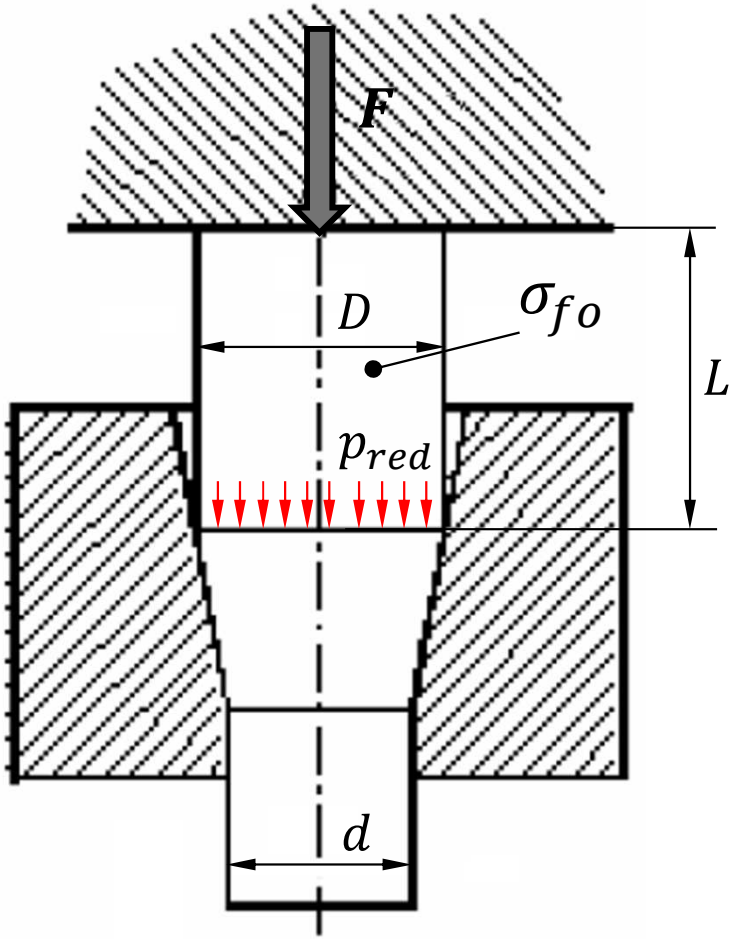
Reduction, extrusion, ironing

Content

- **Reduction**
- **Forward (direct) extrusion**
  - parts
  - profiles
- **Backward (indirect) extrusion**
- **Combined extrusion**
- **Ironing**

Reduction

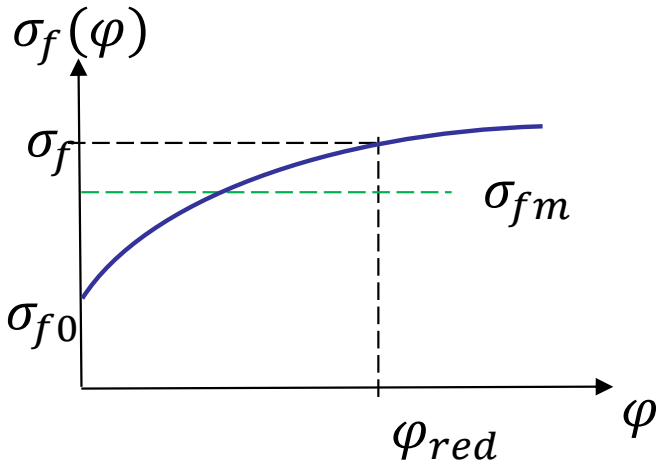
Reduction of cross section by pushing through a conical die.
Possible diameter change is around 10 %.



Limitations: - $p_{red} < \sigma_{fo}$

- $L/D < L/D_{buckling}$

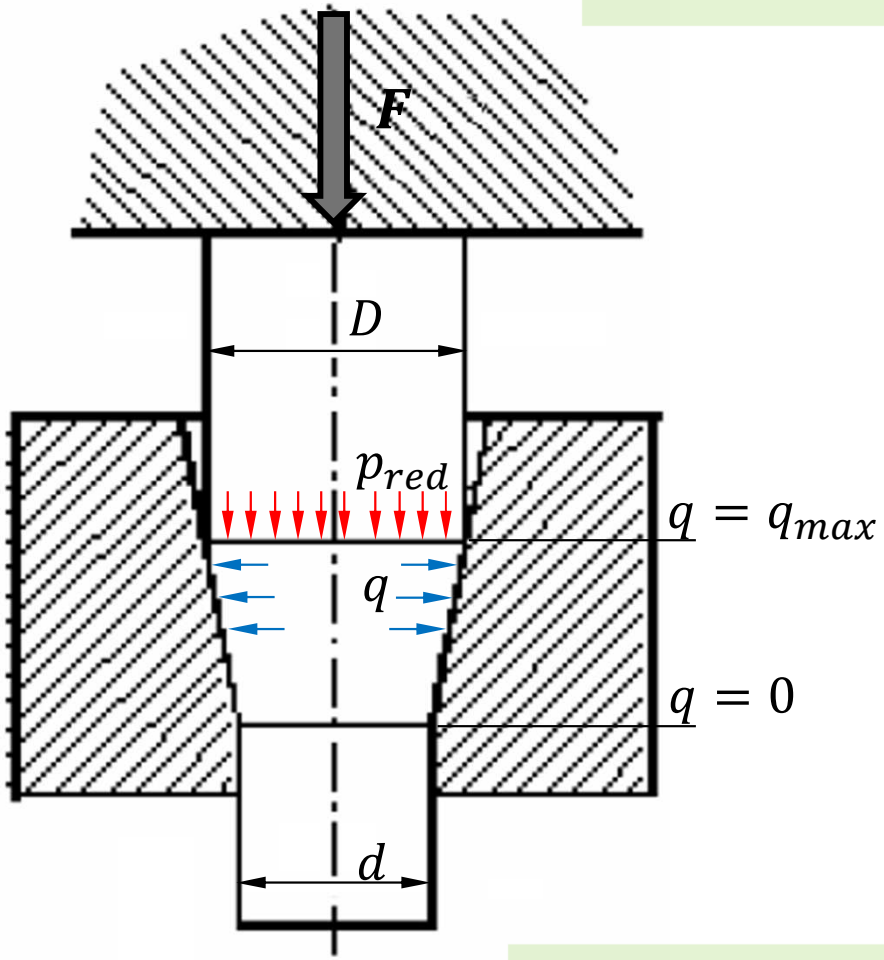
Mean flow stress:



Reduction

Reduction stress:

$$p_{red} = \sigma_{fm}\left(\frac{1+B}{B}\right)(e^{B\varphi_{red}} - 1) + 0{,}77\sigma_{fm}\,\alpha$$



$$B = \frac{\mu}{\tan\alpha} \approx \frac{\mu}{\alpha} \qquad \varphi_{red} = \ln\frac{D^2}{d^2}$$

μ – Coulomb friction coefficient
α – half cone angel (radian)

σ_{fm} – mean flow stress

Reduction force:

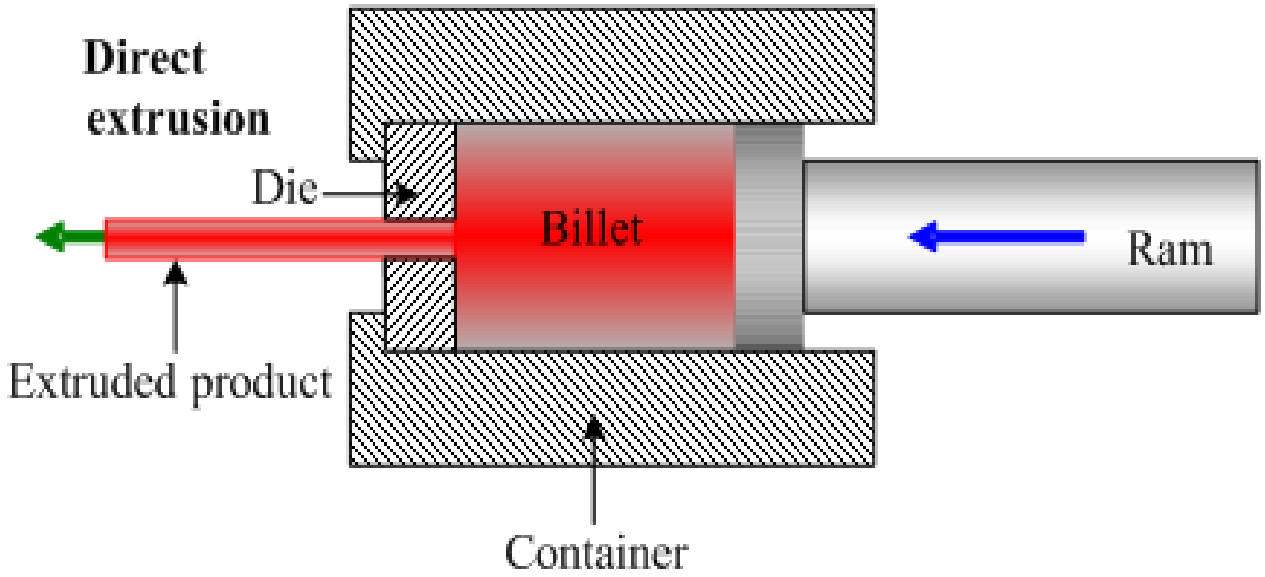
$$F = \frac{D^2\pi}{4}p_{red}$$

Max pressure:

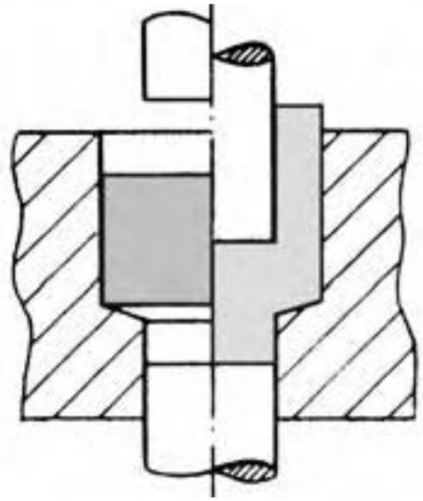
$$q_{max} = \sigma_{fm}\left[1 + \left(\frac{1+B}{B}\right)(e^{B\varphi_{red}} - 1) + 0{,}77\sigma_{fm}\alpha\right]$$

Extrusion

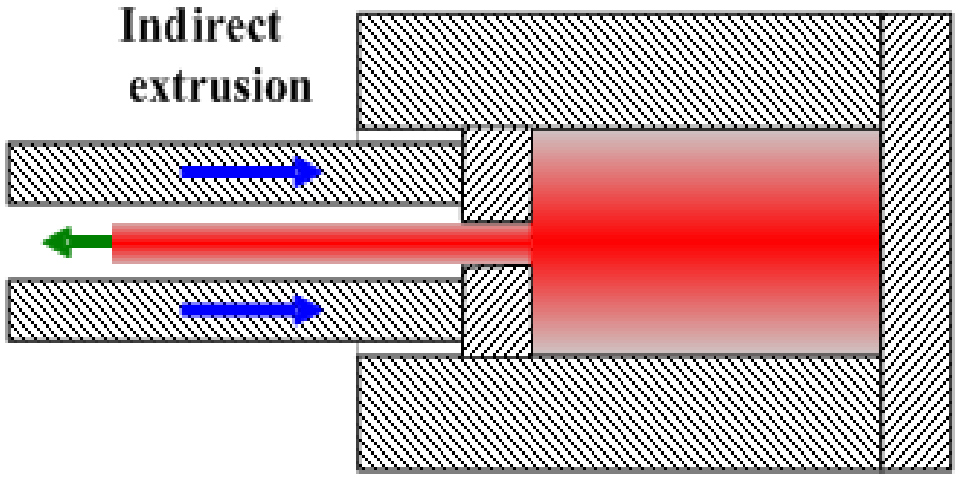
Forward extrusion



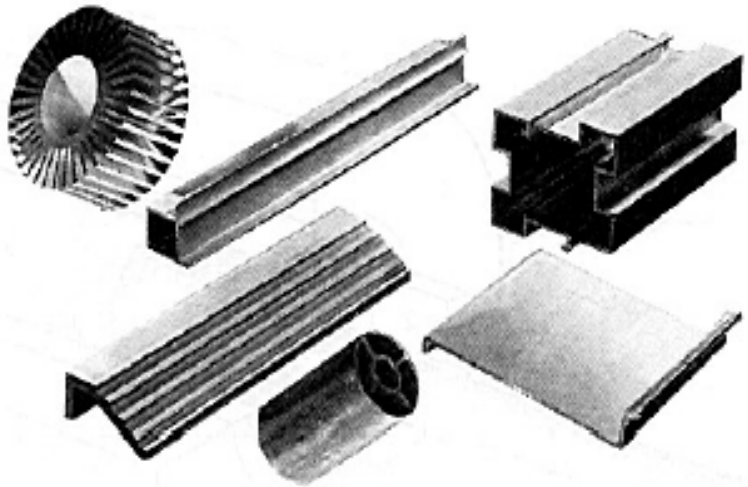
Combined extrusion



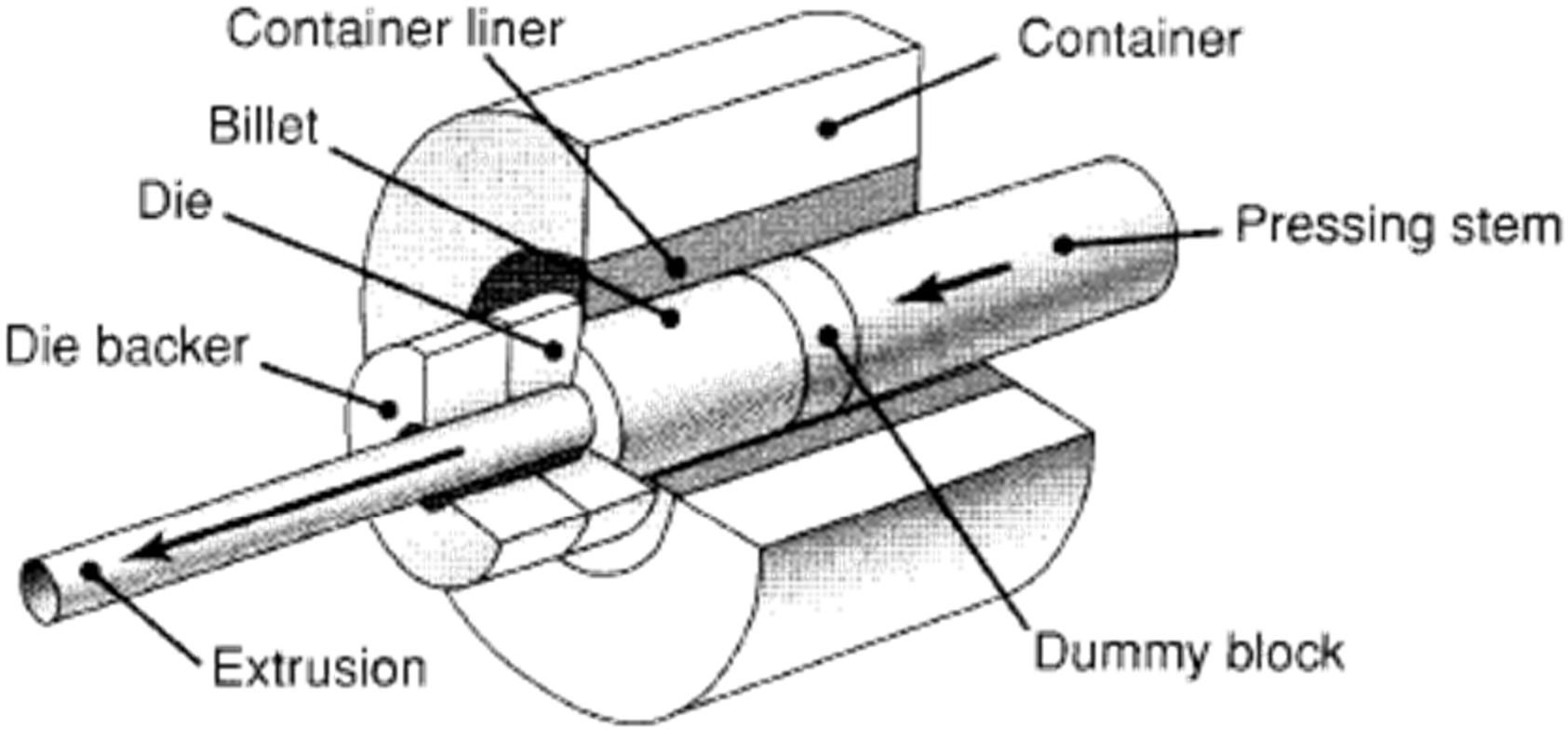
Backward extrusion



Extruded parts

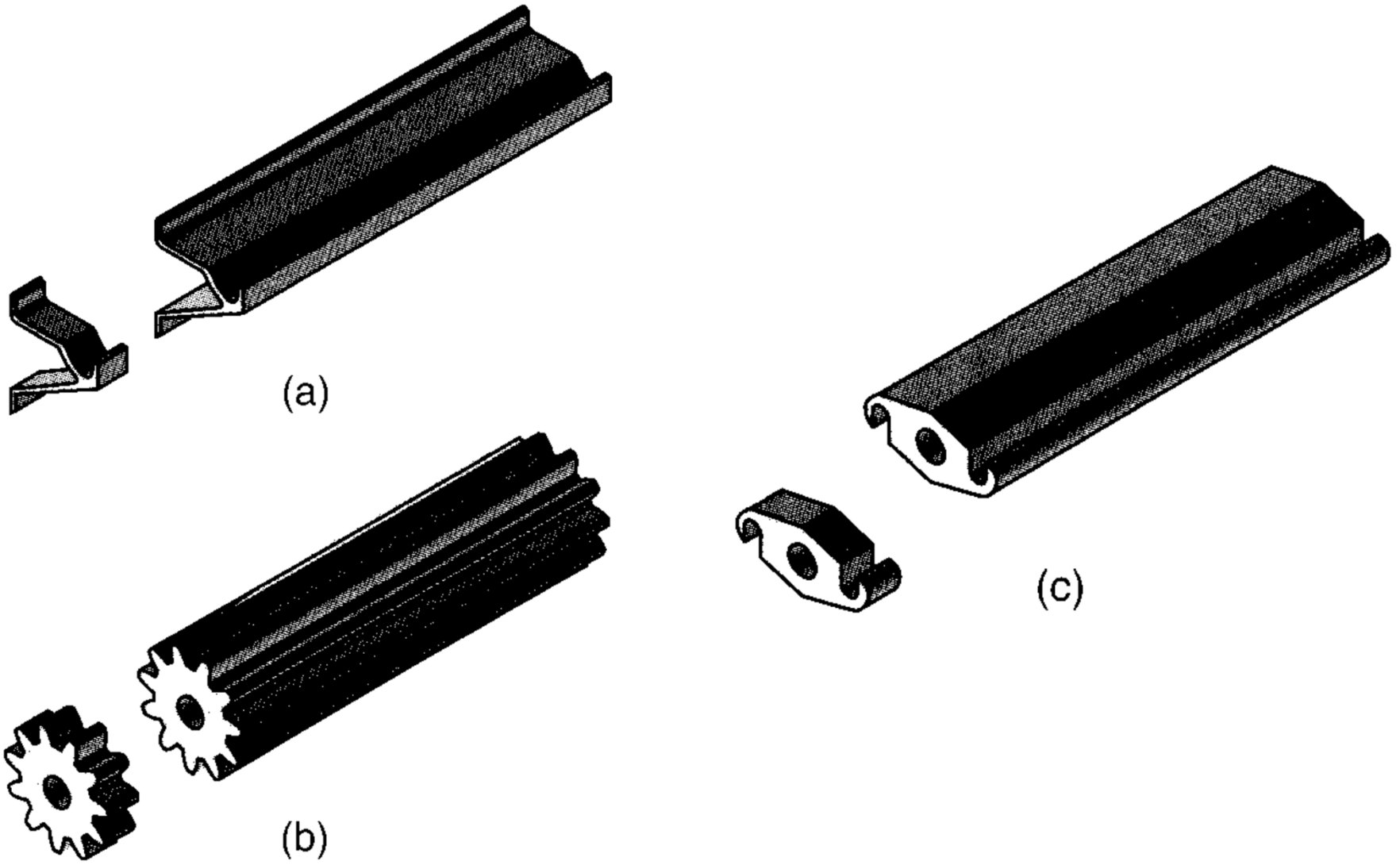


Forward extrusion



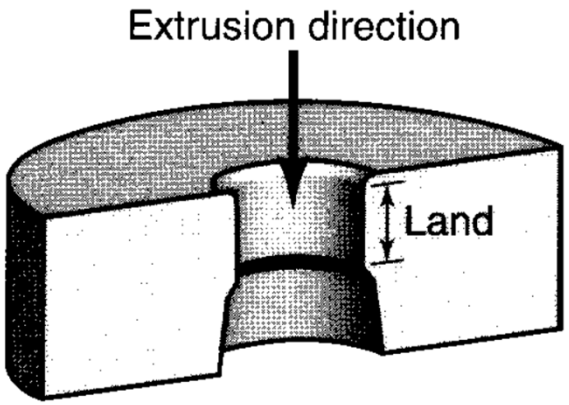
Forward extrusion

Products made by sectioning off extruded profiles :



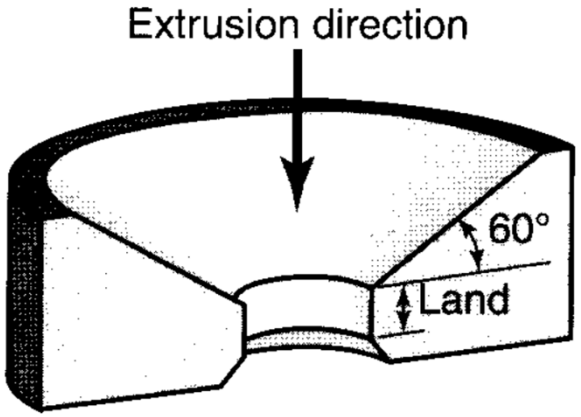
Forward extrusion

Forward extrusion – die design



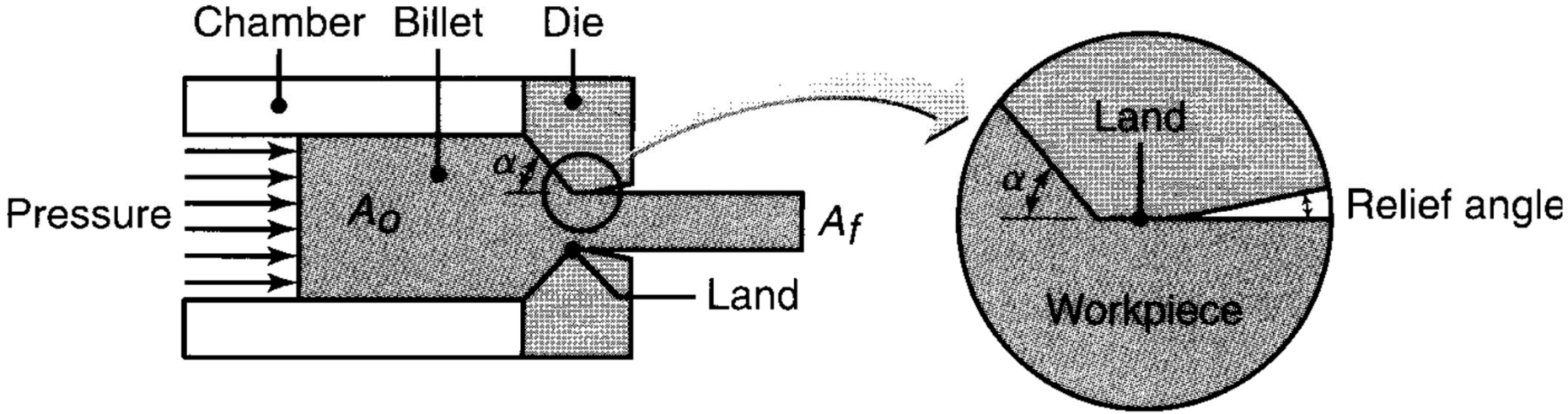
(a)

for nonferrous metals



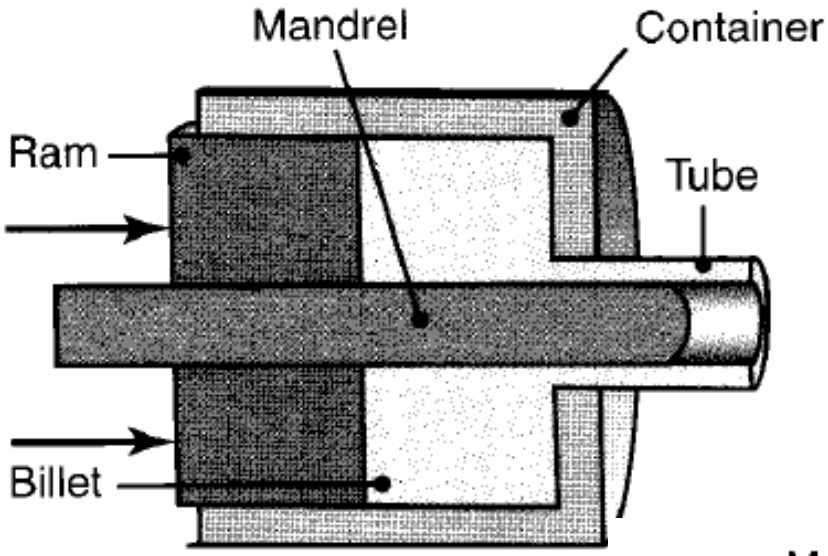
(b)

for ferrous metals



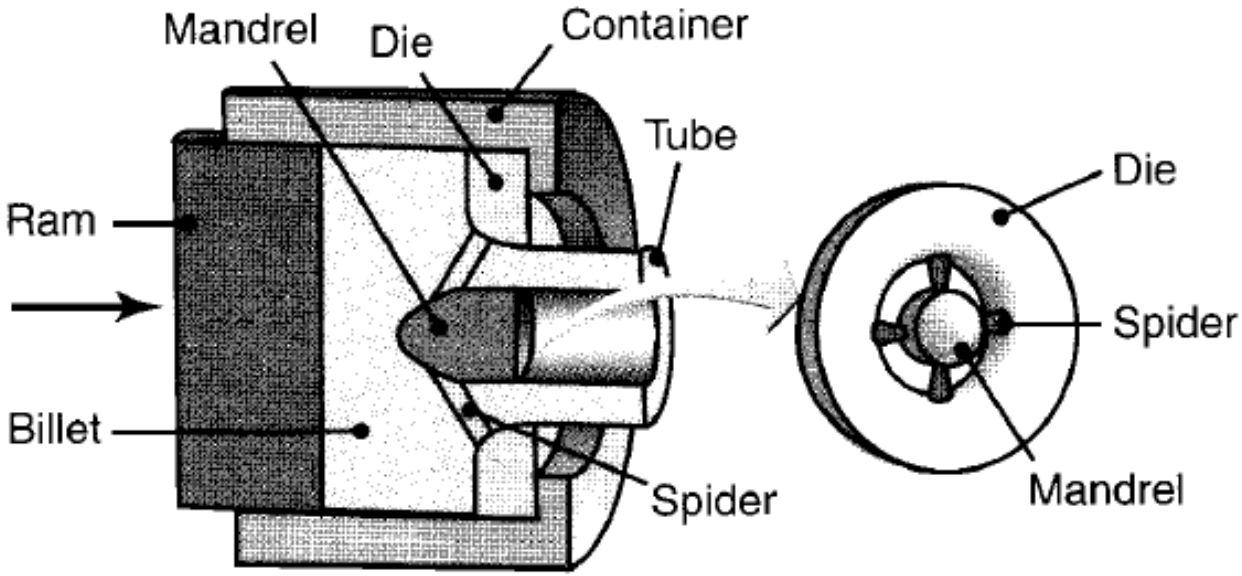
Forward extrusion

Forward extrusion of seamless tubes and hollow cross sections



using an internal mandrel

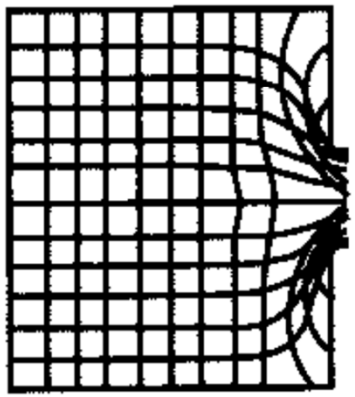
using a spider die



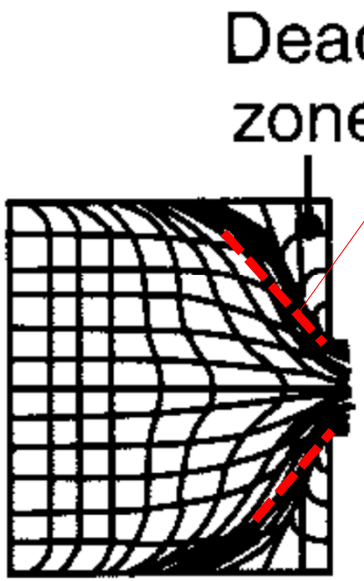
Forward extrusion

Metal flow in right angle extruding dies

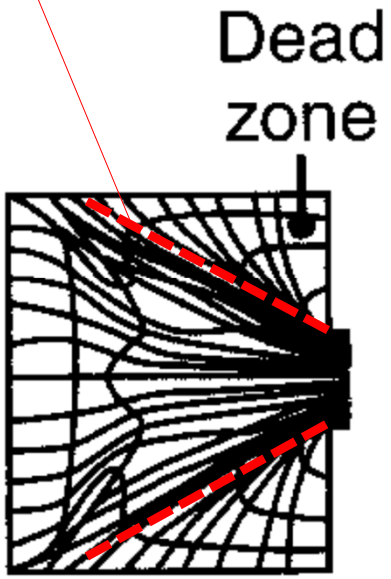
„die angle" is formed on the interface of dead zones and flowing metal



low friction in direct extrusion

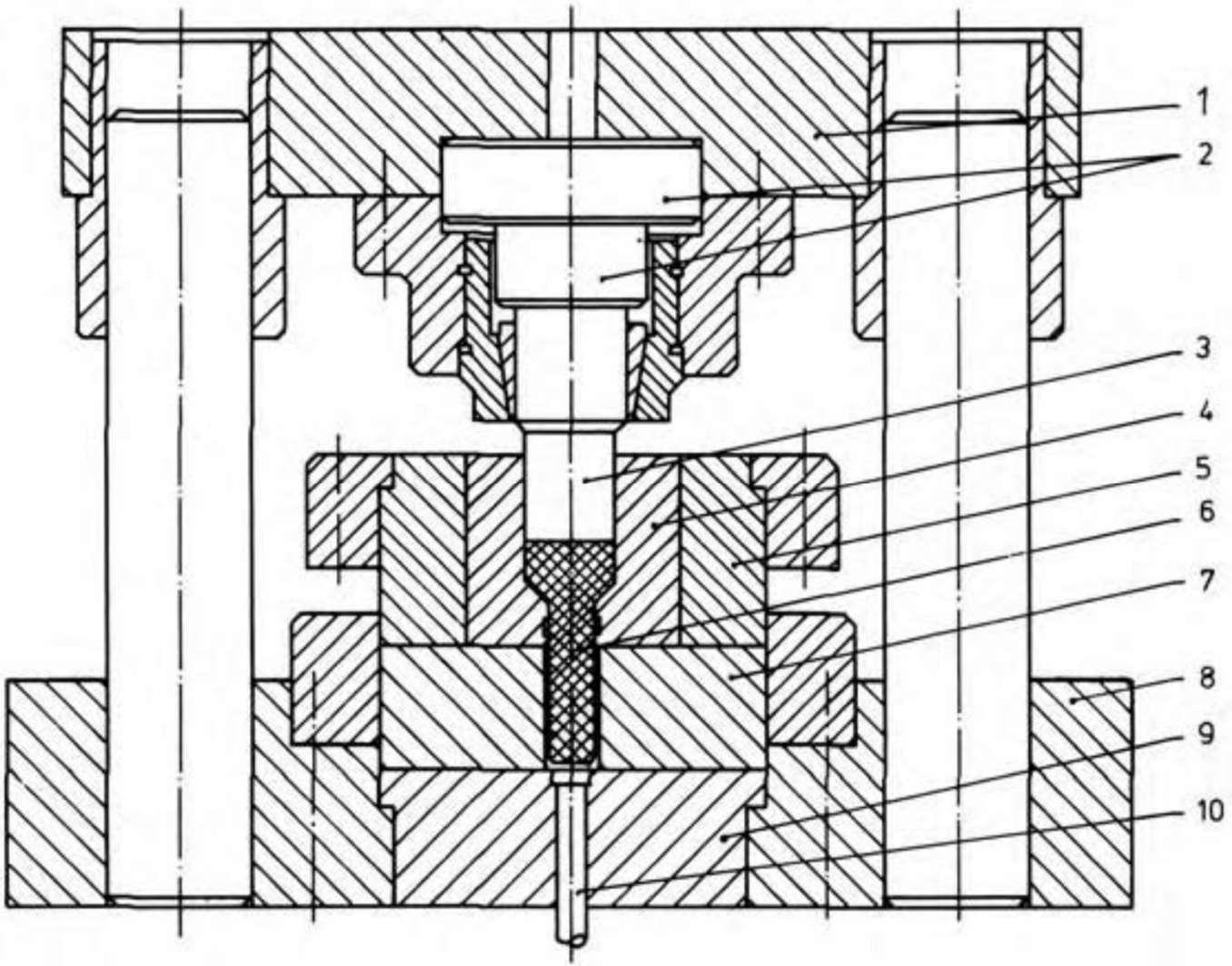


high friction



high friction and/or cooling from outside

Forward extrusion - parts

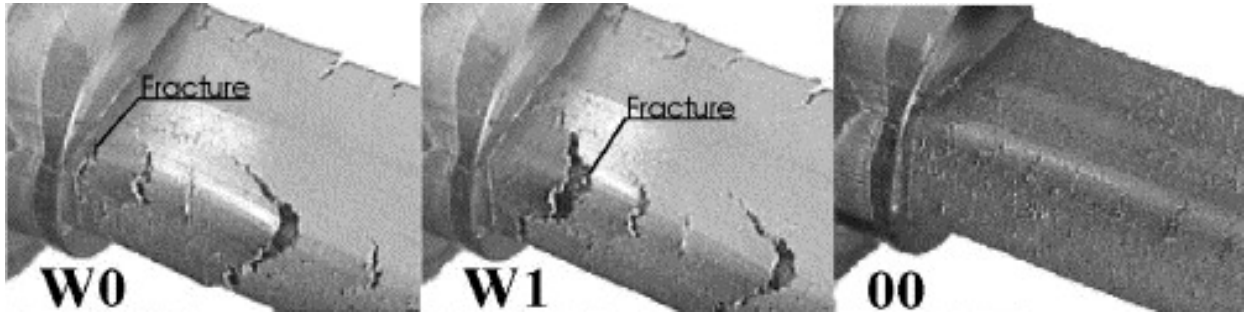


1 top plate
2 pressure plate
3 punch
4 die
5 retaining ring (shrink fit)
6 workpiece
7 distance plate
8 base plate
9 pressure plate
10 ejector

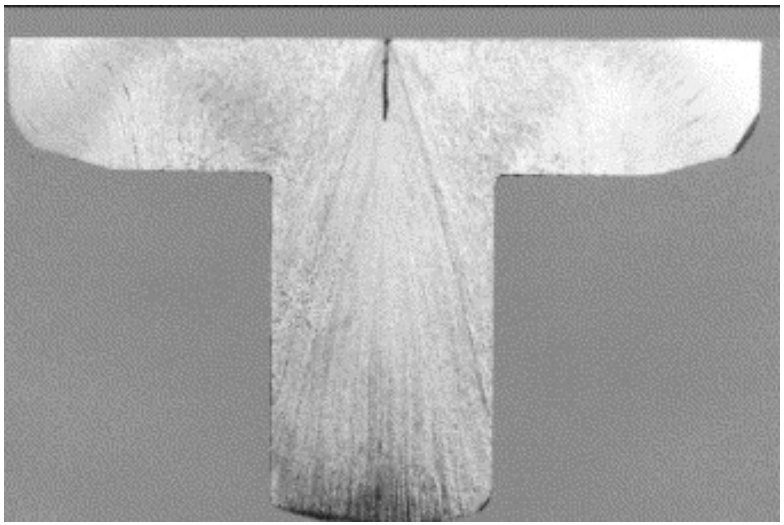
Forward extrusion – defects

Surface cracking

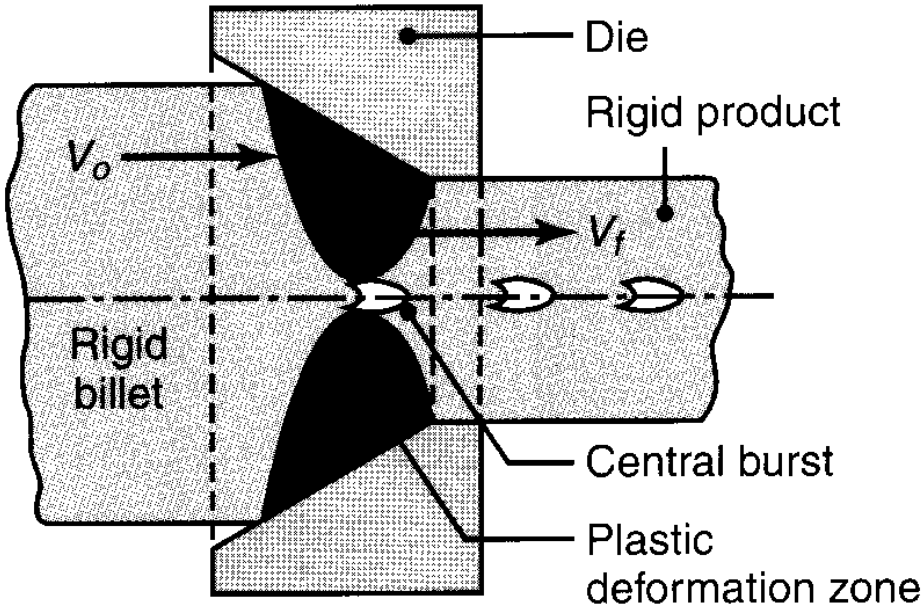
Stick-slip – bamboo defect



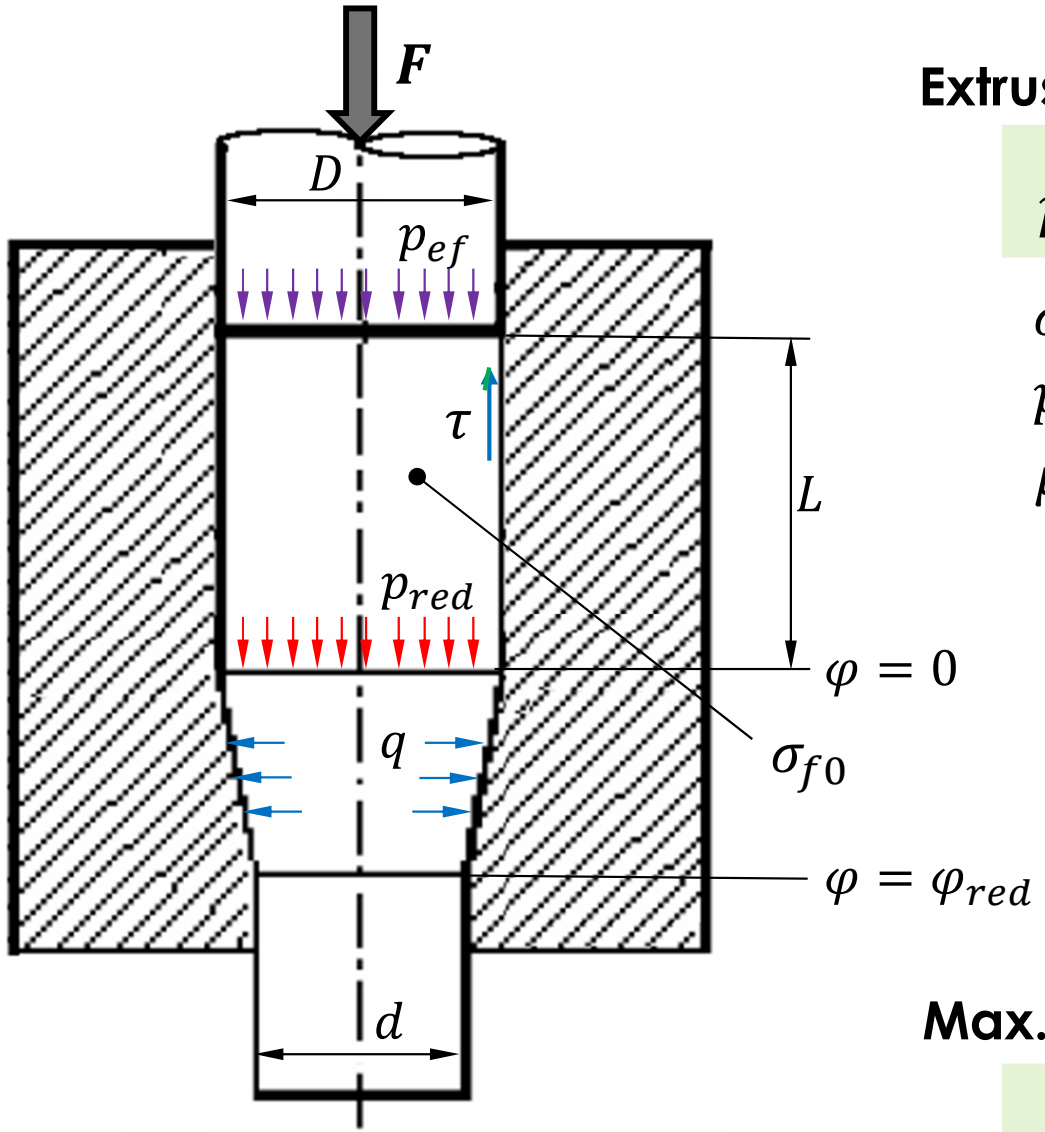
Pipe (fishtail) defect



Internal cracking



Forward extrusion – calculation



Extrusion pressure:

$$p_{ef} = \left(\sigma_{f0} + p_{red}\right) e^{\frac{4\mu L}{D}} - \sigma_{f0}$$

σ_{f0} – initial flow stress

p_{red} – reduction stress (see there)

μ – Coulomb friction coefficient

Extrusion force:

$$F = \frac{D^2 \pi}{4} p_{ef}$$

Max. pressure on recipient:

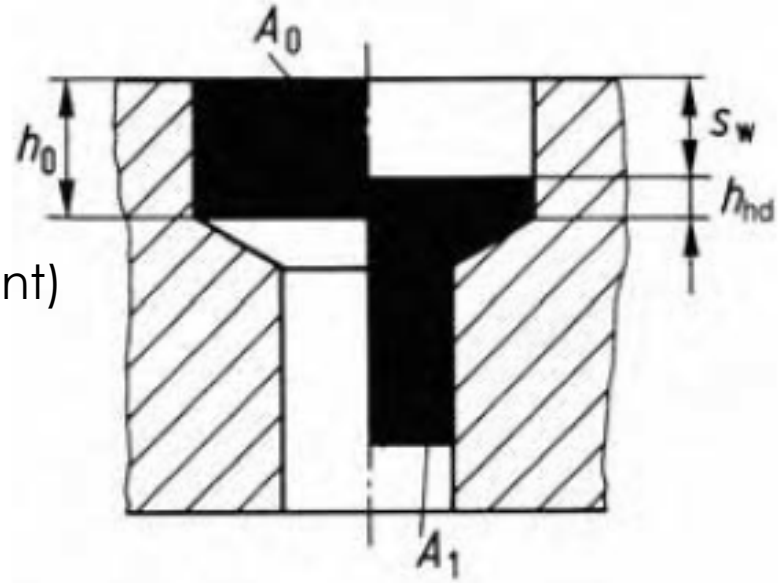
$$q_{max} = \left(\sigma_{f0} + p_{red}\right) e^{\frac{4\mu L}{D}}$$

Forward extrusion – calculation

Mechanical work :

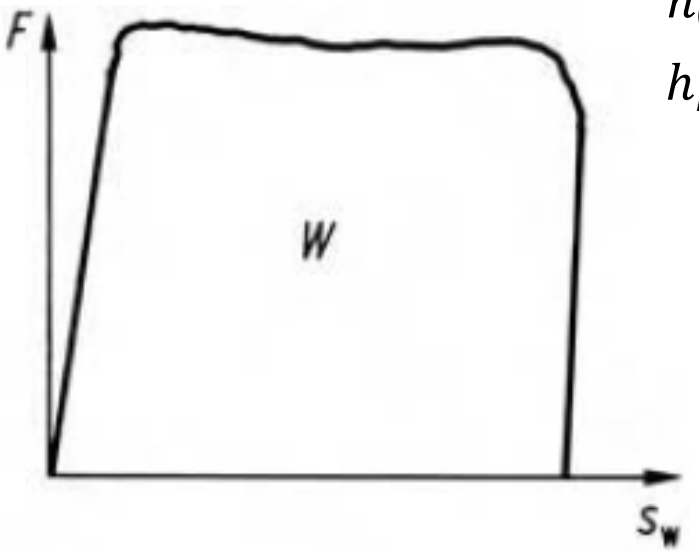
$W = F\ s_w\ x$ x – process factor (use x=1)

$s_w = h_0 - h_{hd}$ s_w – active stroke (displacement)



h_0 – blank height

h_{hd} – head height



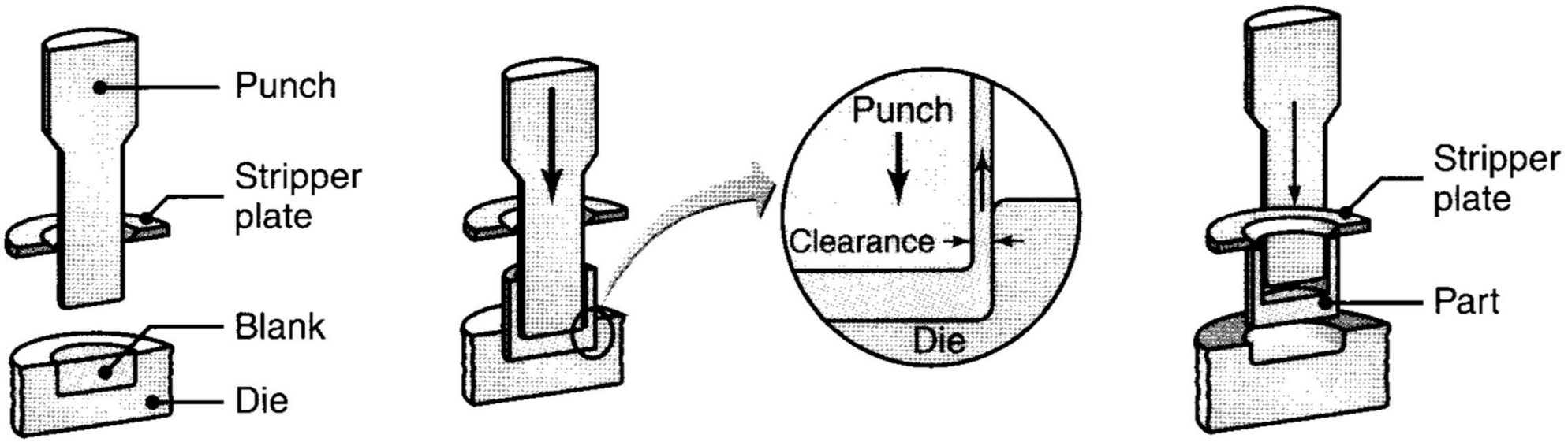
Approximate calculation: $W = \frac{V_o\ \sigma_{fm}\ \varphi_{eqv}}{\eta_f}$

V_0 – blank volume φ_{eqv} – equivalent strain

σ_{fm} – mean flow stress η_f – forming efficiency (0.6–0.8)

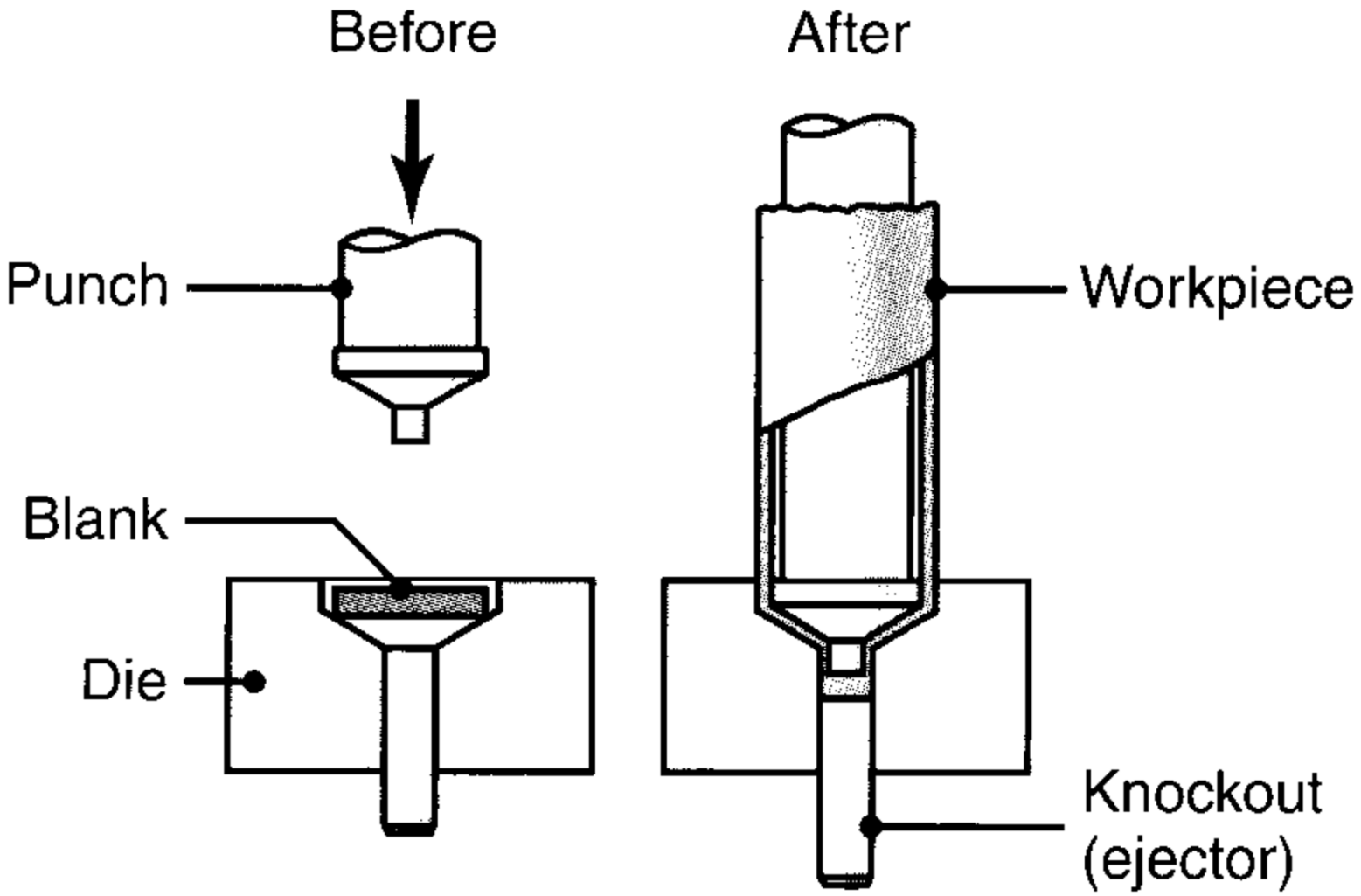
Backward extrusion

Cold backward extrusion process

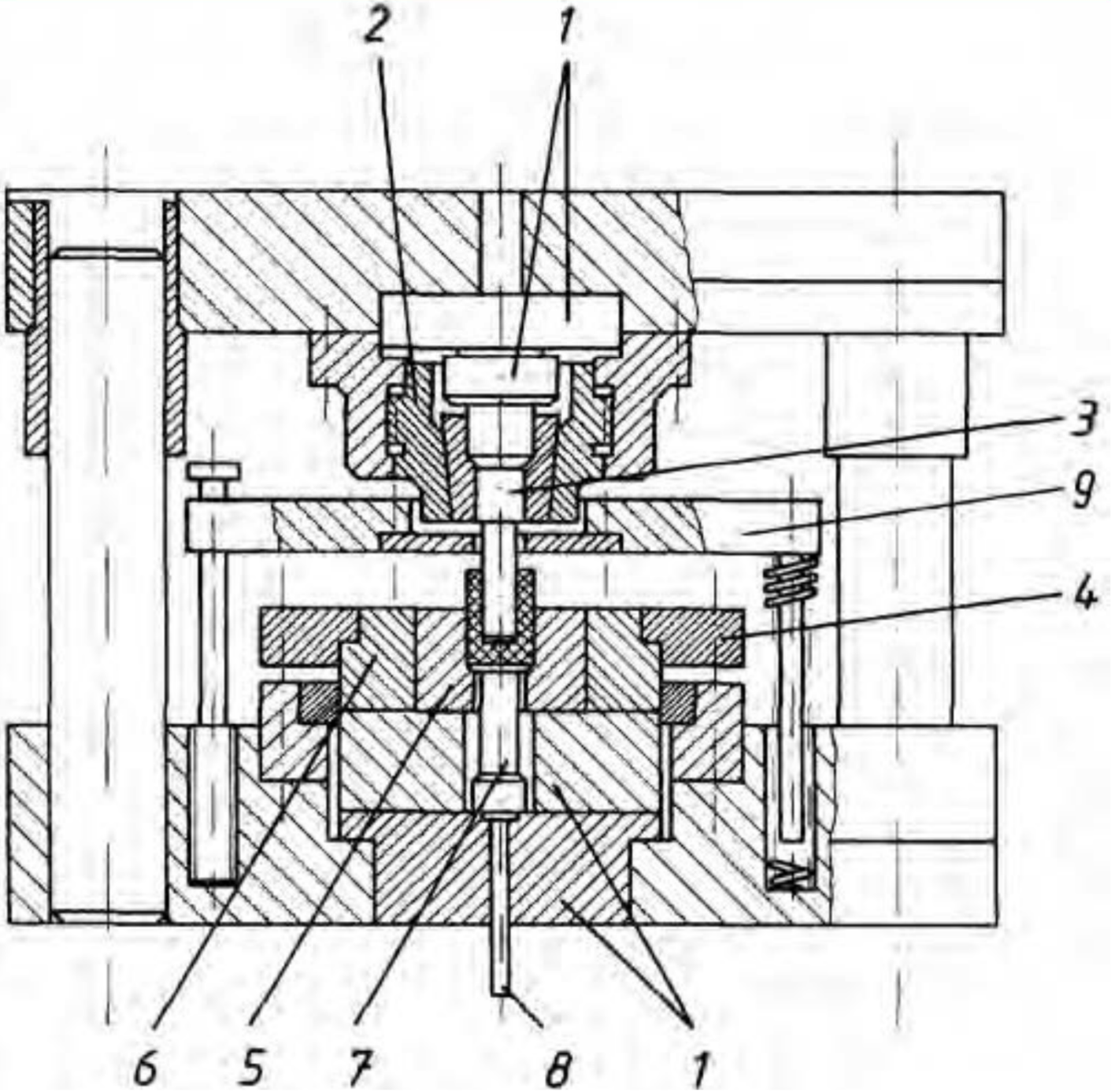


Backward extrusion

Extrusion of a collapsible tube



Backward extrusion – tooling

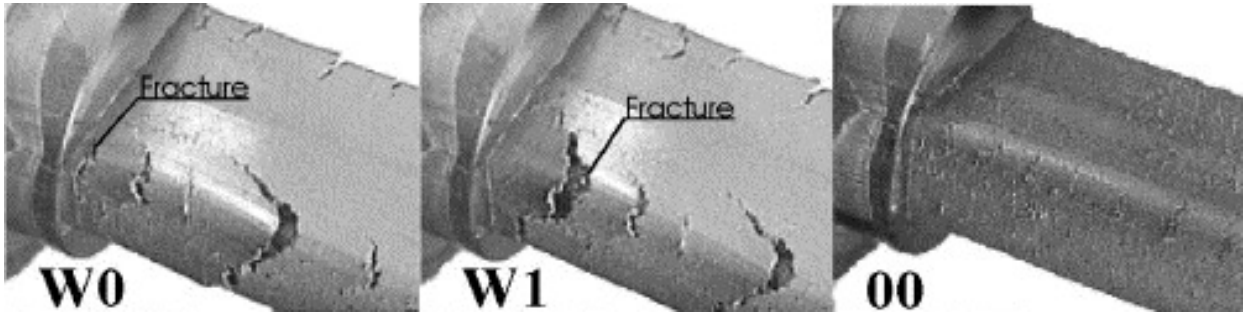


1 die plate
2 clamp nut for punch
3 punch
4 tension ring for the die
5 die
6 retaining ring (reinforcement)
7 counter-punch
8 ejector
9 stripper

Backward extrusion - defects

Surface cracking Stick-slip – bamboo defect

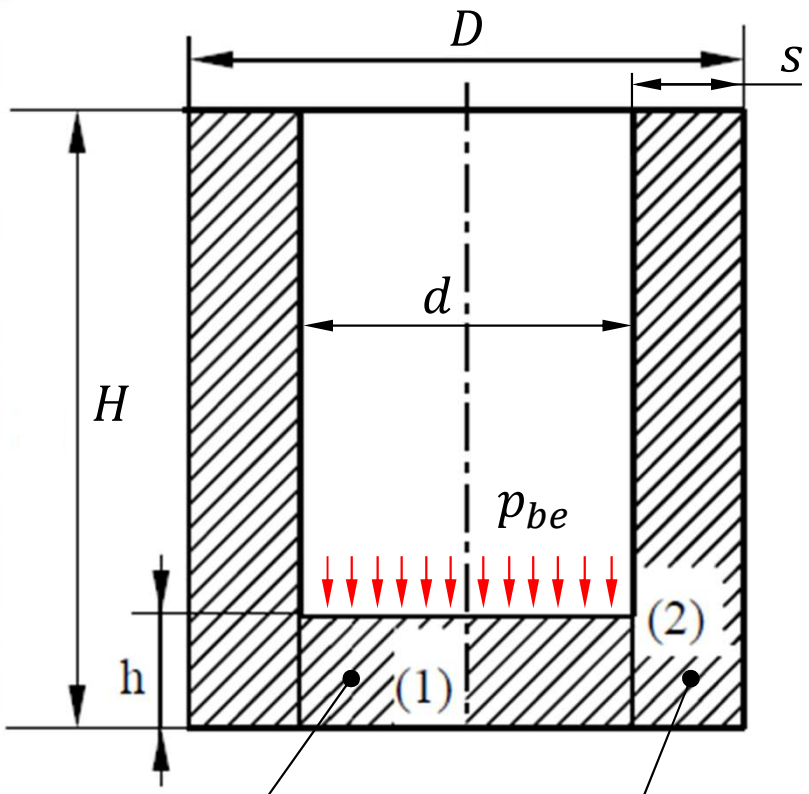
(as in the case of forward extrusion)



Cracks on the inner and outer surface



Backward extrusion – calculation



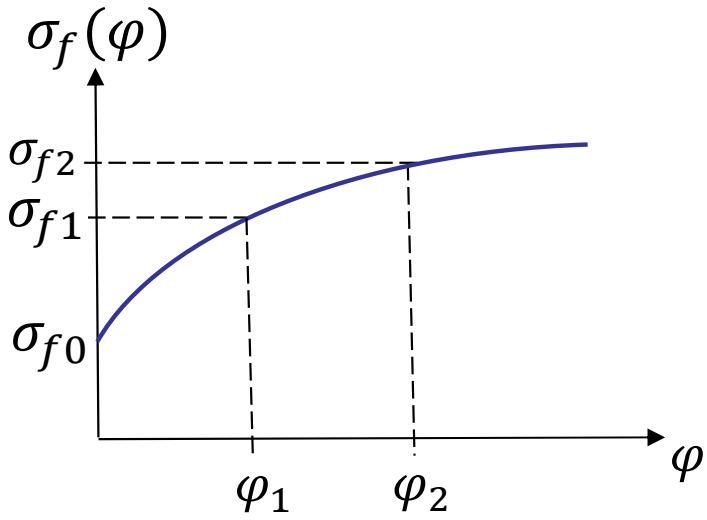
Extrusion pressure on punch:

$$p_{be} = \sigma_{f1}\left(1 + \frac{\mu}{3}\frac{d}{h}\right) + \sigma_{f2}\left(1 + \mu'\frac{h}{s}\right)$$

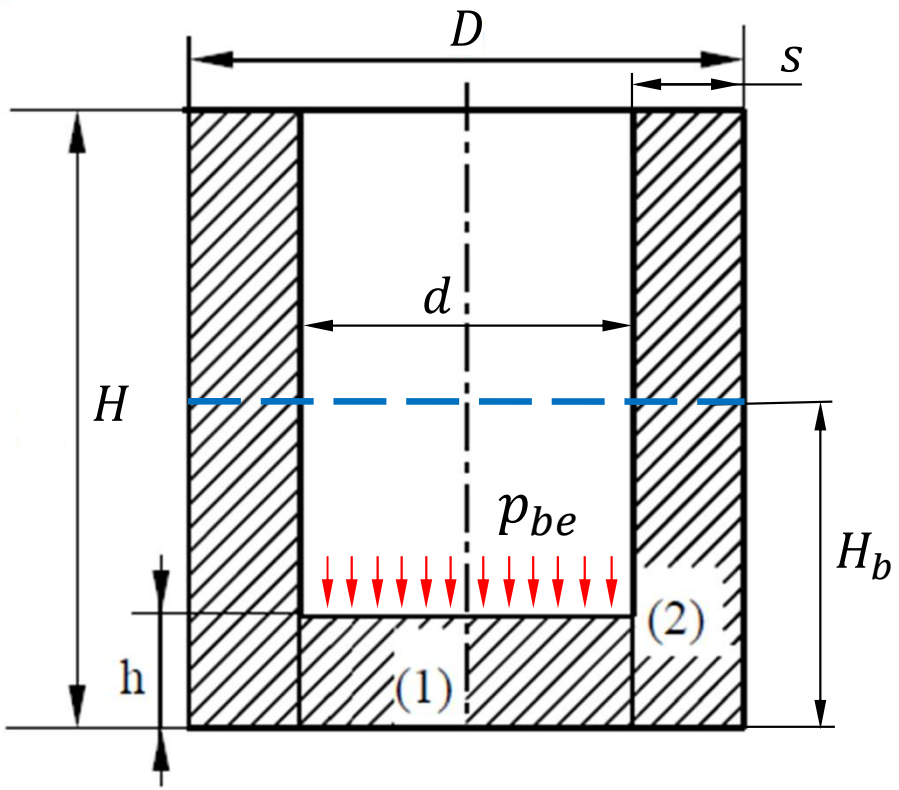
$\mu -$ Coulomb friction coefficient

$$\mu' = \frac{1}{2}\left(\mu + \frac{1}{\sqrt{3}}\right)$$

$$\varphi_1 = ln\left(\frac{H}{h}\right) \qquad \varphi_2 = \varphi_1\left(1 + \frac{d}{8s}\right)$$



Backward extrusion – calculation



Backward extrusion force:

$$F = \frac{d^2\pi}{4} p_{be}$$

Pressure on recipient:

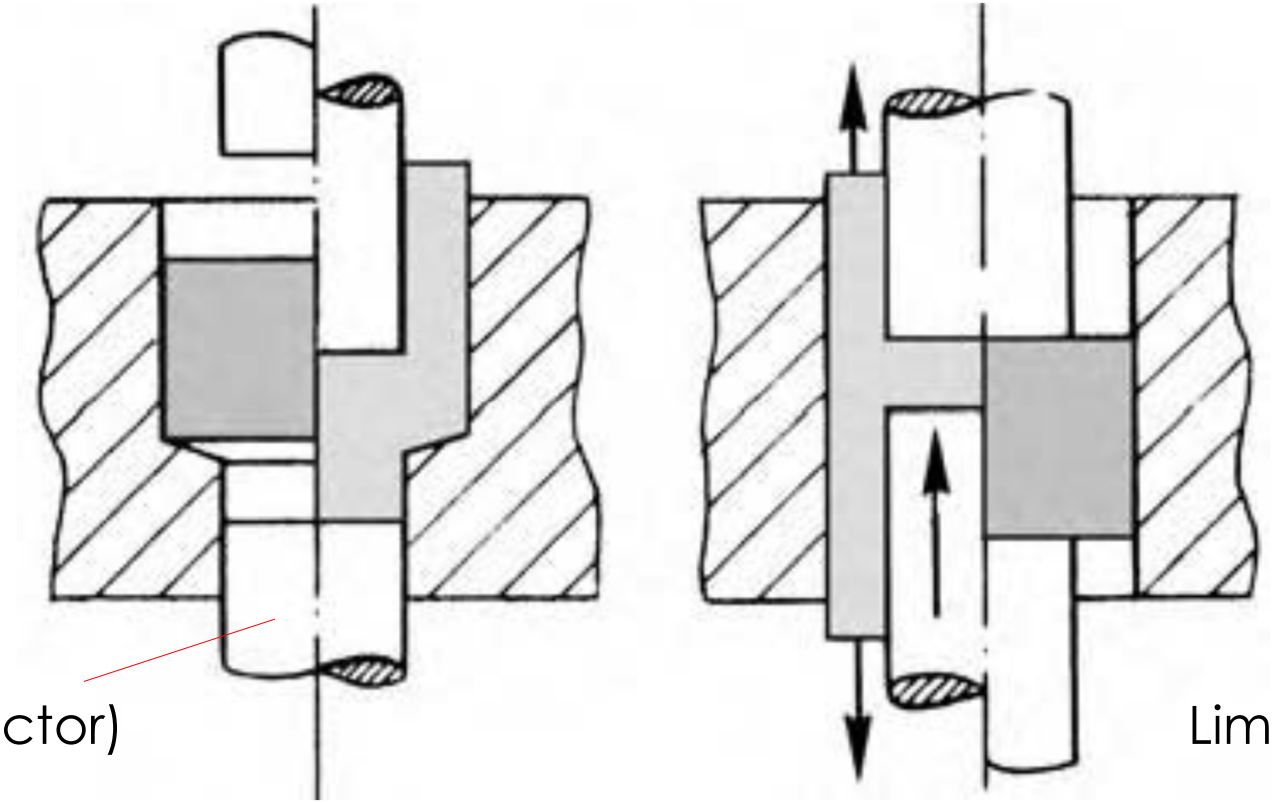
$$q_{max} = p_{be} \frac{d^2}{D^2}$$

Mechanical work: $W = F\ s_w\ x$ x – process factor (use x=1)

$s_w = H_b - h$ s_w – active stroke (displacement) H_b– blank height

Combined extrusion

Combination of forward and backward extrusion :

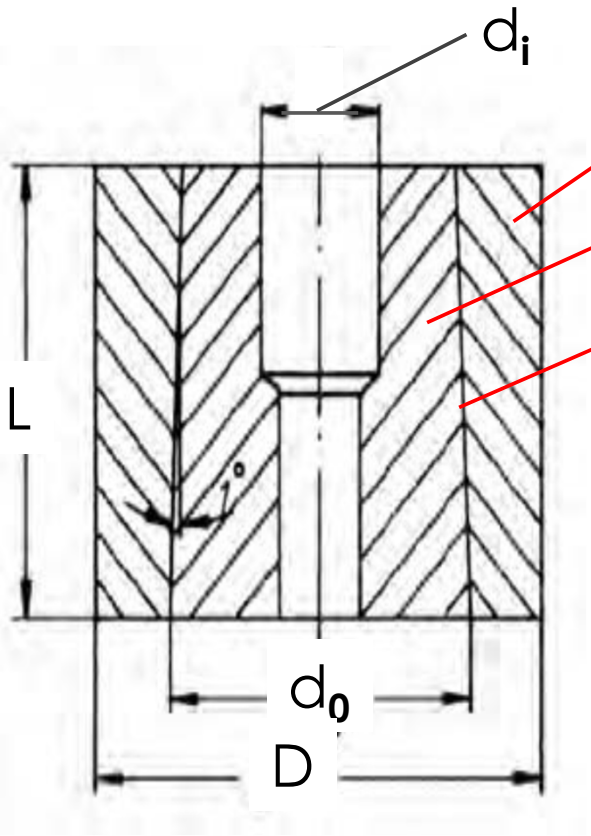


Limiter (ejector)

Limiter ???

The material flows forward and backward as well – one of them should be limited to get identical workpieces.

Reinforced die



retaining ring

die

conical fit (1°)

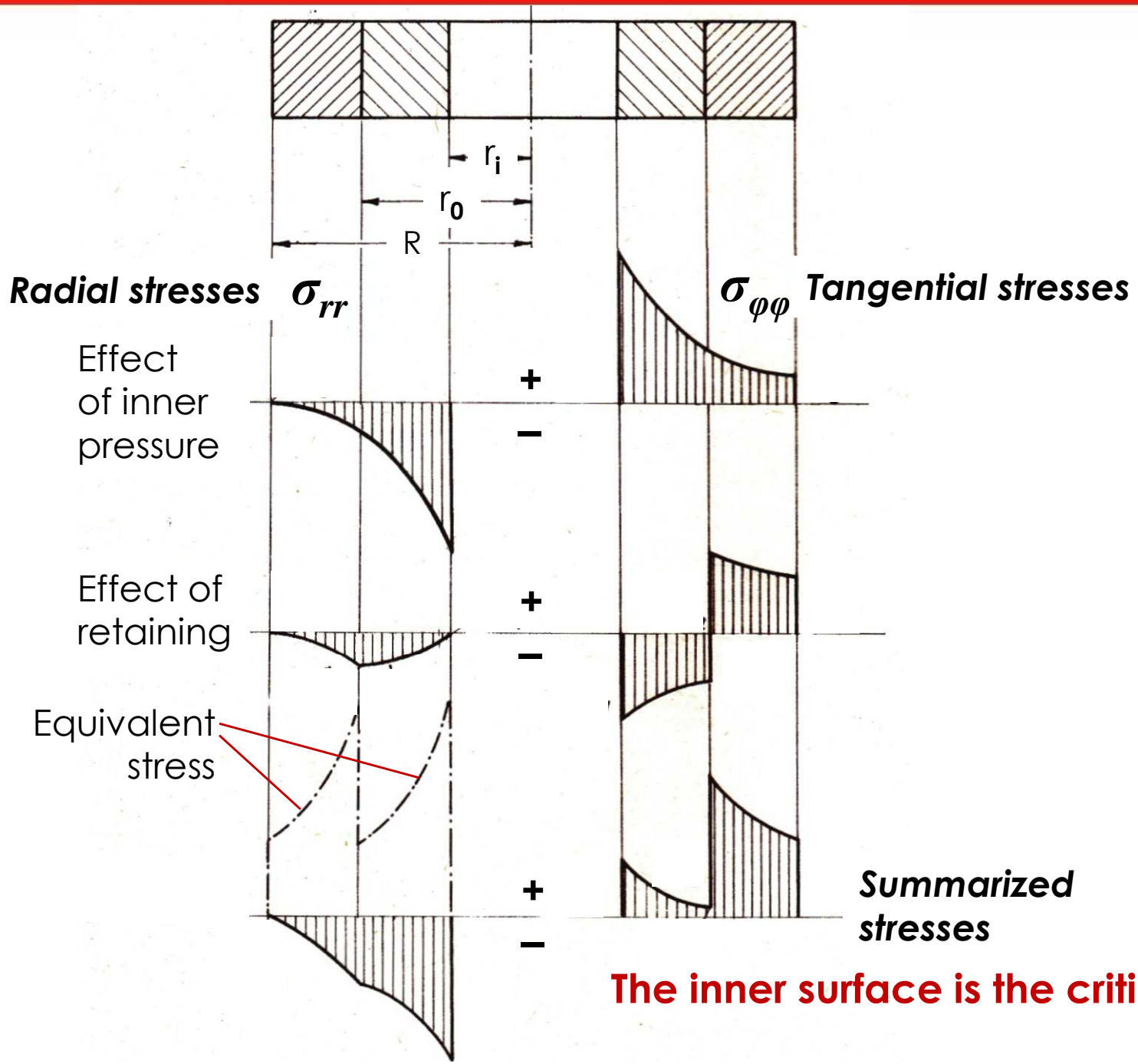
Simplified calculation

The die is a thick-walled tube.

Assumptions:

1. The axial deformation is constant;
2. The material is isotropic and homogeneous;
3. The wall thickness is constant;
4. The pressure acts along the whole length;
5. The pressure distribution is homogeneous.

Reinforced die

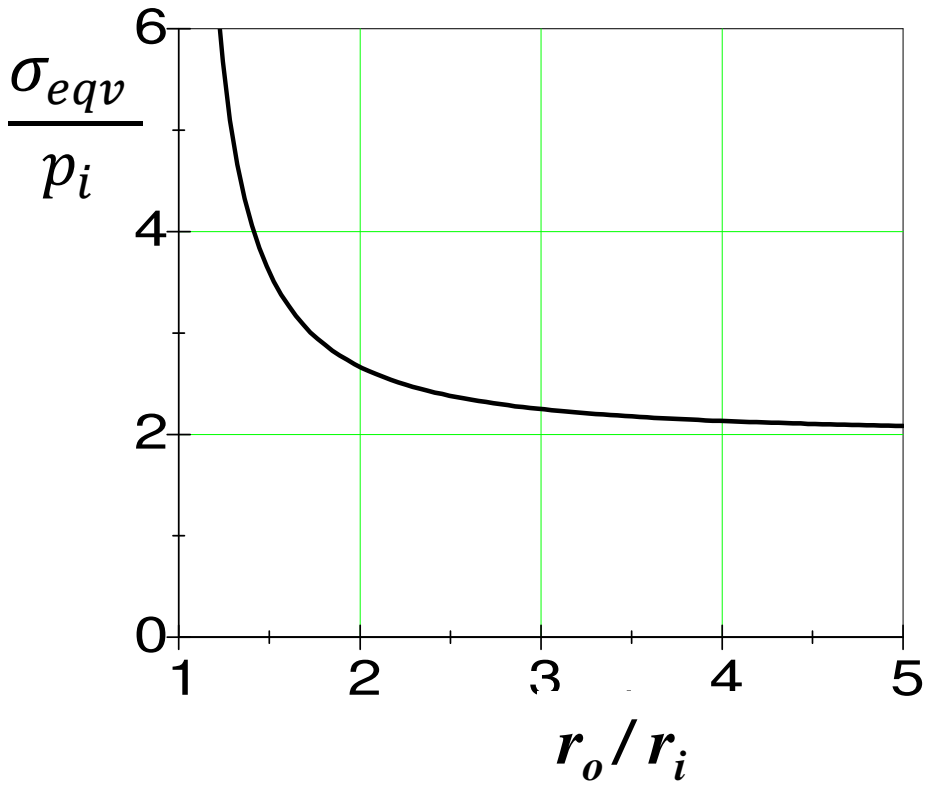


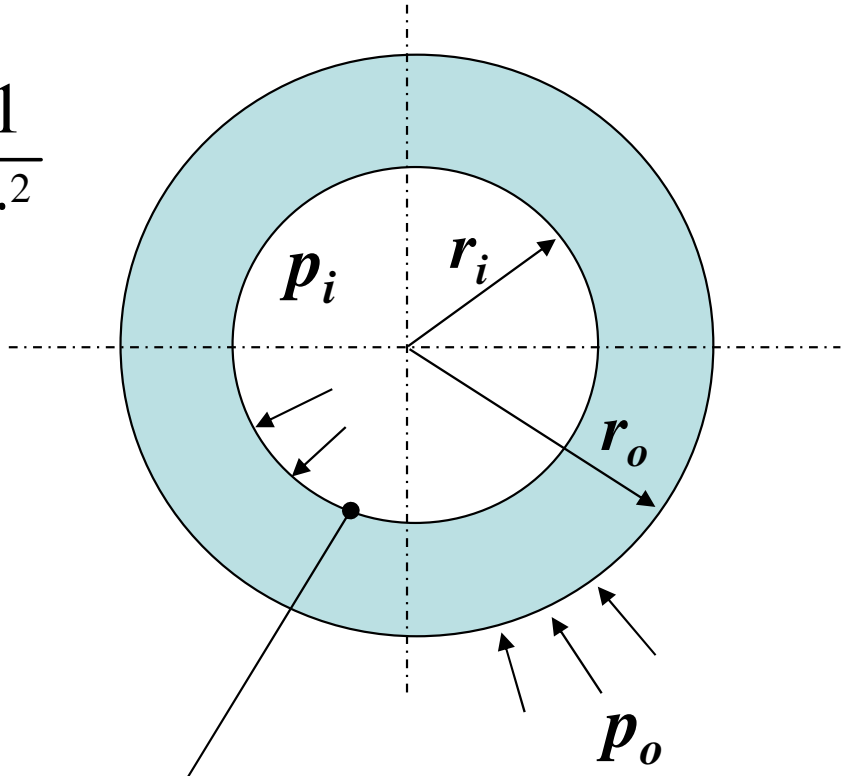
The inner surface is the critical.

Reinforced die

$$\sigma_{rr} = \frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_i^2} - (p_i - p_o)\frac{r_o^2 r_i^2}{r_o^2 - r_i^2}\frac{1}{r^2}$$

$$\sigma_{\phi\phi} = \frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_i^2} + (p_i - p_o)\frac{r_o^2 r_i^2}{r_i^2 - r_i^2}\frac{1}{r^2}$$



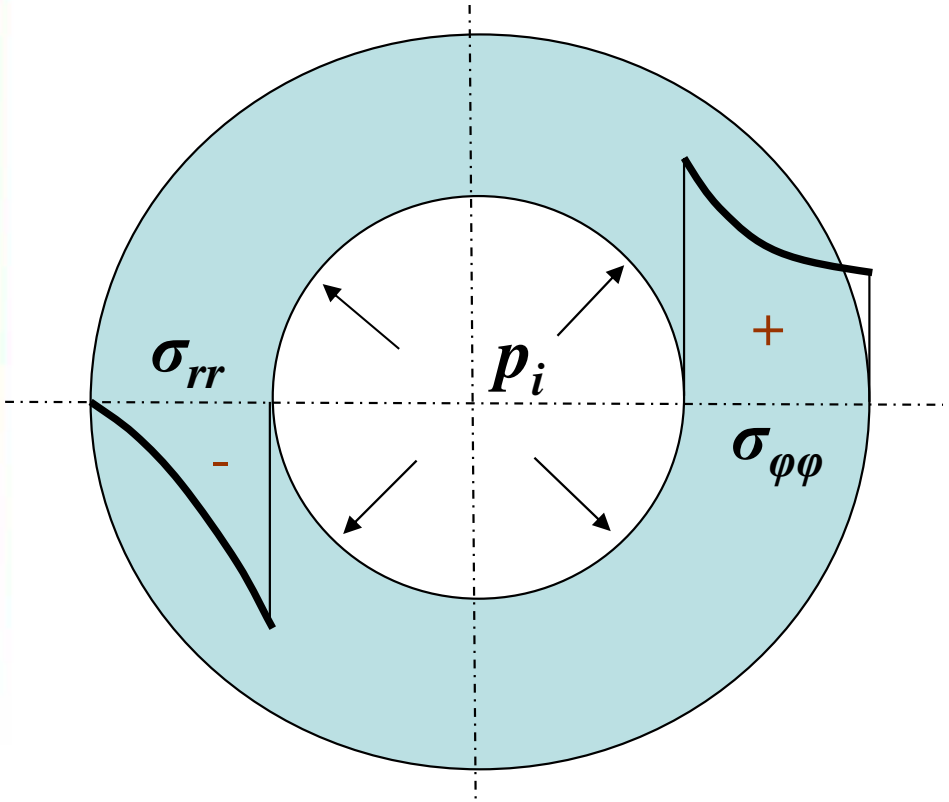


σ_{eqv} – equivalent stress

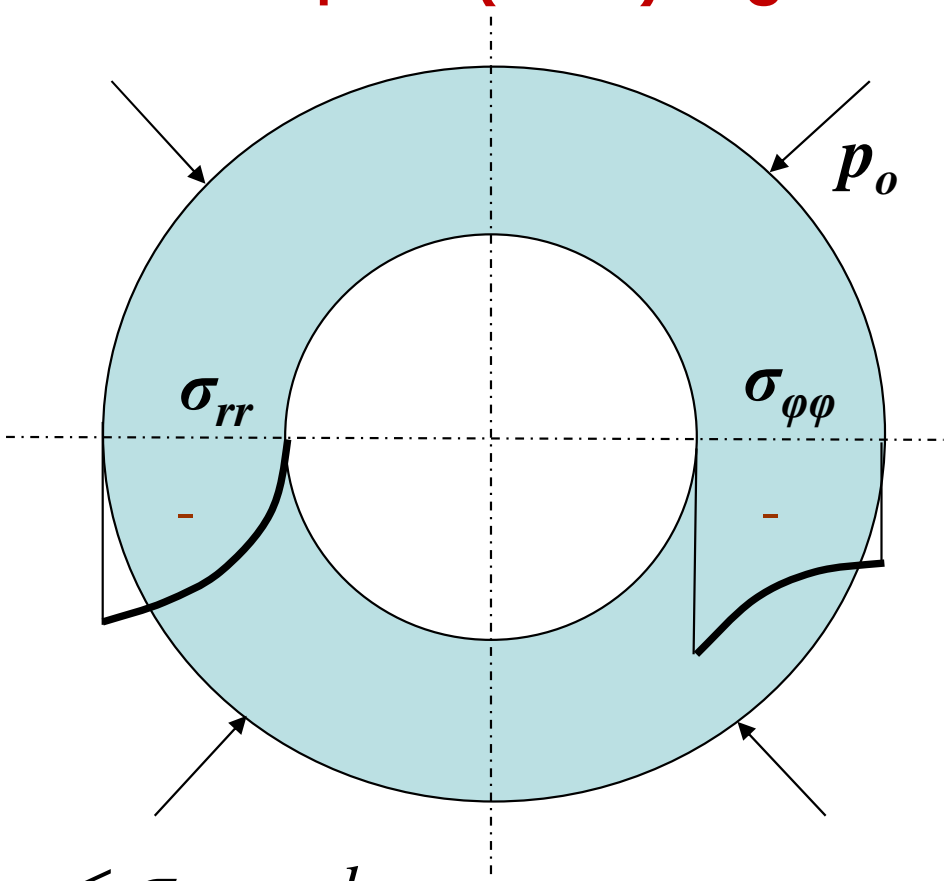
Even the unlimited r_o is useless.

Effect of reinforing

Reinforcing (outer) ring



Recipient (inner) ring



Mohr yield theory: $\sigma_{\max} - \sigma_{\min} \le \sigma_{yield} = k$

$$\frac{\bar{\sigma}_i}{\bar{\sigma}_o} = \left(\frac{r_k}{r_b}\right)^2 = a^2$$

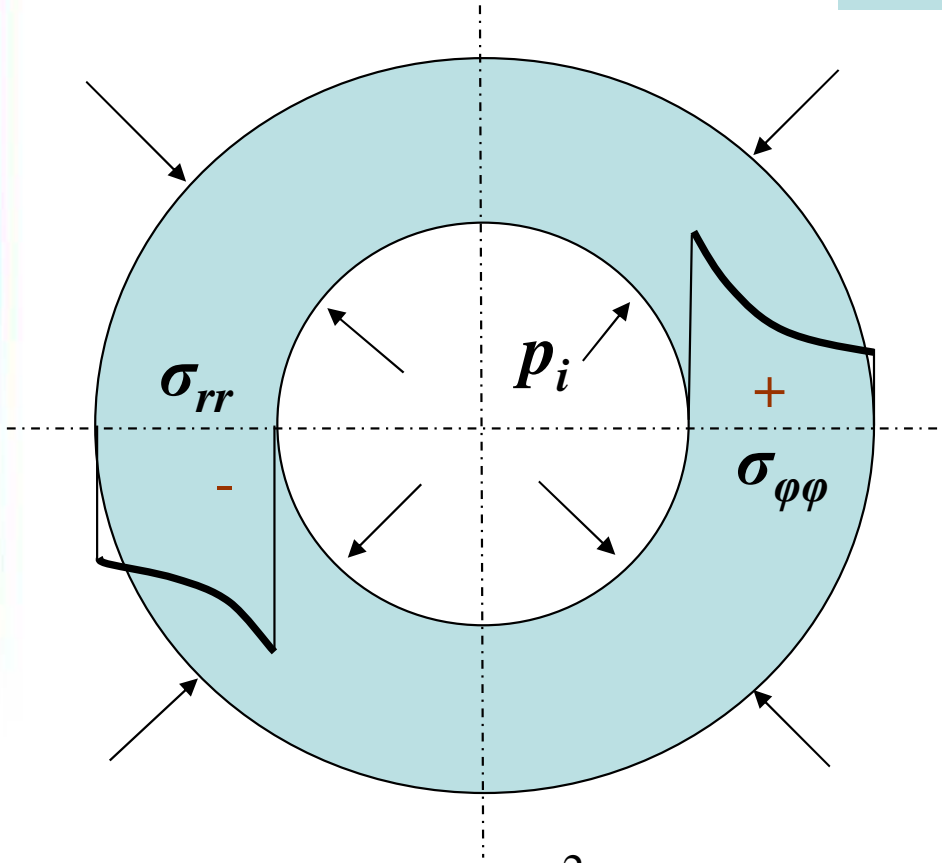
$$\frac{\bar{\sigma}_i}{\bar{\sigma}_o} = \frac{2a^2}{a^2+1}$$

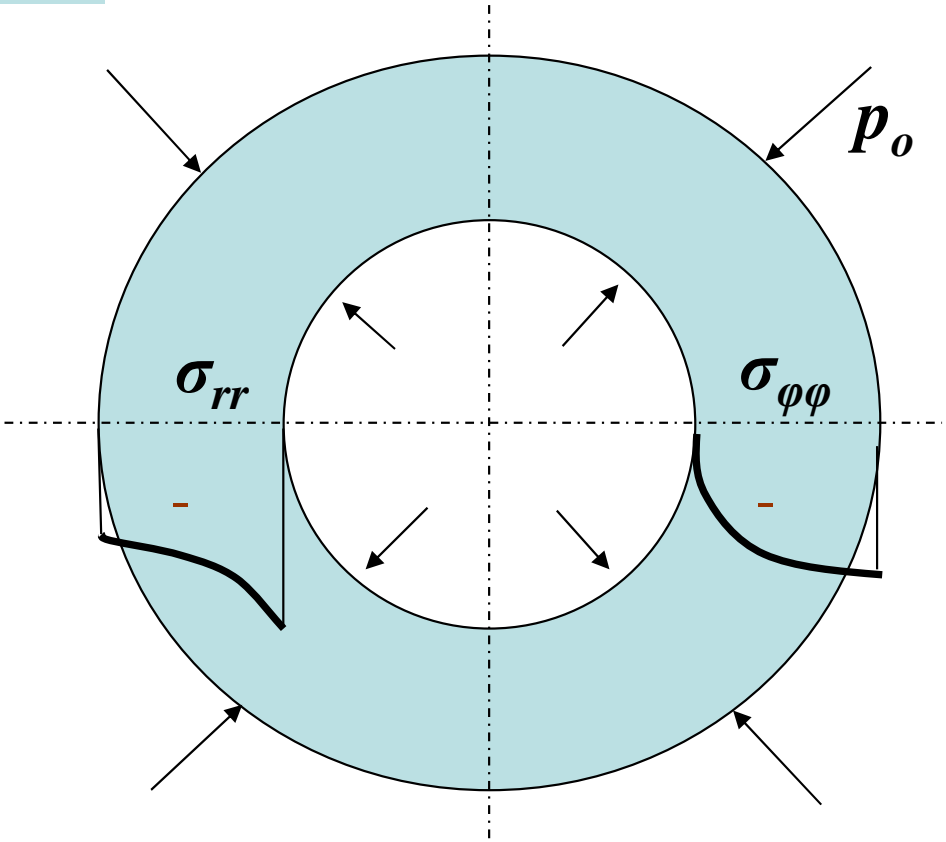
Reinforced die

$\sigma_{\varphi\varphi\, b} > 0$ (steel)

$p_i > p_o$

$\sigma_{\varphi\varphi\, b} = 0$ (carbide)





$$p_{i\,permissible} = k\,\frac{a^2 - 1}{2a^2} + p_o$$

$$p_o = p_i\,\frac{a^2 + 1}{2a^2}, \qquad p_{i\,permissible} = k$$

Dimensioning in Excel is available on the web page.

Reinforced die

Dimensioning in Excel is available on the web page (steel-steel)

The manual for using the file is available as well.

Calculate

Számol

R_k:	107,997		a_{min}:	3,60	p_{1max}:	1047,5

n	k_i	E_i	μ_i	a_i	R_{bi}	δ_i
	1500	210000	0,3	1,930	30	
	1400	210000	0,3	1,865	57,910	0,2751
		210000	0,3			
		210000	0,3			
		210000	0,3			

p_2:	281,7	σ_{tb}:	770,1	p_{krit}:	13440,9

Another Excel file is available for carbide-steel solution.

Die materials for extrusion

	Material		Assembly hardness HRC	Used for				R_e
	Name	No.		Punch	Die	Rein-forcement	Ejector	N/mm^2
Tool steels	S 6-5-2 (M 2)	1.3343	62 to 64	× ×	× ×		× ×	2100
	S 18-0-1 (B 18)	1.3355	59 to 62	× ×	×			2100
	S 6-5-3 (M 4)	1.3344	62 to 64	× ×				2200
	X 165 CrMoV 12	1.2762	60 to 62	×	×		×	2000
	X 40 CrMoV 51	1.2344	50 to 56		×	× ×	×	1200 – 1400
	42 CrMo 4	1.7225	30 to 34			× ×	×	700 – 900
Hard metals	G 40		1100 HV	×	×			
	G50		1000 HV		×			
	G60		950 HV	×	× ×			

× – suitable; × × – used most commonly; elastic modulus of steel = 210,000 N/mm^2

Achievable precision

Cold extrusion - for steel

Applies to	Range in mm						Mass in kg
	up to 10	over 10 to 16	over 16 to 25	over 25 to 40	over 40 to 63	over 63 to 100	
Inside diameter	0.05	0.06	0.06	0.07	0.08		up to 0.1
	0.08	0.09	0.10	0.11	0.12	0.14	– 0.5
	0.10	0.11	0.12	0.14	0.16	0.18	– 4.0
	0.12	0.14	0.16	0.18	0.20	0.22	– 25
Outside diameter	0.09	0.11	0.14	0.18	0.22	0.28	up to 0.1
	0.14	0.18	0.22	0.28	0.35	0.45	– 0.5
	0.18	0.22	0.28	0.35	0.45	0.56	– 4.0
	0.22	0.28	0.35	0.45	0.56	0.71	– 25

Achievable precision

Wall thickness tolerances for backward (impact) extrusion

Wall thickness in mm	Tolerance in mm
0.3 to 0.6	± 0.05
0.6 to 1.0	± 0.075
1.0 to 2.5	± 0.1
>2.5	± 0.2

Surface quality

High surface quality, if :

a) the surface quality of the dies is good,
b) the lubricant and its application have been made correctly,
c) the deformation remains within the permissible limits.

It is possible to achieve surface roughness in the region of

R_t = 5 to 10 µm

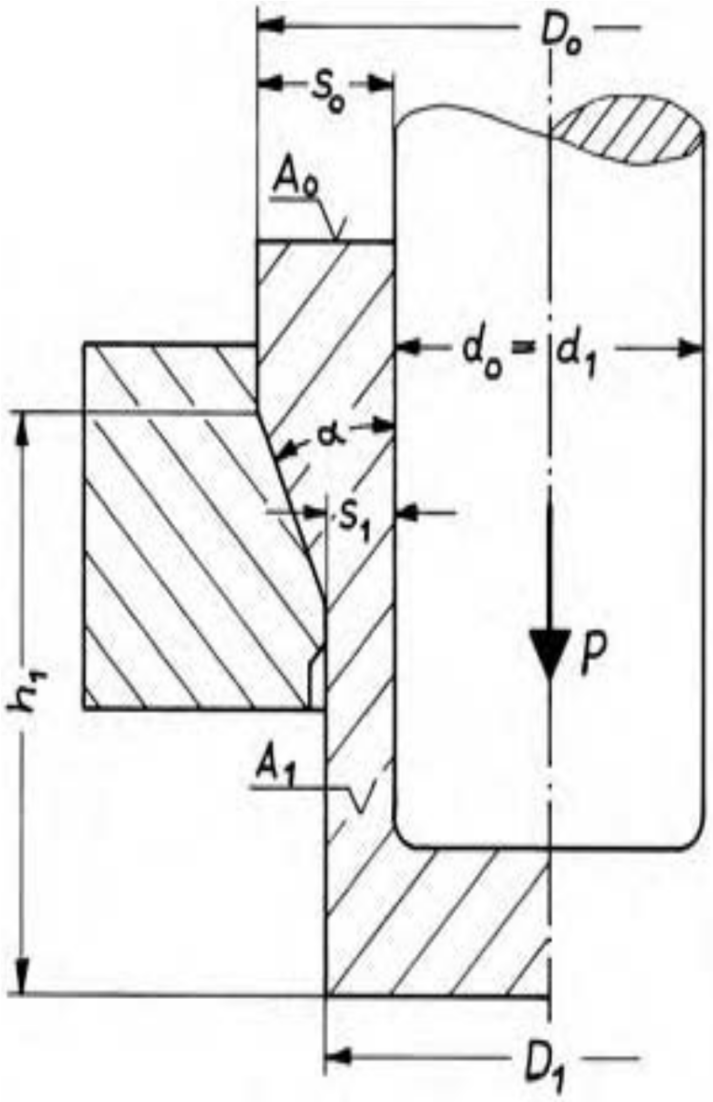
Ironing (wall ironing)

Bulk forming process where the wall is deformed.

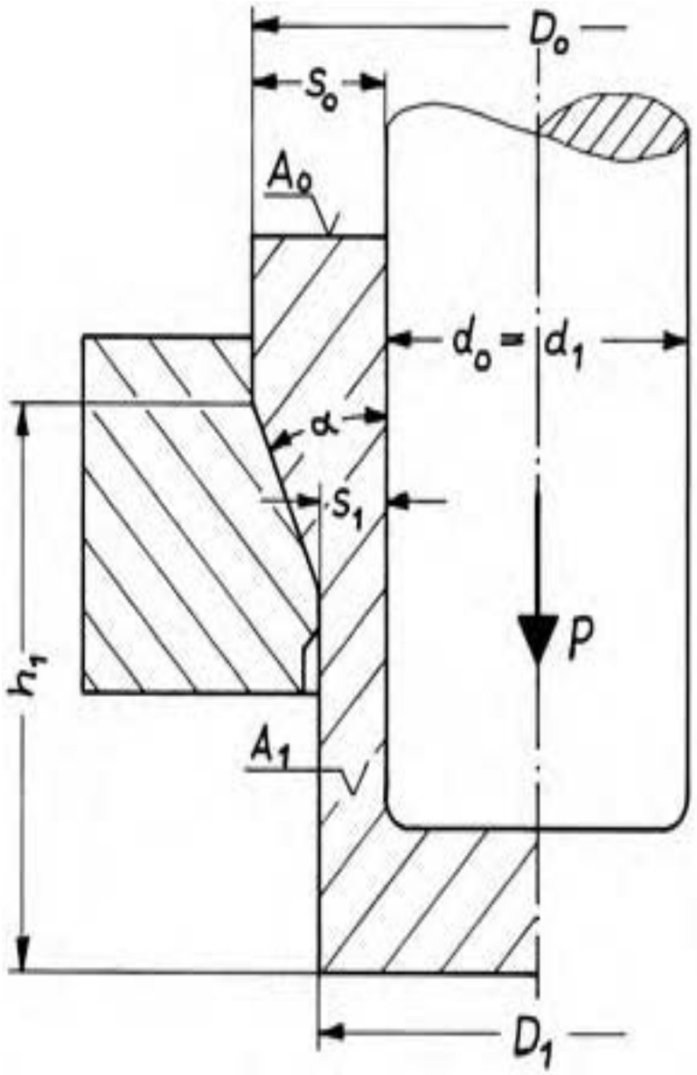
Limit:

If the stress in the formed cup wall exceeds the tensile strength of the cup material, the cup base splits off.

Flanged hollow parts and hollow parts with inner tapering can also be produced.



Ironing - calculation



$$\varphi_p = \ln\frac{A_0}{A_1} = \ln\frac{D_0^2 - d_0^2}{D_1^2 - d_0^2} = \ln\frac{D_0^2 - d_0^2}{D_1^2 - d_1^2}$$

A_0 – ring area before forming

A_1 – ring area after forming

D_0 – external diameter before forming

d_0 – inside diameter before forming

D_1 – external diameter after forming

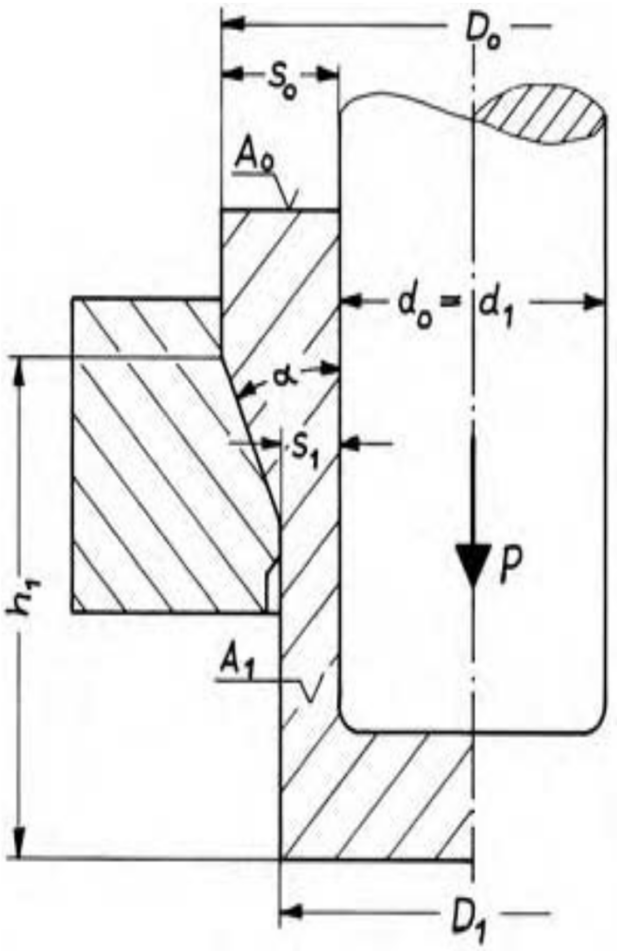
d_1 – inside diameter after forming (usually $d_0 = d_1$)

φ_p – principal strain

Ironing - calculation

Limited diameter, if $d_0 = d_1 = \text{const.}$

$$D_1 = \sqrt{\frac{D_0^2 - d_0^2}{e^{\varphi_P}} + d_0^2}.$$

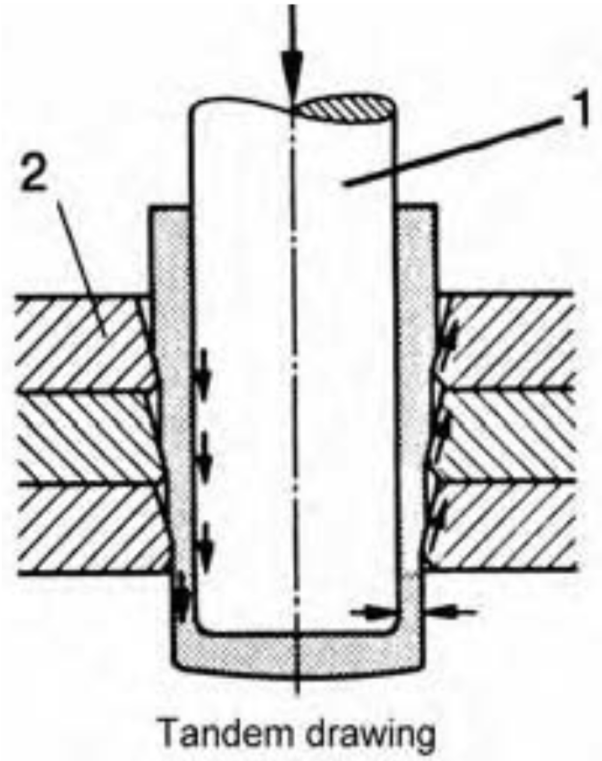


Permissible deformation in one step

Material	$\varphi_{P\,perm}$
Al 99.8; Al 99.5; Al Mg 1; Al MgSi 1; Al Cu Mg 1	0.35
Cu Zn 37(Ms 63)	0.45
Ck 10 – Ck 15,Cq 22 – Cq 35	0.45
Cq 45; 16 Mn Cr 5; 42 Cr Mo 4	0.35

Ironing - calculation

Number of ironing operations required:



Tandem drawing

$$n = \frac{\varphi_{\mathrm{p}}}{\varphi_{\mathrm{p\,perm}}} = \frac{\left(\ln \frac{A_0}{A_{\mathrm{n}}}\right) \cdot 100}{\varphi_{\mathrm{p\,perm}}}$$

n – number of ironing operations required

A_0 – cross-sectional area before the first operation

A_n – cross-sectional area after the last (n^{th}) operation

$\varphi_{p\,perm}$ – permissible deformation per step

φ_p – principal strain.

Limit: $F < A_1\,\sigma_{flow} < A_1\,R_m$

If $F > A_1\,\sigma_{flow}$: a further, undesired deformation happens

If $F > A_1\,R_{\mathrm{m}}$: then the cup splits off near the base

Forward extrusion

Thank you for your attention!