Metal Forming – BSc 2024/25-1

Upsetting, upset forging

Introduction

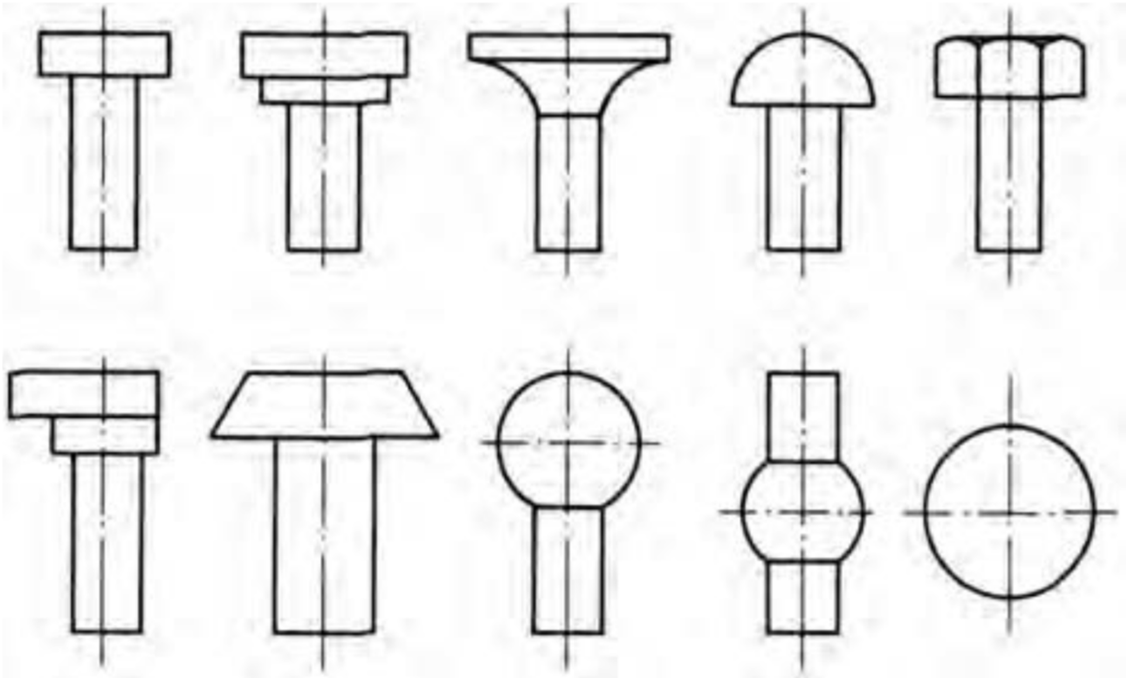
Definition:

Upset forging is a **bulk forming process** where the effect of the **pressure is on the longitudinal axis** of the workpiece.

Application:

Production of mass-produced parts :

screws, rivets, head bolts, valves etc.



Introduction

Screw production

0 shear off stock

1 pre-form head

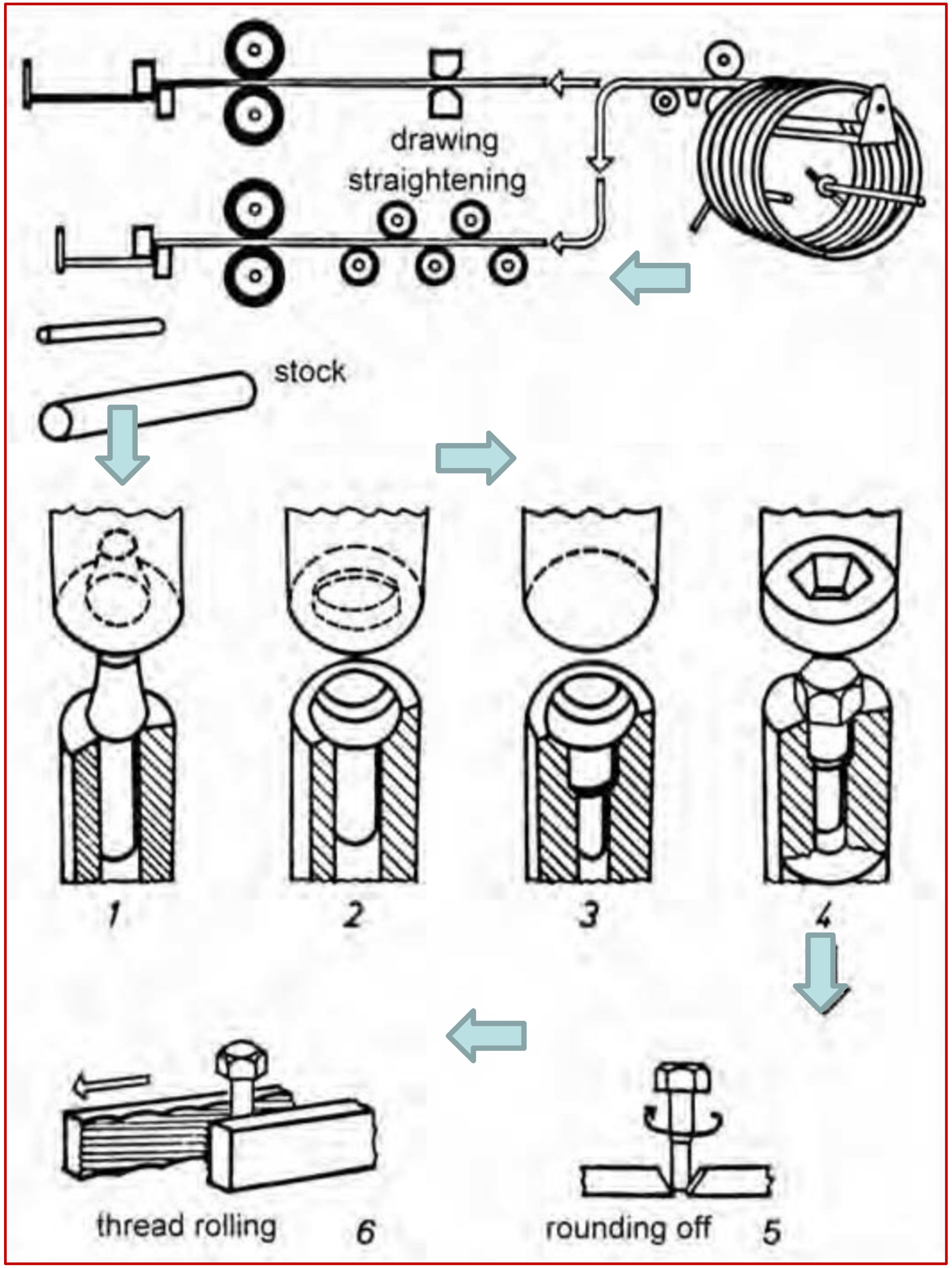
2 finish head

3 reduce shank to diameter for thread rolling

4 stamp out hexagon

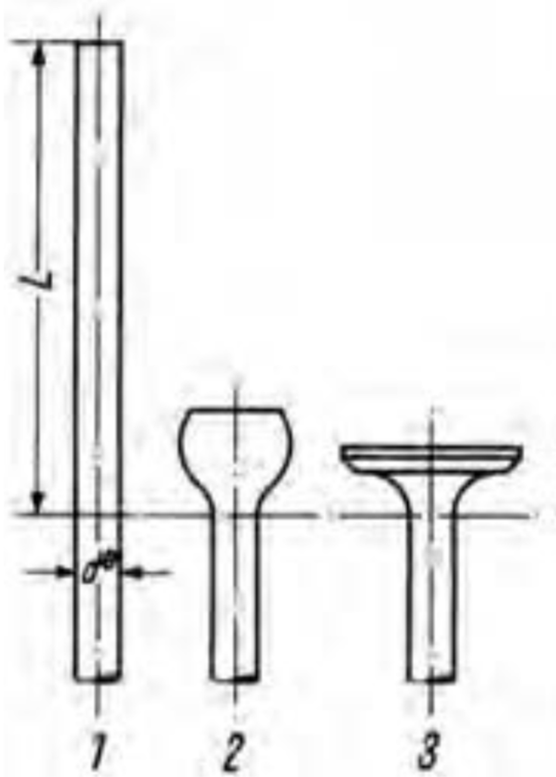
5 chamfer shank (round off)

6 thread rolling



Introduction

Engine valve



1 initial blank

2 preform (several steps, induction heated)

3 final heading

Limits - material

Limits: material and geometry

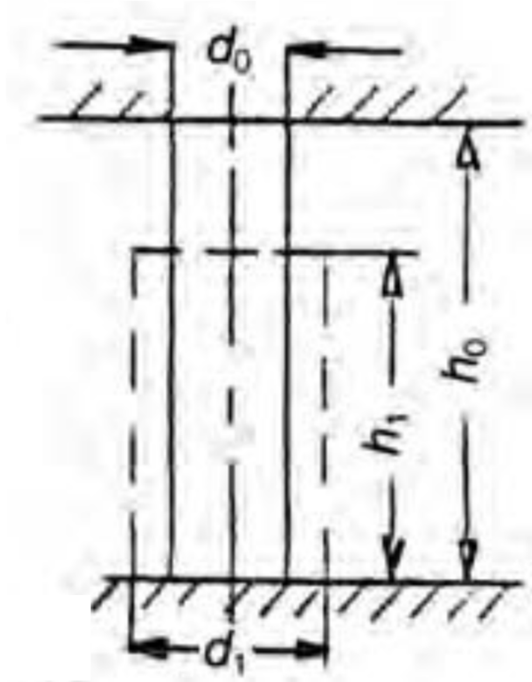
Material's formability

Important:

surface layer quality

Equivalent logarithmic strain:

$$\varphi = ln\frac{h_0}{h_1} = 2ln\frac{d_1}{d_0}$$

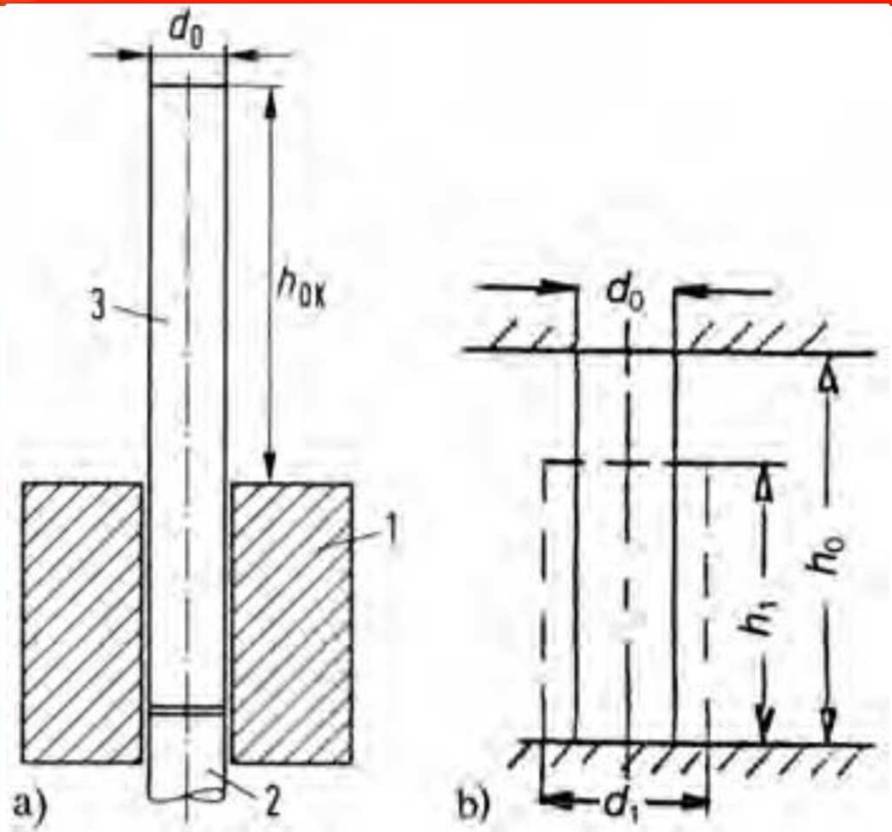


Limits - material

Permissible deformation for some materials

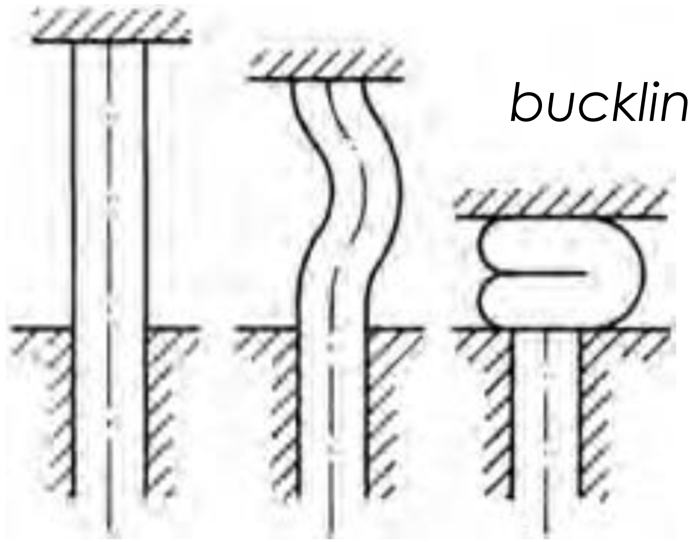
Material	φ_{max}
Al 99.88	2.5
Al MgSi 1	1.5 – 2.0
CuZn 37	1.2 – 1.4
St 42–St 50	1.3 – 1.5
34 CrMo 4	0.8 – 0.9
42 CrMo 4	0.7 – 0.8

Limits - geometry



a) free length not inserted in the die
   1 bottom die
   2 ejector
   3 stock before upset forging;

b) open-die upset forging between parallel surfaces



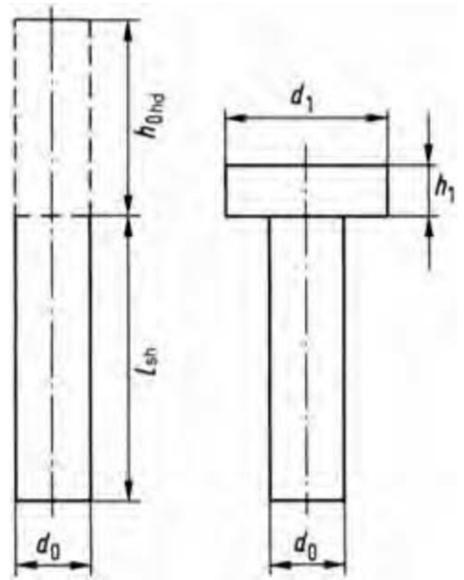
buckling

Upsetting ratio

$$s = \frac{h_0}{d_0}$$

h_0 - stock's free length
d_0 - initial diameter

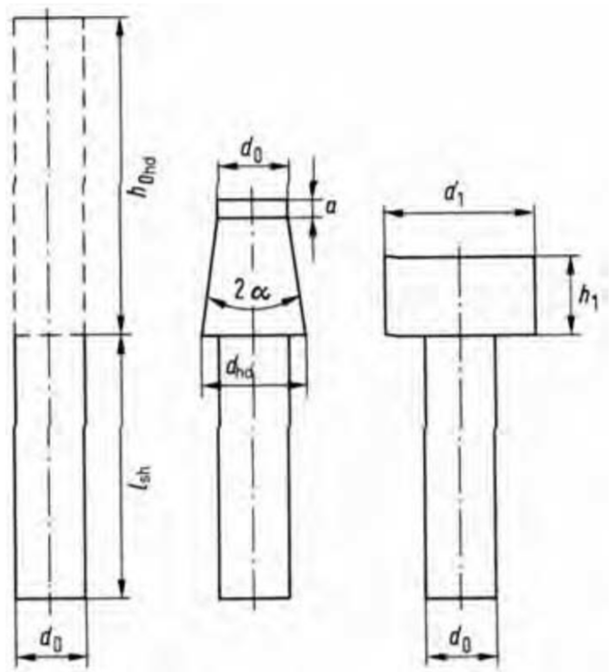
Limits - geometry



Maximum upsetting ratio – forming in one step

$$s = \frac{h_{0hd}}{d_0} < 2$$

h_{0hd} - stock's free length
d_0 - initial diameter



Maximum upsetting ratio – forming in two steps

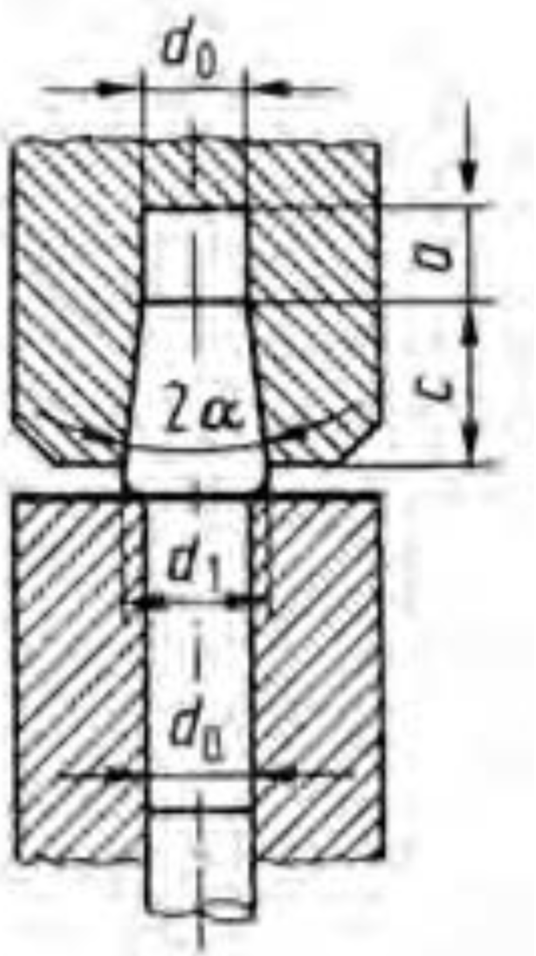
$$s = \frac{h_{0hd}}{d_0} < 4.5$$

h_{0hd} - stock's free length
d_0 - initial diameter

This case is typical for standard screw heads.

Preforming

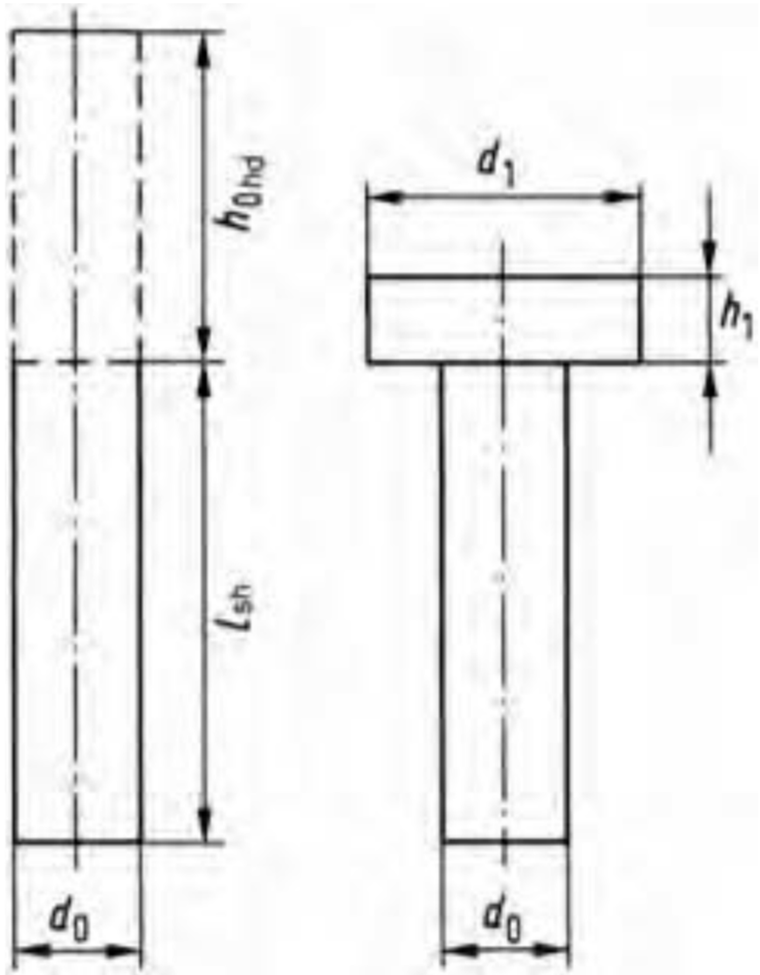
Forming in two steps – pre-form shape



Upsetting ratio $s = h_0/d_0$	Cone angle $2\ \alpha$ [degree]	Guide length a [mm]	Length of the tapered part of the pre-former c [mm]
2.5	15	$0.6\ d_0$	$1.37\ d_0$
3.3	15	$1.0\ d_0$	$1.56\ d_0$
3.9	15	$1.4\ d_0$	$1.66\ d_0$
4.3	20	$1.7\ d_0$	$1.66\ d_0$
4.5	25	$1.9\ d_0$	$1.45\ d_0$

Calculations

Upsetting force



$$F = A_1 \cdot \sigma_{f1}\left(1 + \frac{1}{3}\mu\frac{d_1}{h_1}\right)$$

F - upsetting force

A_1 - surface after upset forging

σ_{f1} - flow stress at the end of upsetting

μ - coefficient of friction (0.1 – 0.15)

d_1 - diameter after upsetting

h_1 - height after upsetting

Calculations

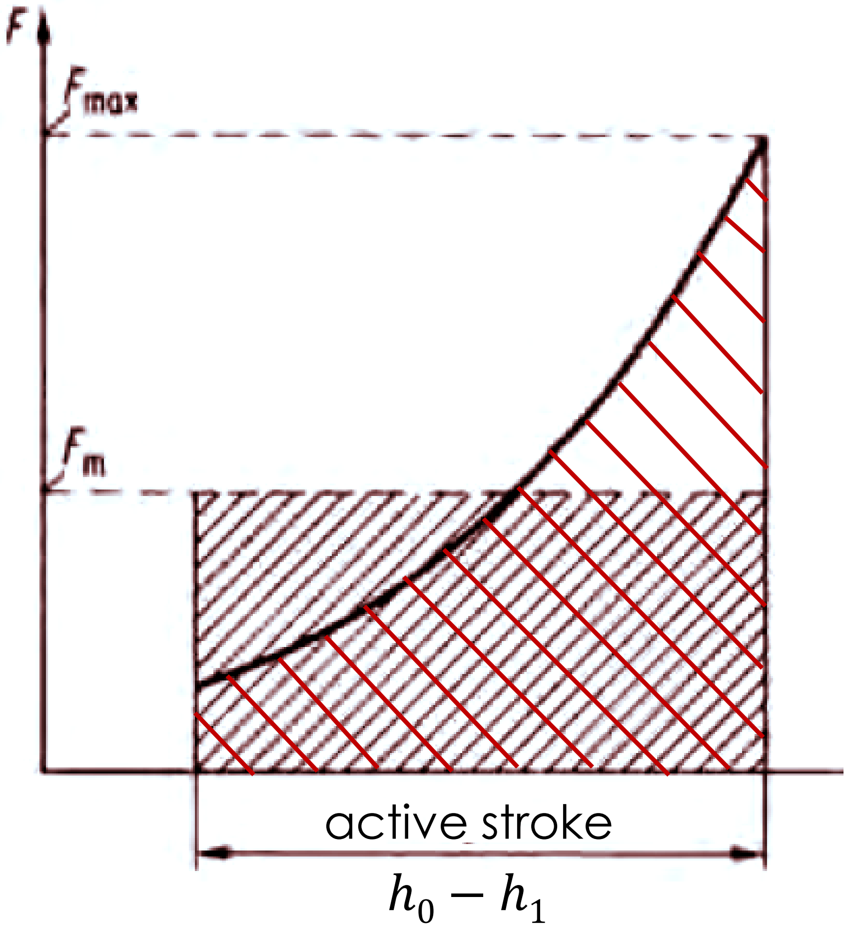
Upsetting work

$$W = \frac{V \cdot \sigma_{fm} \cdot \varphi_{eq}}{\eta_F}$$

or

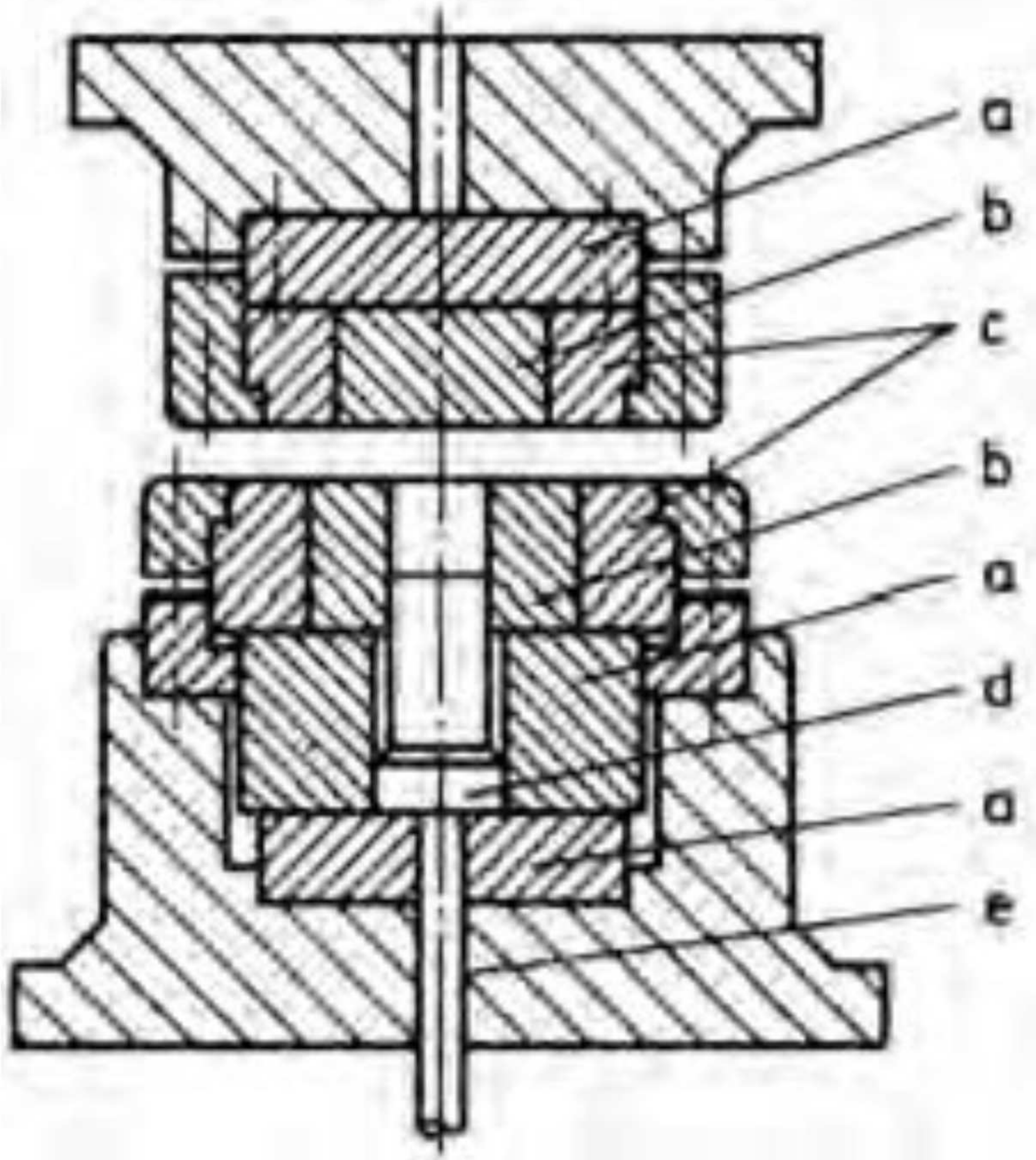
$$W = F(h_0 - h_1) \cdot x$$

$$x = \frac{F_m}{F_{max}} \qquad x \cong 0.6$$



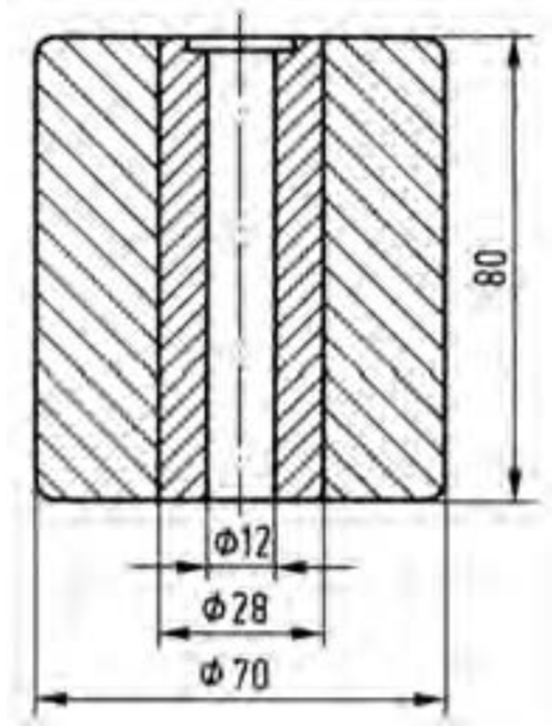
- W - upsetting work
- V - volume involved in deformation
- σ_{fm} - mean flow stress
- φ_{eq} - equivalent strain
- η_F - deformation efficiency (0.6 – 0.9)
- h_0 - stock height
- x - process factor
- F_m - mean force
- F_{max} - maximum force

Tooling

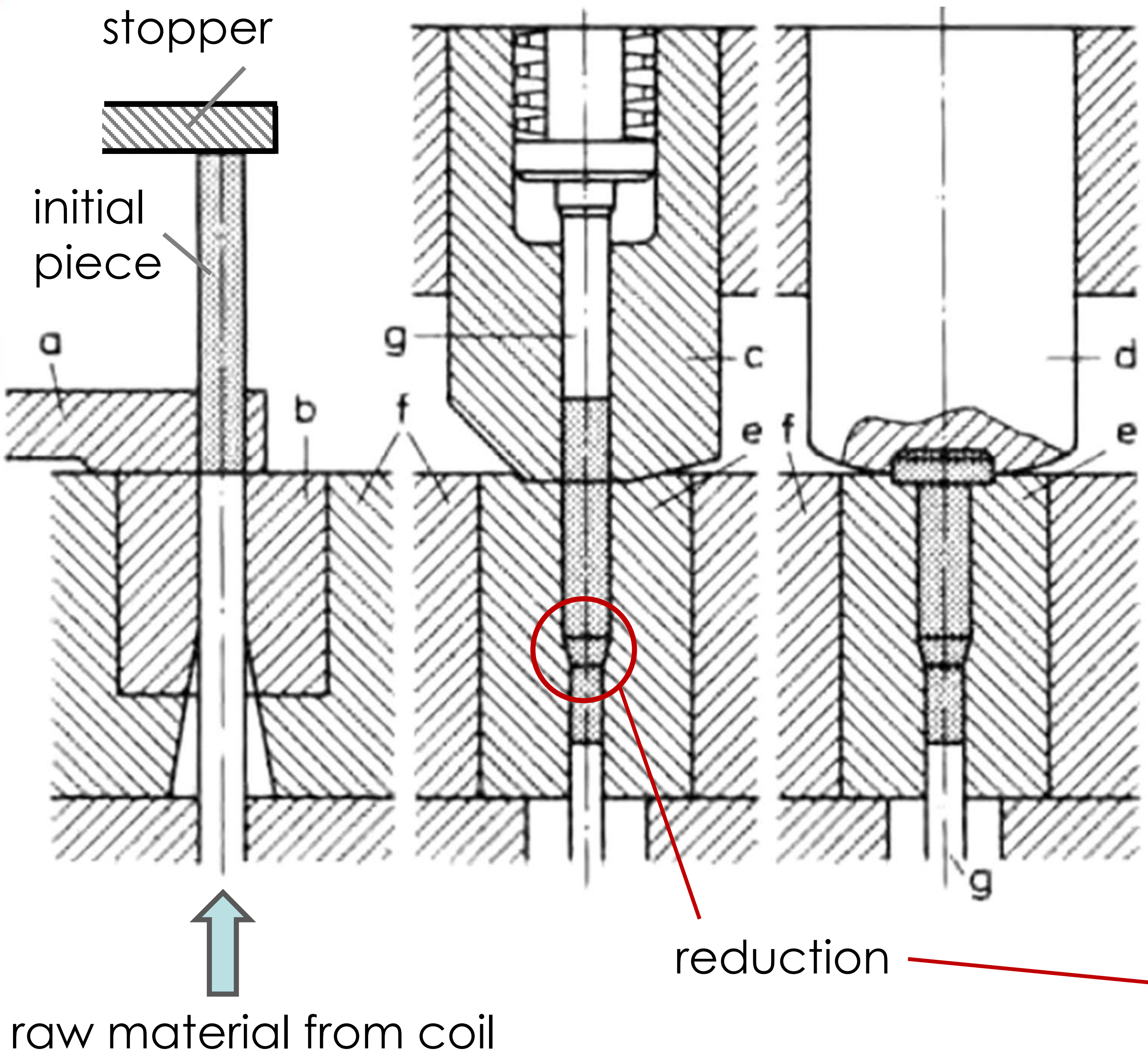


a) pressure plate
b) punch (snap die)
c) retaining ring (shrink fit)
d) counterpunch
e) ejector

Reinforced die

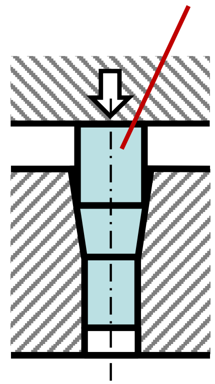


Tooling



a) shearing blade
b) shearing bottom die
c) pre-former
d) heading punch
e) bottom / reducing die
f) reinforcement
g) ejector

The axial stress here shall be smaller than the flow stress.

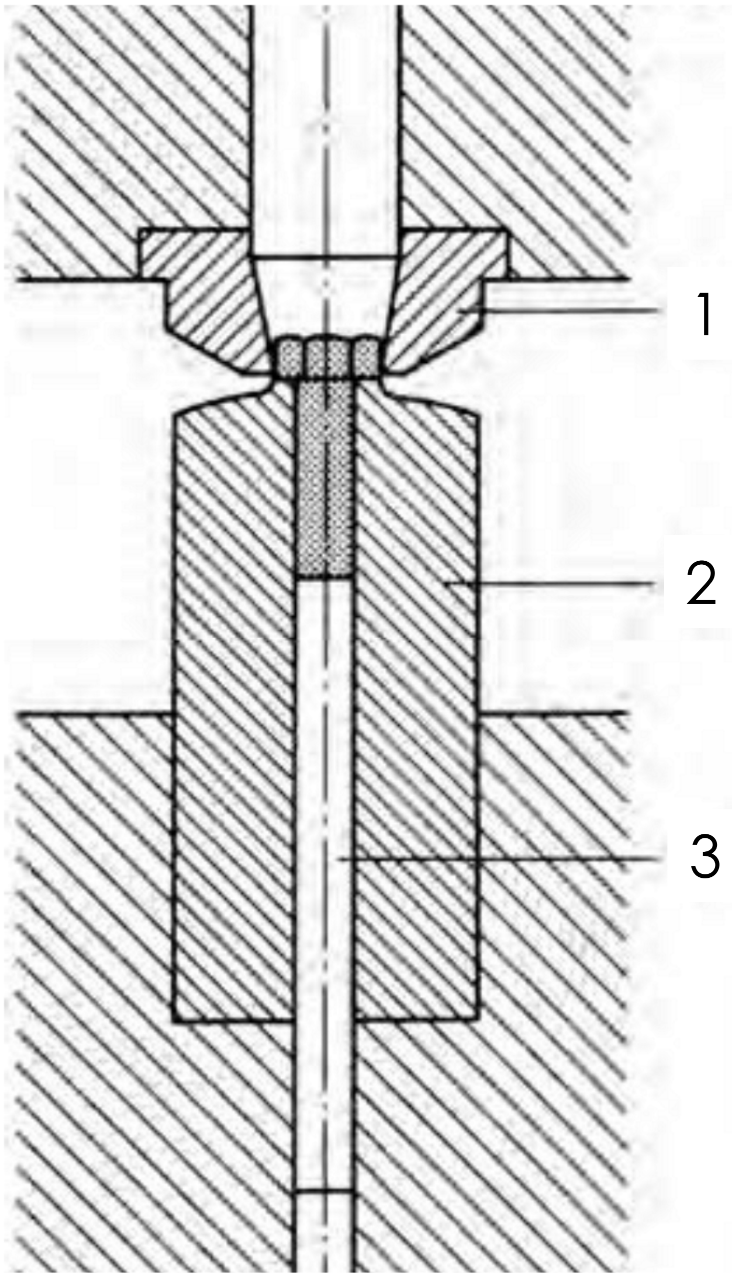


Scheme of reduction

Tooling

Cutting of the hexagonal head

1) cutting die
2) punch
3) ejector



Die materials for upsetting - 1

Description of the tool	Steel grade used for the tool		Hardness of the tool HRC
	Short designation	Material no.	
a) Shearing blade	X 155 CrVMo 12 1 X 165 CrMoV 12 S 6-5-2 60 WCrV 7	1.2379 1.2601 1.3343 1.2550	57 to 60 57 to 60 57 to 60 48 to 55
b) Shearing bottom die	X 155 CrVMo 12 1 X 165 CrMoV 12 S 6-5-2 60 WCrV 7	1.2379 1.2601 1.3343 1.2550	57 to 60 57 to 60 57 to 60 54 to 58
c) Solid pre-former	C 105 W 1 100 V 1 145 V 33	1.1545 1.2833 1.2838	57 to 60 57 to 60 57 to 60
c) Shrunk pre-former	X 165 CrMoV 12 S 6-5-2	1.2601 1.3343	60 to 63 60 to 63
d) Solid finishing punch	C 105 W1 100 V 1 145 V 33	1.1545 1.2833 1.2838	58 to 61 58 to 61 58 to 61
d) Shrunk finishing punch	X 165 CrMoV 12 S 6-5-2	1.2601 1.3343	60 to 63 60 to 63

Die materials for upsetting - 2

e) Solid bottom die	C 105 W 1 100 V 1 145V33x	1.1545 1.2833 1.2838	58 to 61 58 to 61 58 to 61
e) Shrunk bottom die	S 6-5-2 X 155 CrVMo 12 1 X 165 CrMoV 12	1.3343 1.2379 1.2601	60 to 63 58 to 61 58 to 61
f) Retaining ring	56 NiCrMoV 7 X 40 CrMoV 5 1 X 3 NiCoMoTi 1895	1.2714 1.2344 1.2709	41 to 47 41 to 47 50 to 53
g) Ejector	X 40 CrMoV 5 1 60 WCrV 7	1.2344 1.2550	53 to 56 55 to 58
Shearing tool: (slide 14, item 1)			
1 Bottom die	S 6-5-2	1.3343	58 to 61
2 Punch	60 WCrV 7 X 155 CrVMo 12 1 X 165 CrMoV 12	1.2550 1.2379 1.2601	58 to 61 58 to 61 58 to 61
3 Ejector	X 40 CrMoV 51 60 WCrV 7	1.2344 1.2550	53 to 56 55 to 58

Precision

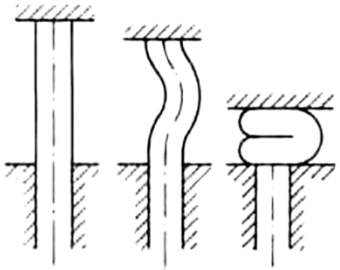
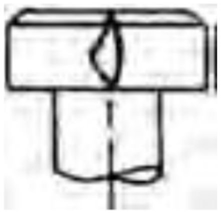
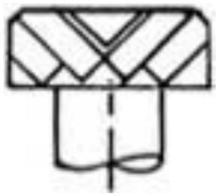
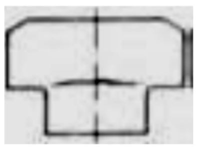
Cold upsetting tolerances

Nominal size in mm	5	10	20	30	40	50	100
Head height tolerance in mm	0.18	0.22	0.28	0.33	0.38	0.42	0.5
Head diam. tolerance in mm	0.12	0.15	0.18	0.20	0.22	0.25	0.3

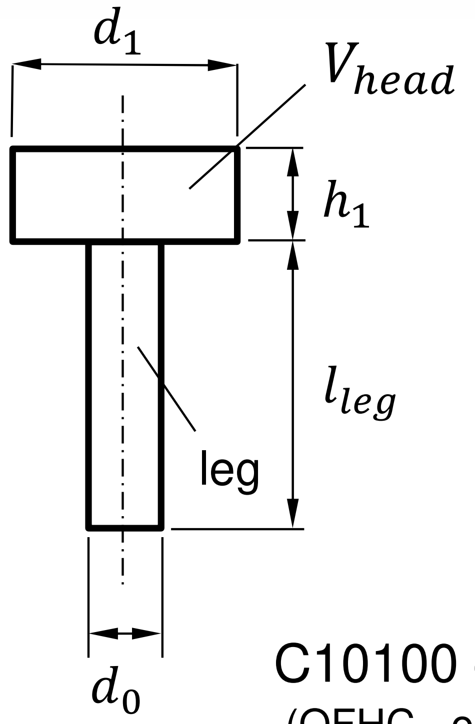
Hot upsetting

Tolerances are approximately **five times higher**.

Defects

Defect	Cause	Solution
Buckling 	Upsetting ratio is too high	Reduce by pre-forming
Longitudinal crack in the head 	Die scars or surface damage in the starting material.	Check the stock for surface damage.
Shear cracks in the head 	Formability exceeded	Reduce degree of deformation Divide forming into two operations.
Internal cracks in the head 	Formability exceeded	Reduce degree of deformation Divide forming into two operations.

Example



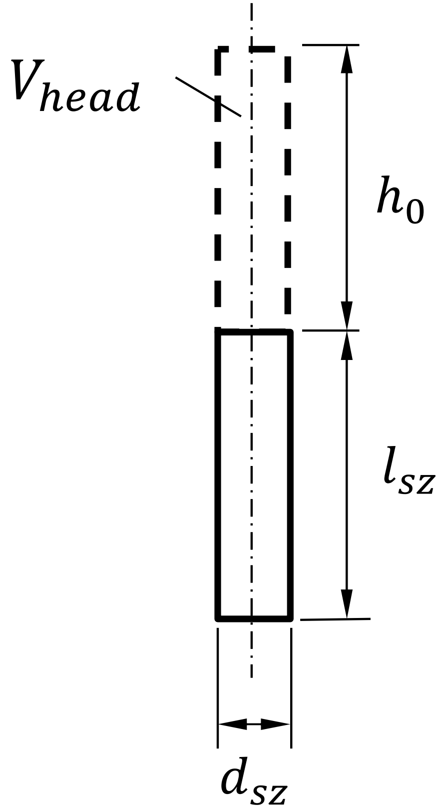
h_1=5 mm
d_1=20 mm
d_0=10 mm
l_{leg}=20 mm

C10100 commercial purity Cu
(OFHC - oxygen-free, high-conductivity copper

Head volume:

$$V_{head} = \frac{d_1^2 \, \pi}{4} h_1 = 1570 \, mm^3$$

$$h_0 = 19{,}98 \cong 20 \, mm$$



Upsetting ratio:

$$s = \frac{h_0}{d_0} = 2$$

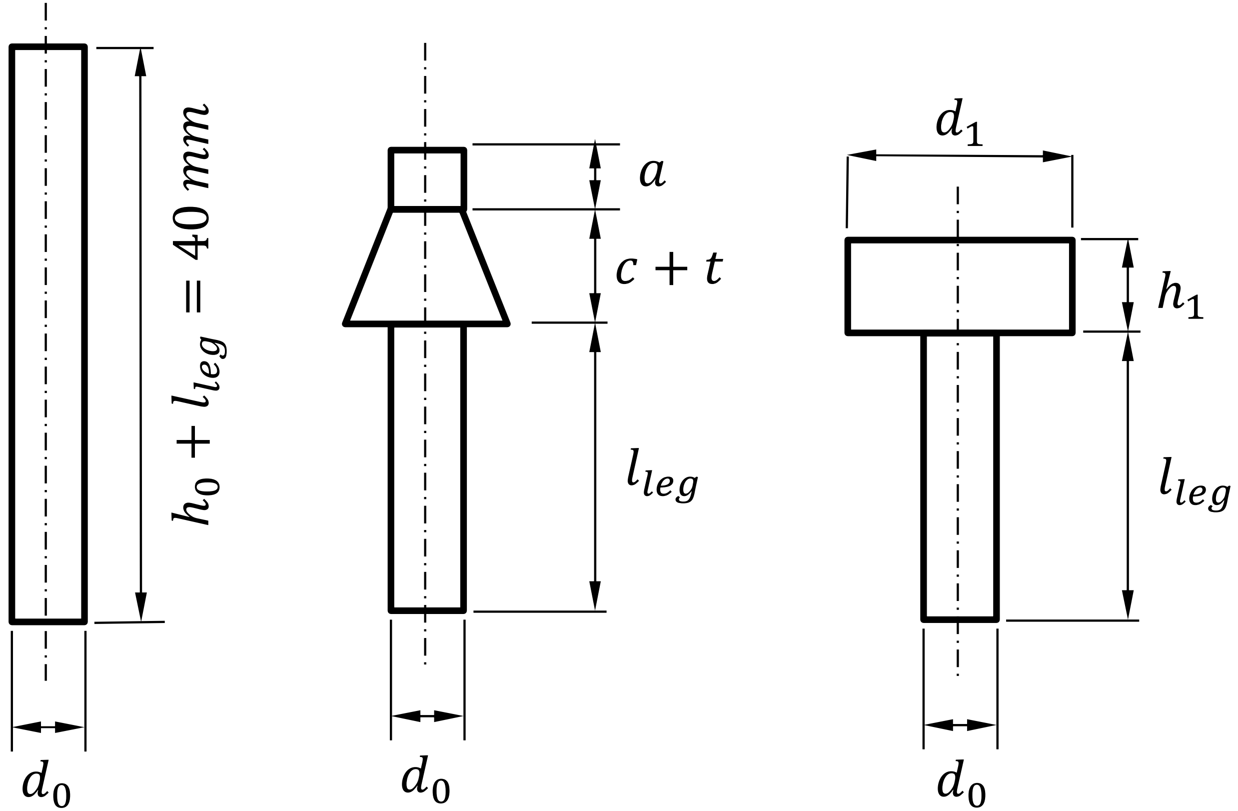
max. for 1 step

→ 2 steps for safety

Example

Formability: $\varphi = ln\left(\frac{h_0}{h_1}\right) = ln\left(\frac{20}{5}\right) = 1{,}38$ *good*

Pre-form geometry:

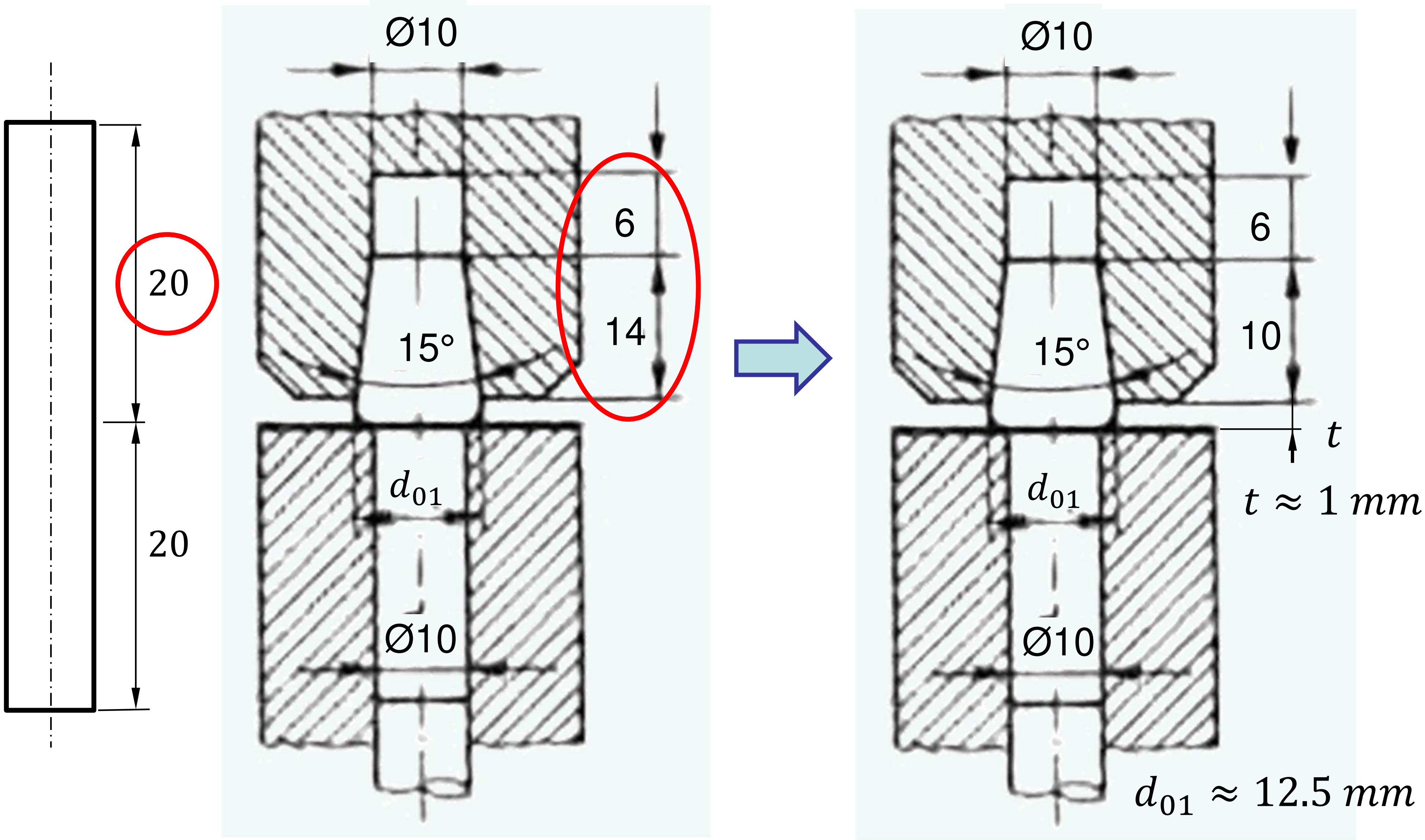


Using the table on slide 9:

a = 0.6 d_0 = 6 mm   α = 7,5°   c = 1,37 d_0 = 13.7 mm → 14 mm

Example

Check the validity of pre-form geometry



Example

Force at pre-forming

$$F_{01} = A_{01} \cdot \sigma_{f01} = \frac{d_{01}^2 \pi}{4} \cdot \sigma_{f01}$$

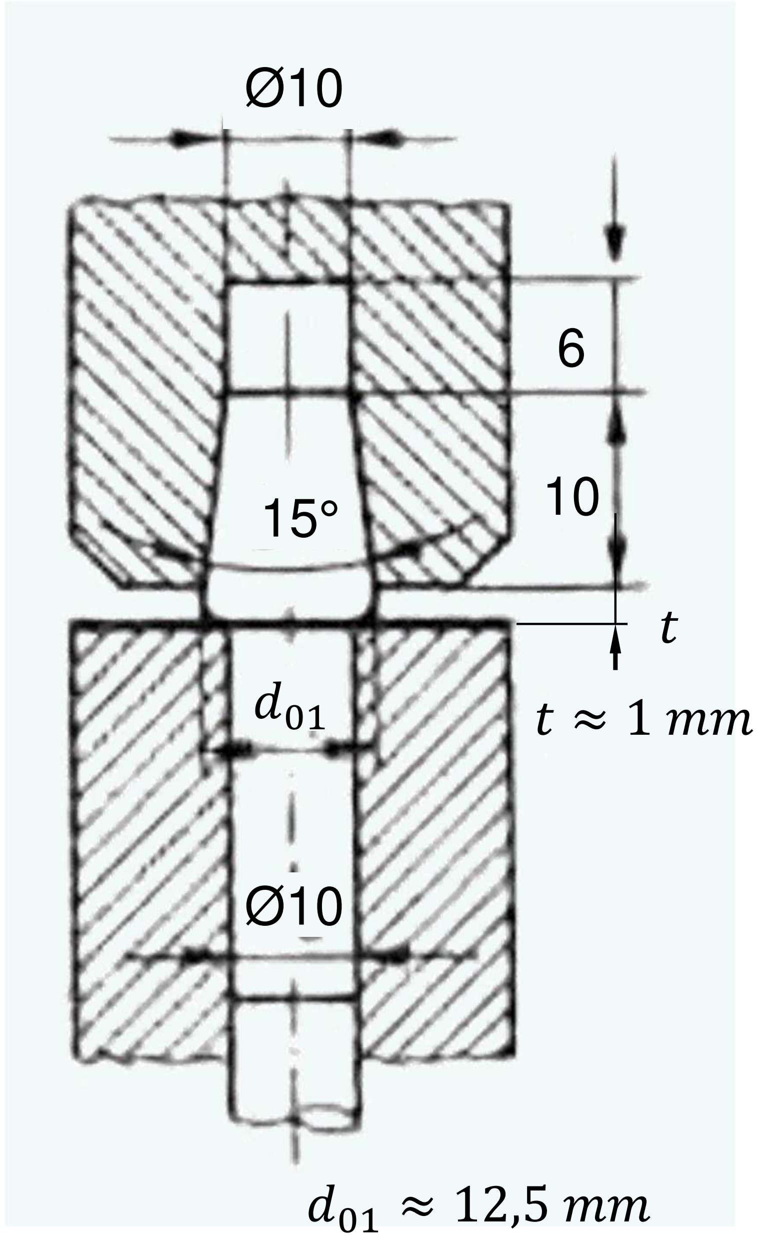
$$\varphi_{01} = 2\ ln\left(\frac{d_{01}}{d_0}\right) = 2\ ln\left(\frac{12.5}{10}\right) = 0{,}44$$

$$\sigma_{f01} = 84 + 286 \cdot {\varphi_{01}}^{0.442} = 283\ MPa$$

(also the axial stress on the punch)

$$F_{01} = 298\ mm^2 \cdot 283\ MPa$$

$$\boldsymbol{F_{01} = 84\ kN}$$



Example

Force at ready forming

$$F_1 = A \cdot \sigma_{f1}\left(1 + \frac{1}{3}\mu\frac{d_1}{h_1}\right)$$

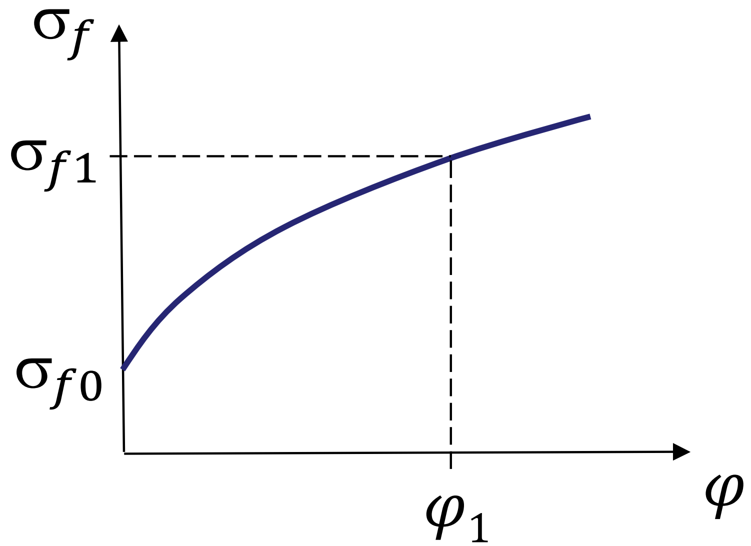
$$\sigma_f = C_1 + C_2\varphi^n \qquad \varphi_1 = 1.38$$

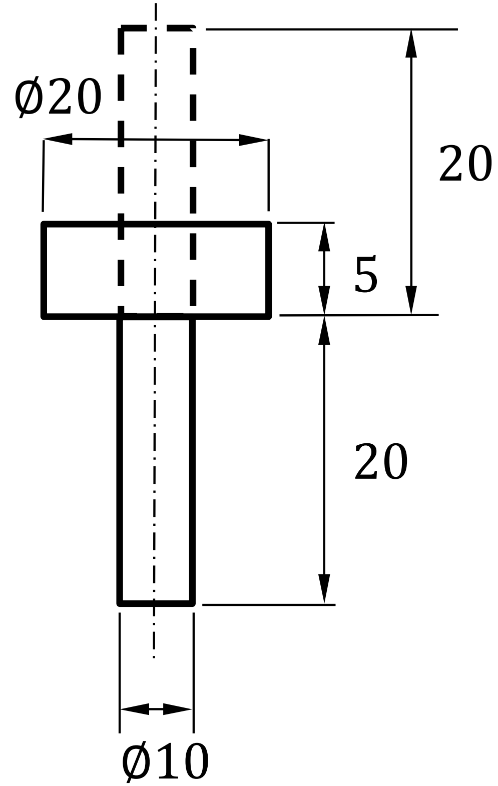
$$A = \frac{20^2\pi}{4} = 314\,mm^2$$

$$\sigma_{f1} = 84 + 286 \cdot {\varphi_1}^{0.442} = 413\,MPa$$

$$\mu = 0.1$$

$$\boldsymbol{F_1} = 314 \cdot 413\left(1 + \frac{1}{3} \cdot 0{,}1\,\frac{20}{5}\right) = \mathbf{147\,kN}$$





Example

Work at ready forming (Method 1)

$$W = \frac{V_{head} \cdot \sigma_{fm} \cdot \varphi}{\eta}$$

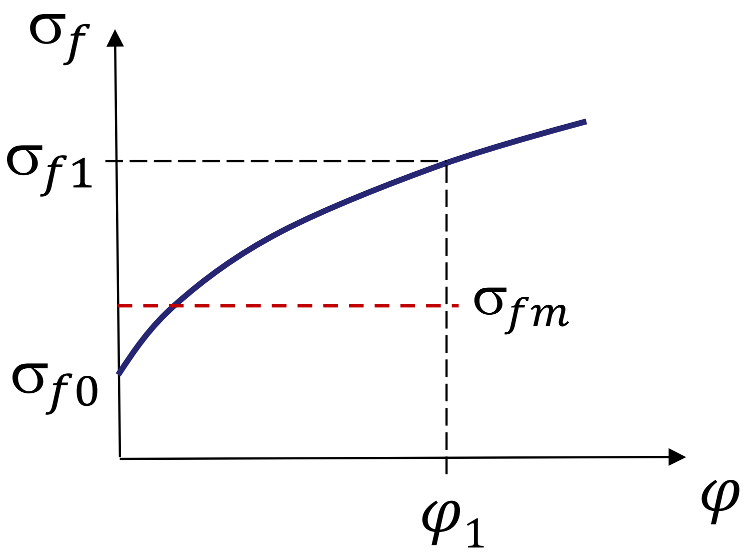
$\eta = 0.6 \ldots 0.9$

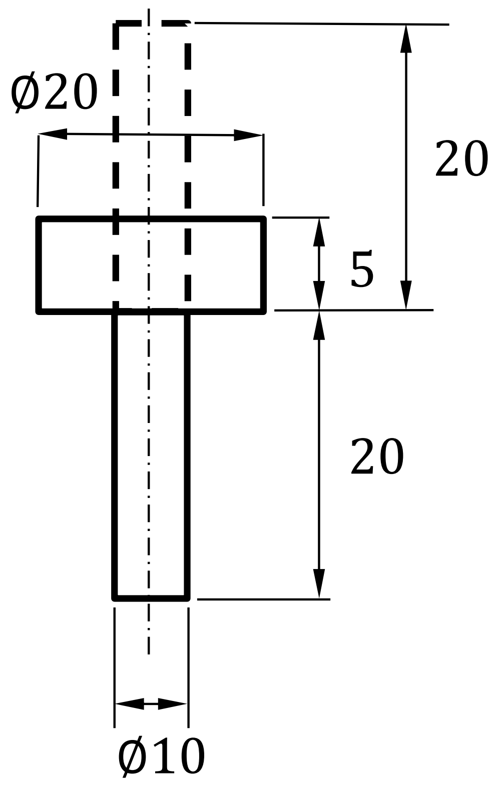
let assume $\eta \cong 0.6$

$\varphi_1 = 1.38$

$$\sigma_{fm} = \frac{\sigma_{f0}+\sigma_{f1}}{2} = \frac{84+413}{2} = 249\ MPa$$

$$W_{ready} = \frac{1570\ mm^3 \cdot 249\ MPa \cdot 1.38}{0.6} = \mathbf{899}\ J$$





Example

Making the two forming steps parallel

Assume, as it is usual, we are using such tooling and forming machine which makes possible to make the two steps parallel. Therefore, the total force at one machine stroke is the sum of the two forces:

$$\boldsymbol{F_{stroke}} = F_{01} + F_1 = 84 + 147 = \mathbf{231\ kN}$$

The total work at one stroke is the sum of the two works:

$$W_{stroke} = W_{pre} + W_{ready}$$

Estimated work at preforming (Δh_{01} active stroke is 20-6-10-1= 3 mm):

$$W_{pre} \approx F_{01} \cdot \Delta h_{01} = 84\ kN \cdot 3\ mm = 252\ J$$

Total work at one machine stroke

$$\boldsymbol{W_{löket}} = 252 + 899 = \mathbf{1151\ J}$$

Example

Power for parallel operation

Assume, the forming machine can make 80 strokes per minute (that means 80 workpieces), therefore the ***work for one second***:

$$W = \frac{80}{60} W_{löket} = 1.33 \cdot 1151\, J = 1531\, J$$

The minimum required power and minimum loadability of the forming machine to perform the given technology:

P_{min} = 1.53 kW

F_{min} = 231 kN

⇨ These are needed to select a machine, taking into consideration its efficiency.

In addition, **the tooling has to be applicable** on the forming machine to perform the given technology.

Production of screws and nuts:

https://www.youtube.com/watch?v=3kxcw08p_oY

Thank you for your attention !