Metal Forming – BSc 2024/25-1

Wire, rod, and pipe drawing

Overview

Wire/rod drawing

- application
- deformations, drawing speeds and forces
- equipments, dies and die materials

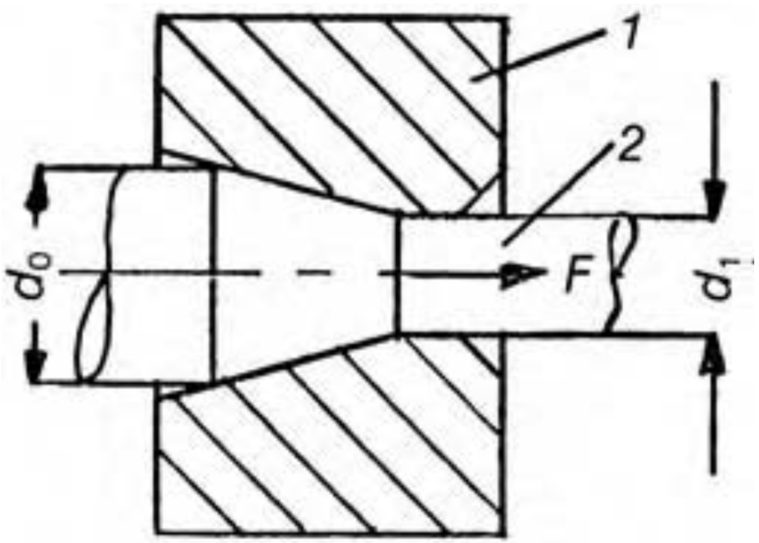
Tube drawing

- tube drawing processes
- strain and drawing force
- drawing tools

Lubrication

Defects

Wire drawing



A wire of a larger size is pulled through a drawing ring of a smaller size.

The deformation per drawing steps is rather limited (generally 0.1- 0.3).

- coarse drawing: *d* = 16 to 4.2 mm
- medium drawing: *d* = 4.2 to 1.6 mm
- fine drawing: *d* = 1.6 to 0.7 mm
- ultra-fine drawing: $d < 0.7$ mm (down to a few microns)

According to the machine used (continuous operation):

- single-draft drawing
- tandem drawing

The machines are operating continuously.

Stock, application

Starting stock: wire drawing: hot-rolled wires
rod drawing: rods produced by hot rolling or extrusion

Applications

wires and rods with smooth surfaces and low tolerances.

Material	Application
Low-carbon steels C 10 – C22	Wires, wire meshes, barbed wire, pins, nails, screws and bolts, rivets
High-carbon steels (up to 1.6% C)	Rod material for automatic processing, wire cables
Alloyed steels	Industrial springs, welding wires
Cu and Cu alloys	Wires, wire meshes, screws, bolts and shaped parts, parts for the electrical industry
Al and Al alloys	Screws and bolts, shaped parts, electrical lines, etc.

Deformations

Strain $$\varphi = ln\frac{A_0}{A_1}$$

A_0 : cross-section before drawing
A_1 : cross-section after drawing

Permissible deformations

Material		Intake strength R_m	Intake diameter d_0	Drawing reduction between two draws, φ	Total deformation φ	Number of drawing stations
Steel wire		400	4 – 12	0.18 – 0.22	3.80 – 4.00	8 to 21
		1200	0.5 – 2.5	0.12 – 0.15	1.20 – 1.50	
Cu alloy		soft	8 – 10	0.40 – 0.50	3.50 – 4.00	5 to 13
		250	1 – 3.5	0.18 – 0.20	2.00 – 3.00	
Al alloy		soft	12 – 16	0.20 –0.25	2.50 – 3.00	5 to 13
		80	1 – 3.5	0.15 – 0.20	1.50 – 2.00	

Deformations

Reductions of higher than 45% may result in lubricant breakdown, leading to surface-finish deterioration.

Sizing pass:

Light reduction to improve surface finish and dimensional accuracy. It deforms only the surface layers, so it produces highly non-uniform deformation of the material and its microstructure. The properties of the material will vary with location within the cross-section.

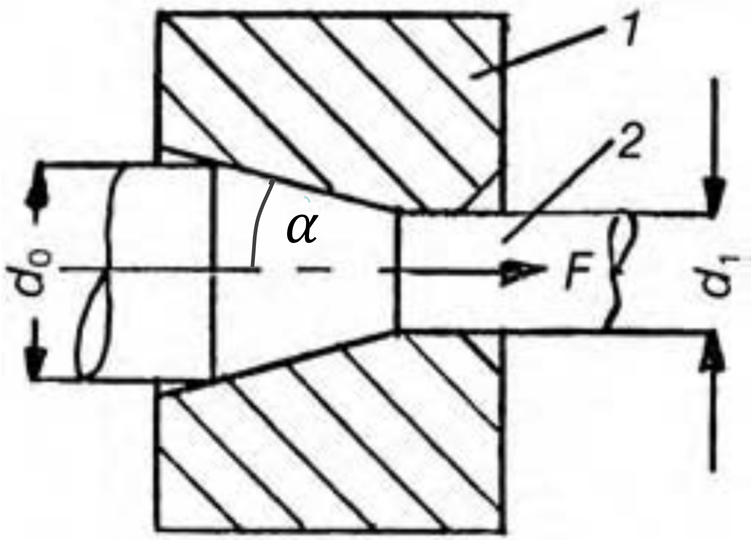
Bundle Drawing:

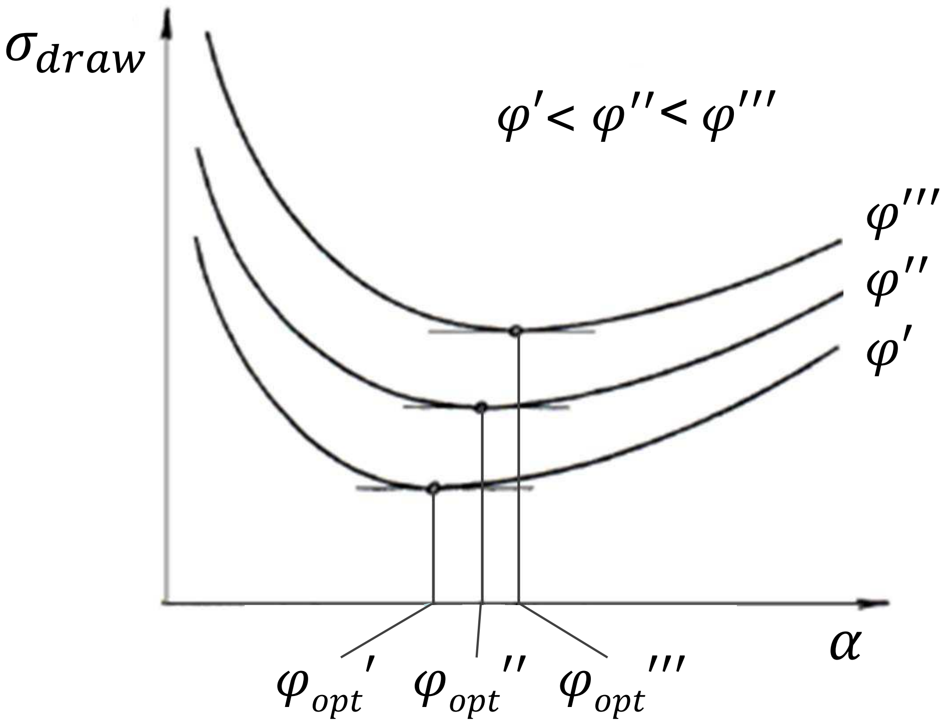
Drawing many wires (even a hundred or more) simultaneously as a bundle. The cross section is polygonal, rather than round.

Drawing force

$$F = A_1\,\sigma_{fm}\,\varphi\left(\frac{\mu}{\alpha} + \frac{2\alpha}{3\varphi} + 1\right)$$

F	*drawing force*
σ_{fm}	*mean flow stress*
μ	*friction coefficient*
α	*half cone angle (radian)*





Optimal drawing angle: $2\alpha \approx 16°$

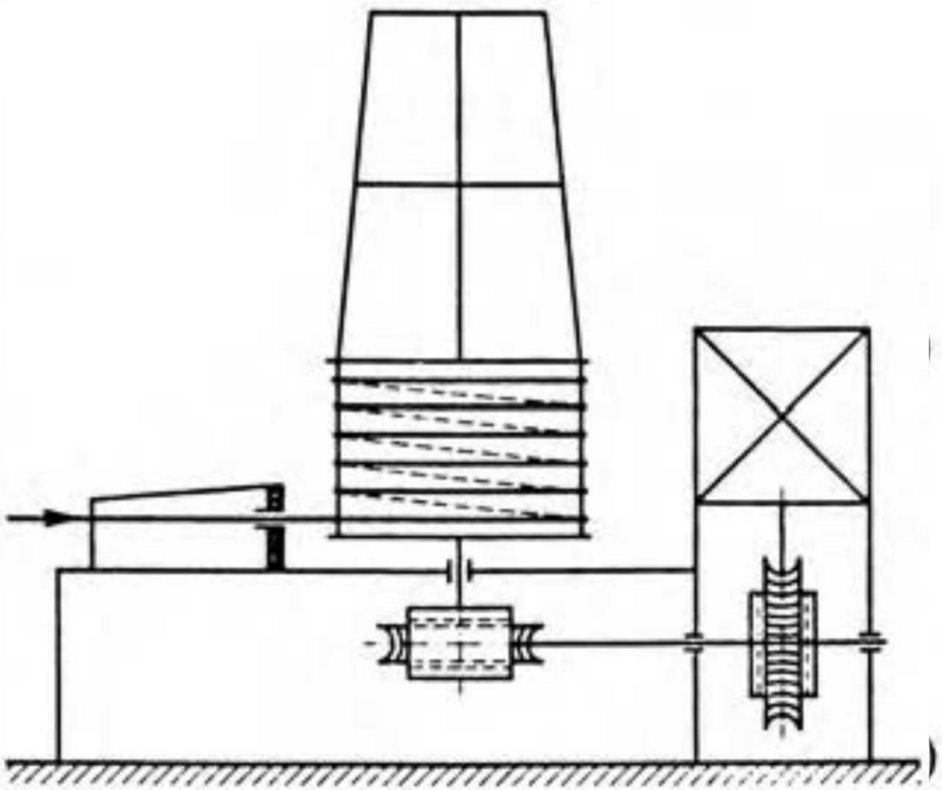
Drawing speeds

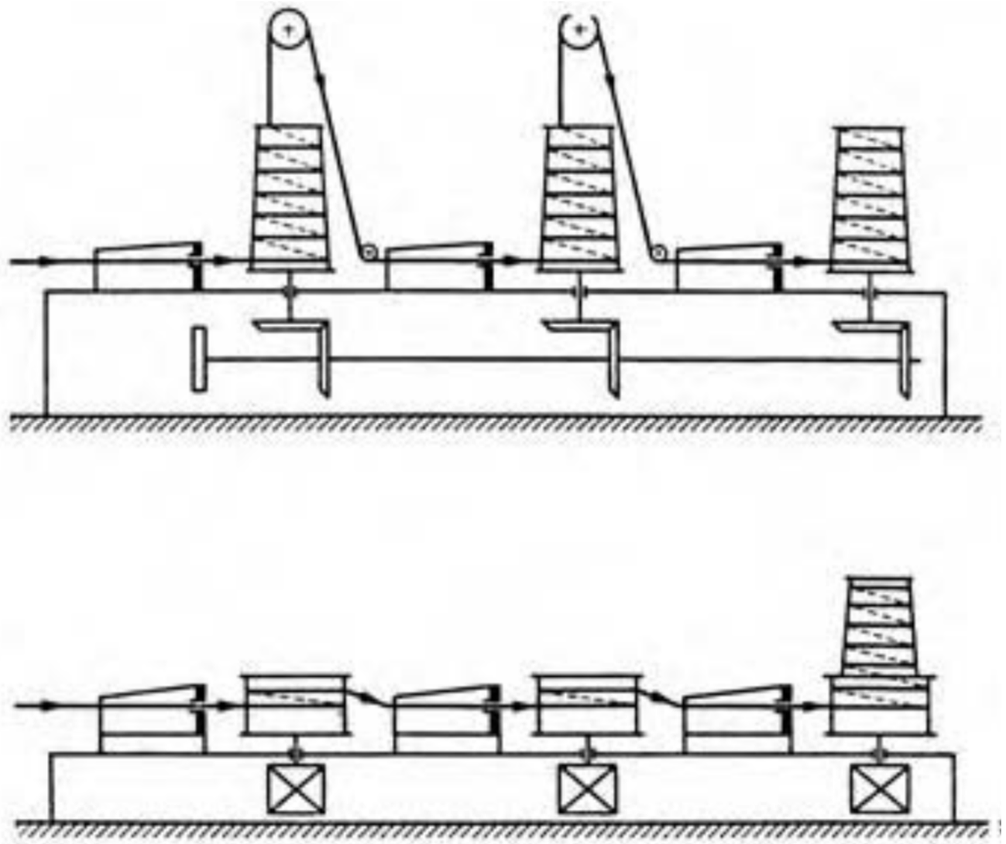
Single

Material	Intake strength R_m in N/mm^2	υ_{max} in m/s
Steel wire	(iron wire) 400	20
	800	15
	1300	10
Cu (soft)	250	20
Brass, bronze	400	
Al and Al alloys	80 – 100	25

Tandem The drawing speed differs at every drawing stage. As the volume is constant, the speed is getting higher because the wire cross-section is reduced.

Drawing equipment





Single

Tandem
(needs back pull
between the stages)

Drawing tools (drawing stones)

Three zones:

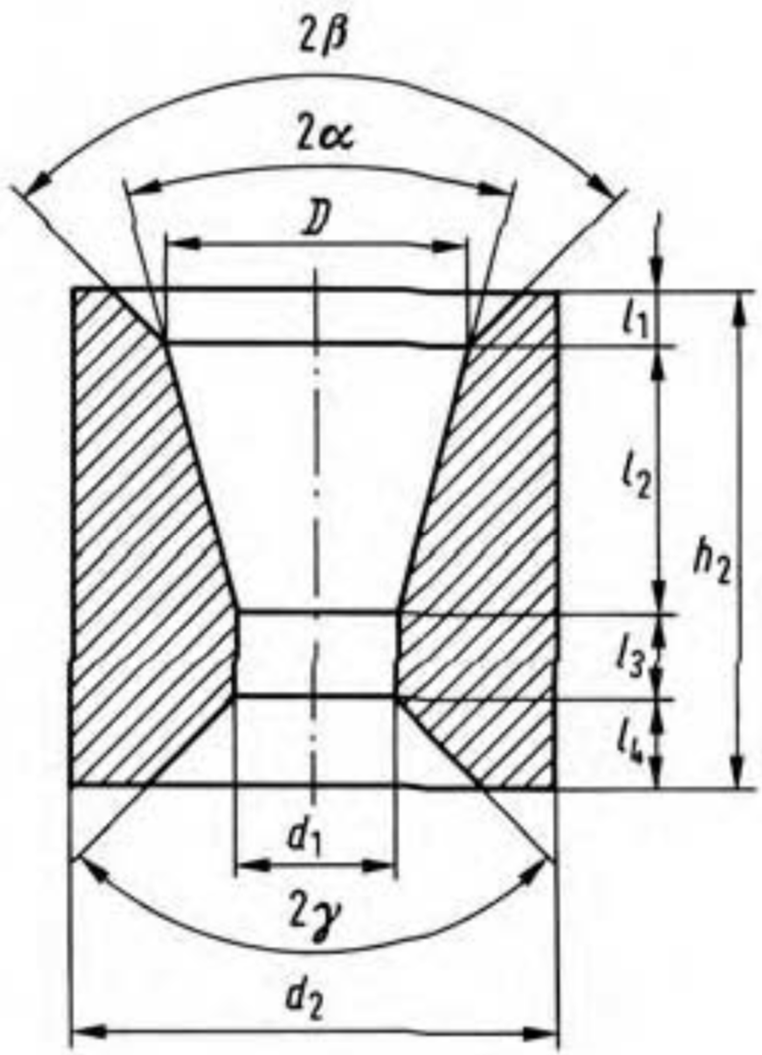
- cone-shaped intake
  (entry angle 2β, approach angle 2α)
- bearing land
- cone-shaped back relief
  (relief angle 2γ)

The length of the cylindrical guiding land:

$$l_3 = 0.15 \cdot d_1$$

The approach angle 2α influences the drawing force and the surface finish of the wire (ref.: optimal angle).

There are dies for profile drawing as well.



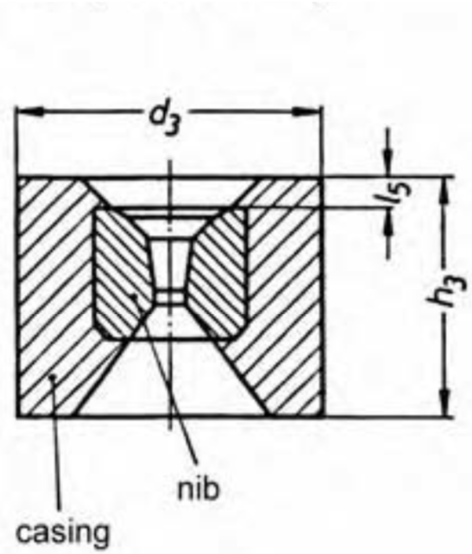
Drawing die materials

Steel drawing dies

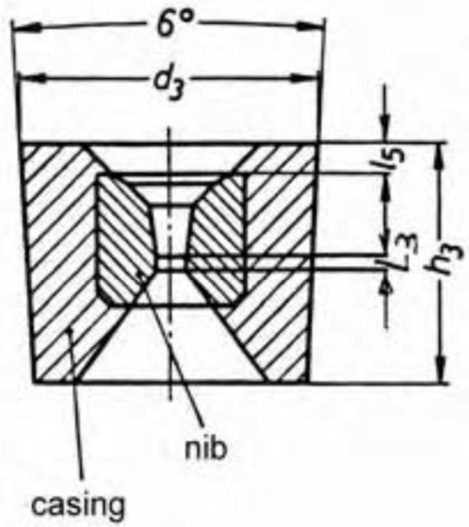
Material	HRC working hardness	Fields of application
1.2203 1.2453 1.2080 1.2436	63 – 67	Rod and tube drawing

Carbide drawing dies (typical designs)

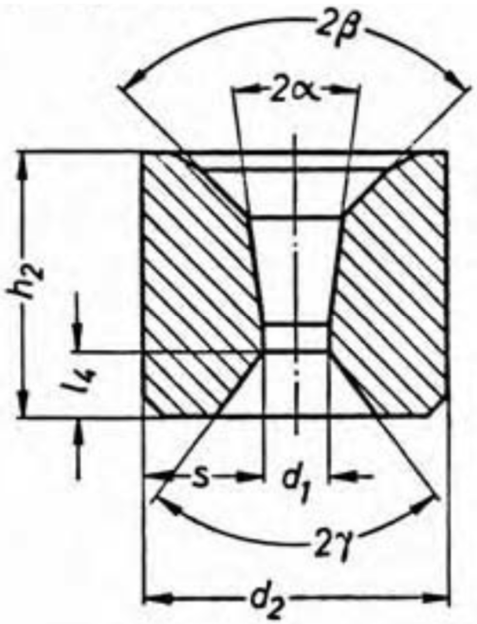
Cylindrical casing



Conical casing



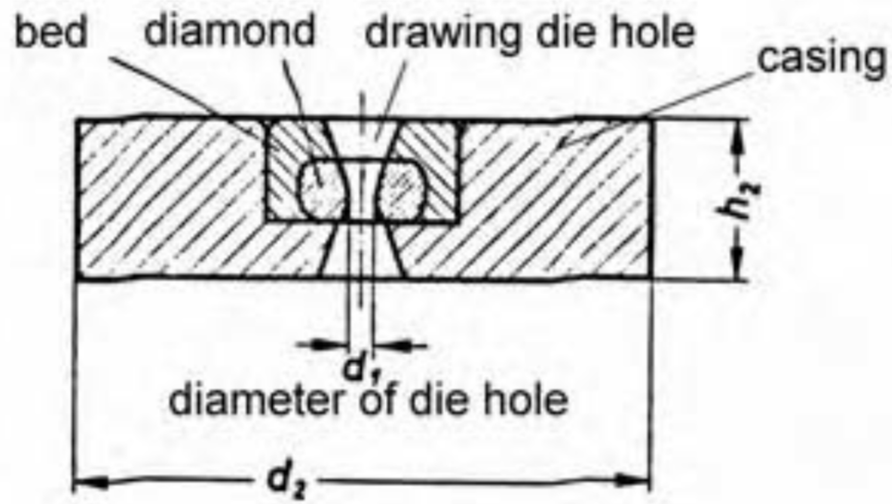
Enlarged die



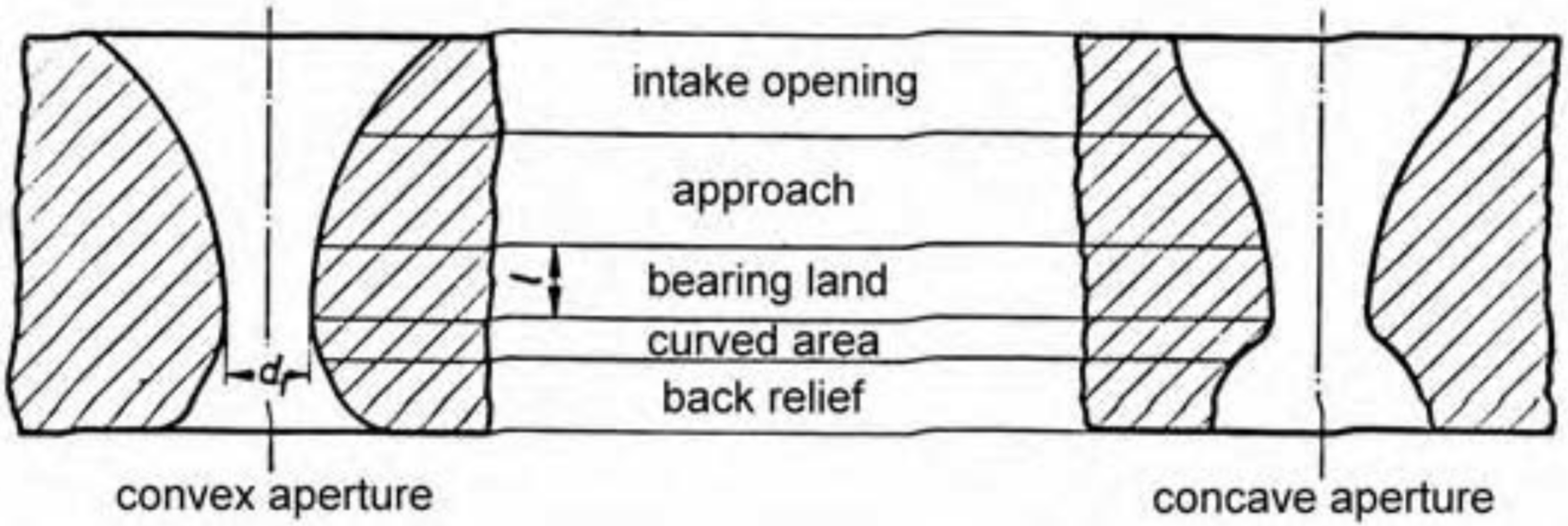
Drawing die materials

***Diamond* drawing dies**

For drawing fine and ultra-fine wires (1.5 mm to 0.01 mm) made of copper, steel, tungsten and molybdenum.



The diamond is sintered into a steel casing.



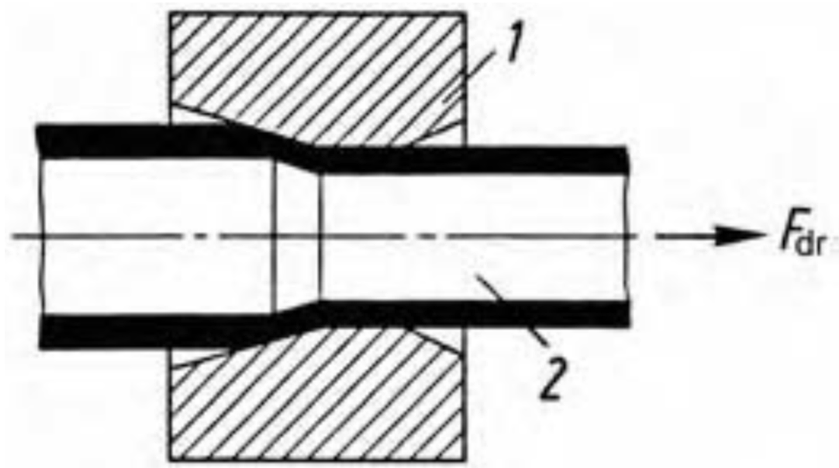
Tube drawing

Drawing of hollow parts, where the outside is formed by a drawing die hole and the inside by a plug or a rod.

Tube drawing processes

Drawing without a mandrel (tube sinking)

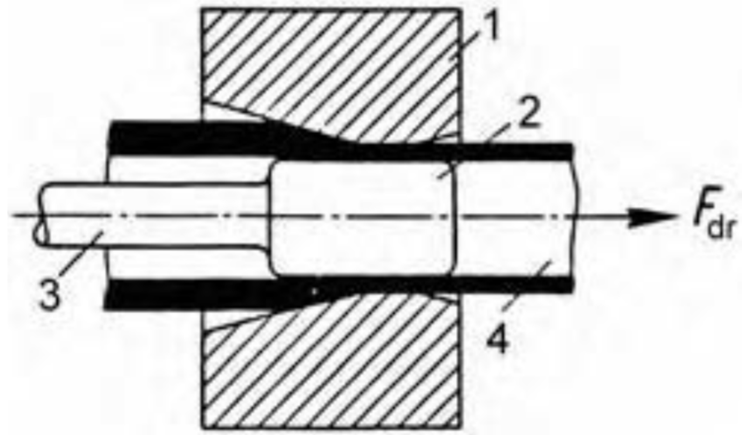
- no support from inside
- only the external diameter's tolerance is good
- only applied to tubes with smaller internal diameters



1 Drawing die, 2 workpiece

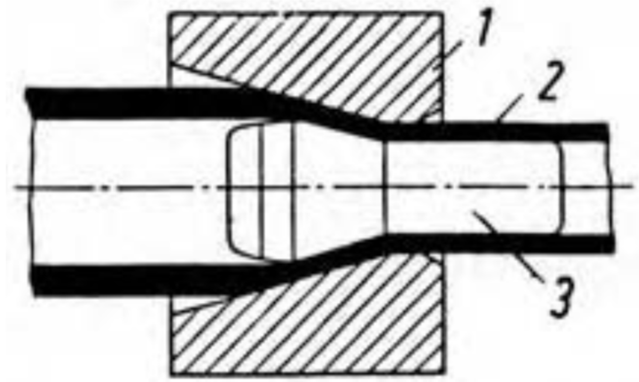
Tube drawing

Drawing over a stationary mandrel (plug), the plug holder length is limited



1 drawing ring, 2 workpiece, 3 mandrel, 4 plug

Drawing over a floating plug (it keeps itself in position)

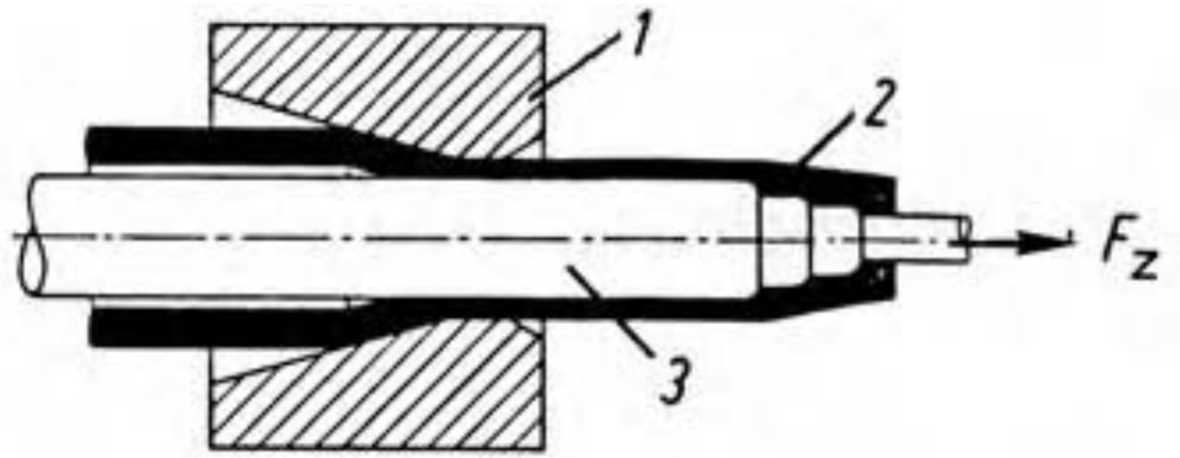


1 drawing ring, 2 workpiece, 3 floating plug

Tube drawing

Drawing over a moving mandrel

The rod and the tube are simultaneously moving in the drawing direction.



1 Drawing ring, 2 workpiece, 3 moving mandrel

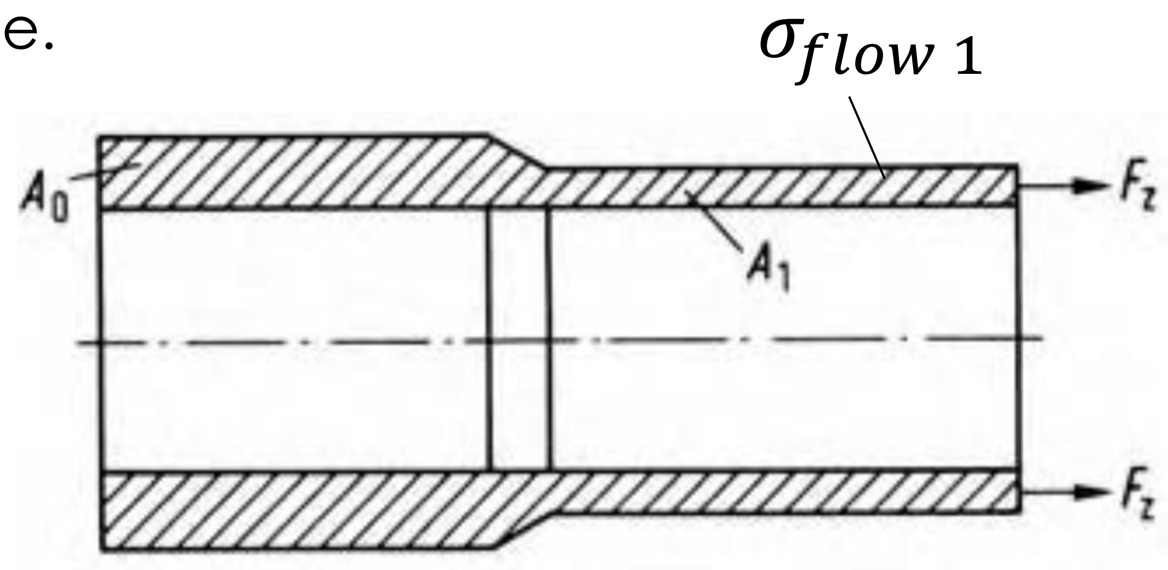
Strain and drawing force

Limit

The limit for the deformation comes from the required drawing force.

$$F_{drawing} < F_{perm.}$$

$$F_{perm.} = A_1 \sigma_{flow\ 1}$$



$$F_{drawing} = \frac{A_1\ \sigma_{flow\ mean}\ \varphi}{\eta}$$

$$\eta = 0.4 - 0.6 \quad for \quad \varphi = 0.15$$

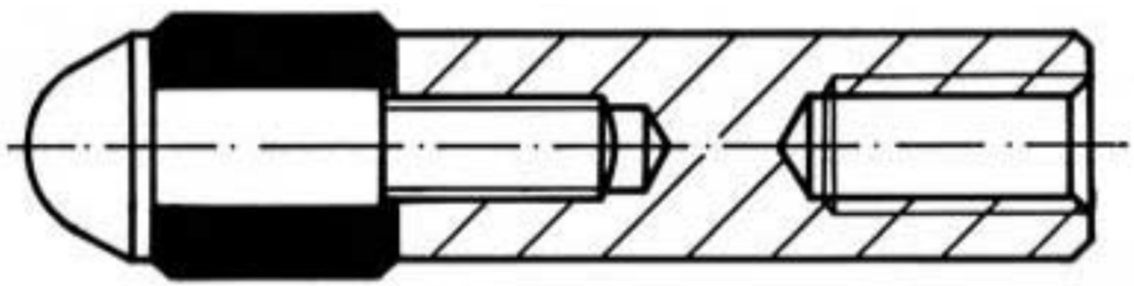
$$\eta = 0.7 - 0.8 \quad for \quad \varphi = 0.50$$

Strain and drawing force

Type of drawing	Permissible deformation, cross area in % (from drawing force)	Principal strain φ_p (–)
Tube sinking	20 – 50	$\varphi_p = \ln \frac{d_0}{d_1}$ $\varphi_{p\%} = \varphi_p \cdot 100$ (%)
Plug drawing	30 – 50	$\varphi_p = \ln \frac{A_0}{A_1}$ $\varphi_p = \ln \frac{D_0^2 - d_0^2}{D_1^2 - d_1^2}$ $\varphi_{p(\%)} = \varphi_p \cdot 100$ (%)
Rod drawing	40 – 60	

Drawing tools

Steel body drawing mandrel with carbide tool:



Drawing mandrel with screwed-on carbide ring

Lubrication - wire and tube drawing

Tube drawing: difficulty of maintaining a sufficiently thick lubricant film inside, at the *mandrel-tube interface*.

Drawing of rods: a common method is phosphate coating.

Lubricating regimes

Wet drawing, in which the dies and the rod are immersed completely in the lubricant.

Dry drawing, in which the surface of the rod to be drawn is coated with a lubricant by passing it through a box filled with the applied lubricant (stuffing box).

Metal coating, in which the rod or wire is coated with a soft metal, such as copper or tin, which acts as a solid lubricant.

Ultrasonic vibration of the dies and mandrels; in this process, vibrations reduce forces, improve surface finish and die life and allow larger reductions per pass without failure.

Defects - wire and tube drawing

Cold forming - residual stresses

stress-corrosion cracking

warp *deformation if a layer of material subsequently is removed (machining, or grinding)*

Rod and wire

center cracking (similar to those in extrusion)

seams longitudinal scratches or folds (seams may open up during subsequent forming operations)

die marks

Flow through conical dies - Summary

Three techniques use conical die

extrusion, drawing (wire & rod) and reduction.

The common basics may lead to one of the three techniques, depending on the border conditions

Zero/small axial stress at ingoing $\longrightarrow$ *wire / rod drawing*

Zero axial stress at outgoing $\longrightarrow$ extrusion

Smaller than flow stress at ingoing $\longrightarrow$ *reduction*

Thank you for your attention!