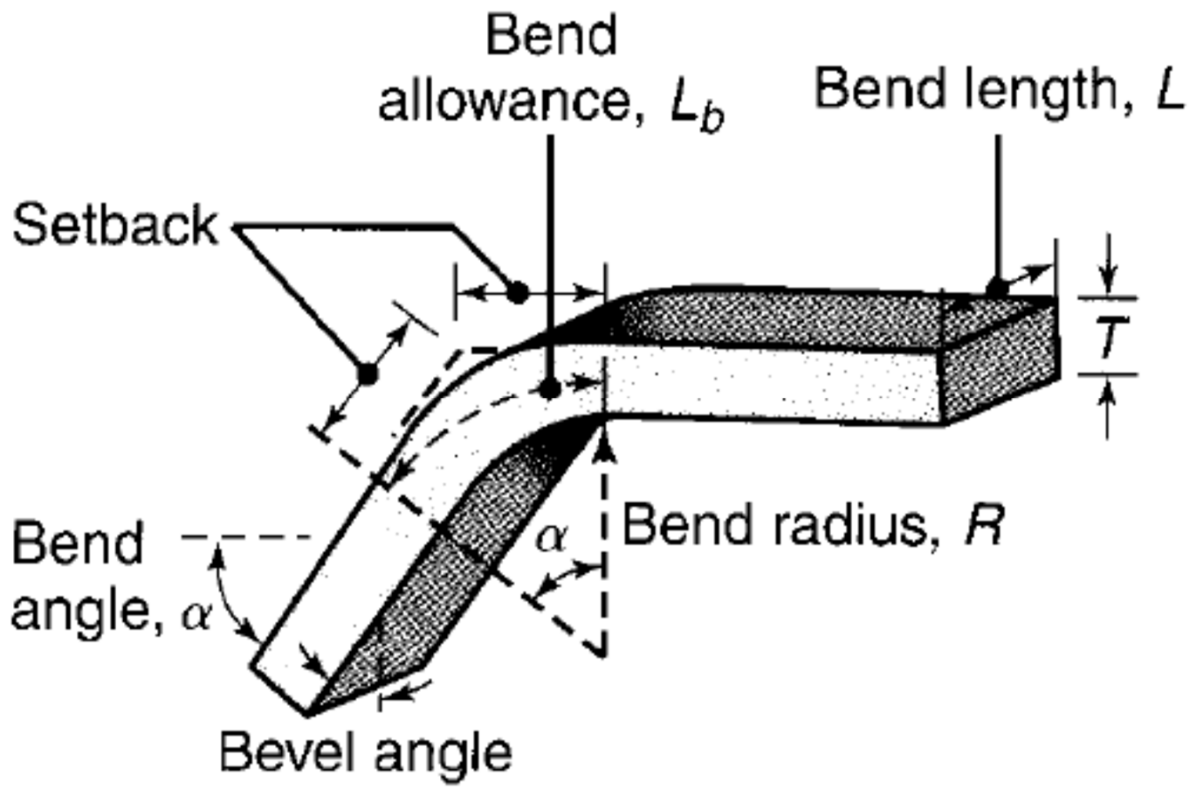
Sheet Metal Forming

Bending

Introduction

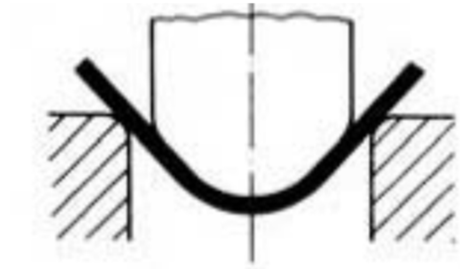
Definition: Bending is the forming of parts, where angled or ring-shaped workpieces are produced from sheet or strip metal.



The bending process

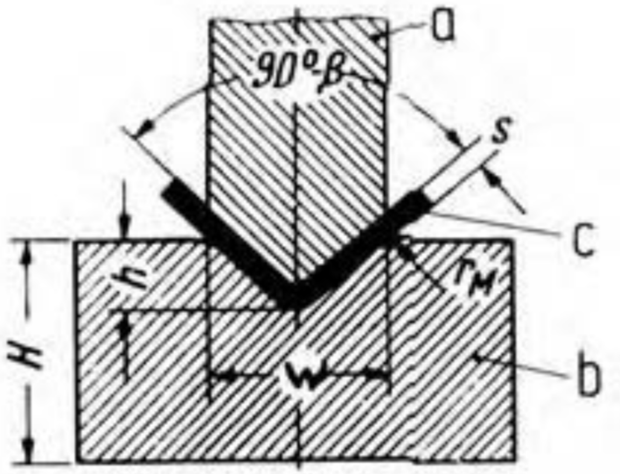
Air bending

Air bending is used mainly to **straighten** workpieces.

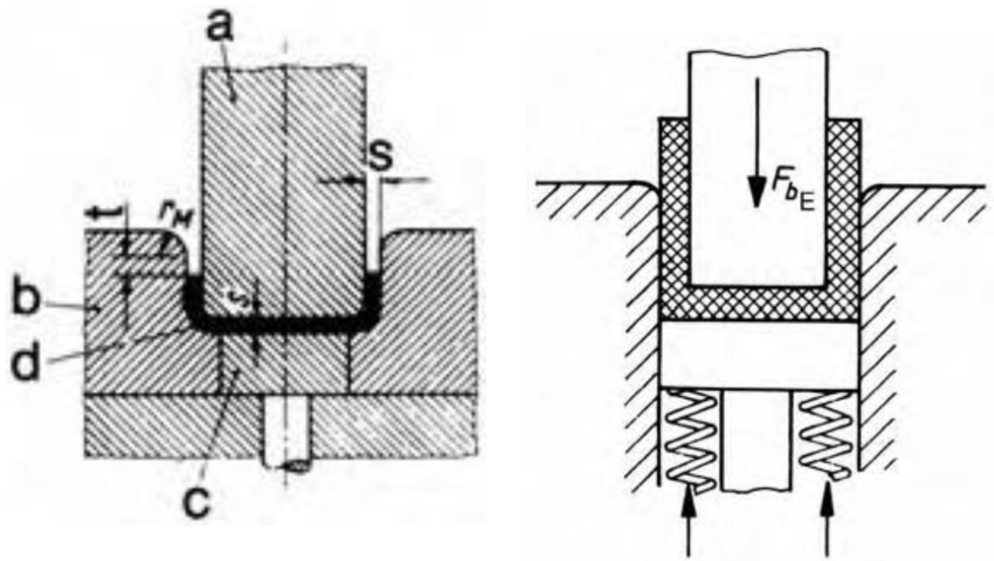


Die bending (bottom bending)

The deformation ends with a localized compressive stress in the die.



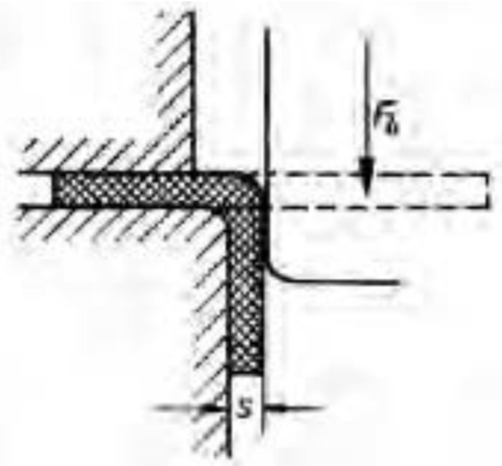
V-bending



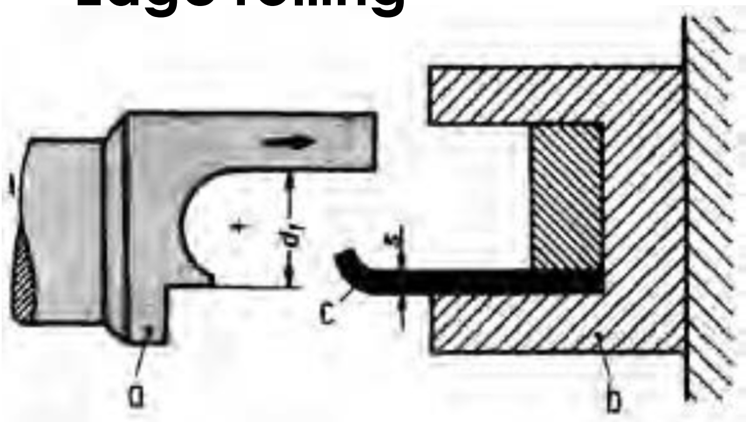
U-bending

The bending process

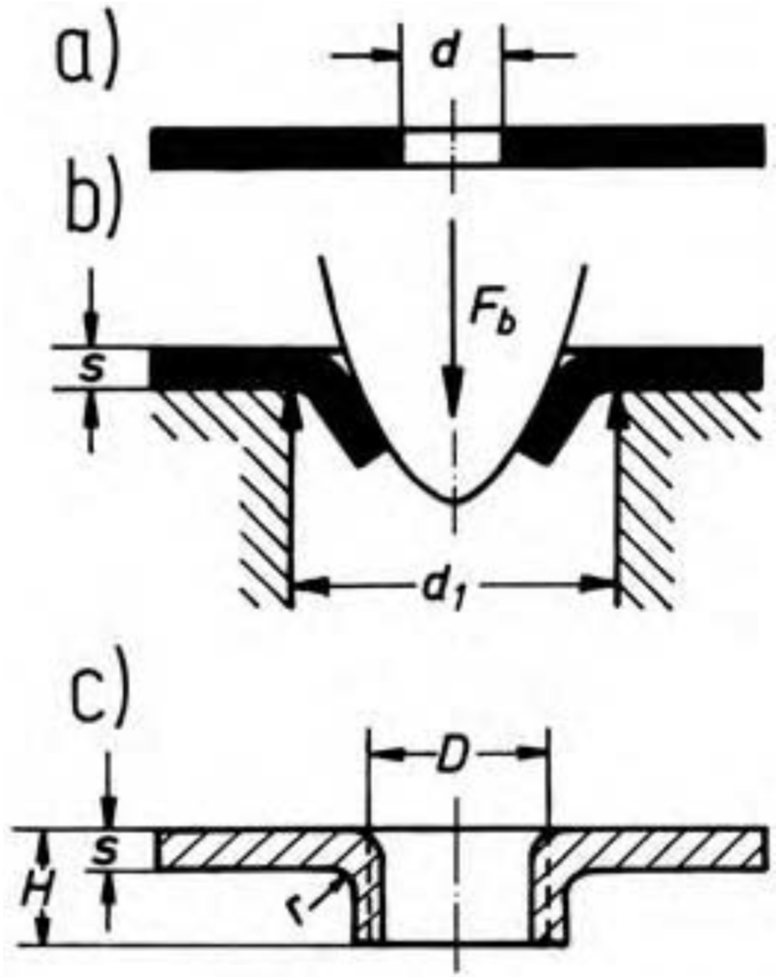
Edge bending



Edge rolling



Flanging

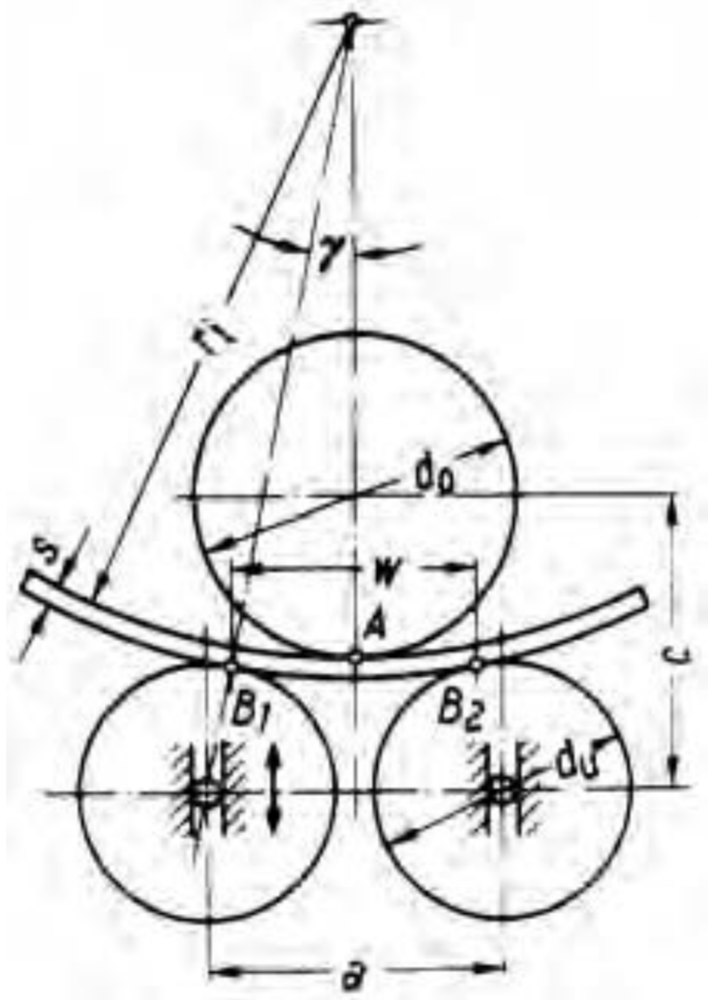


The bending process

Roll bending

The bending moment is created by three rolls. The top roll can be moved around the angle γ and the height of both lower rolls can be adjusted.

By adjusting the relative positions of the rolls, any diameters can be produced, with the smallest diameter limited by the size of the bending rolls.



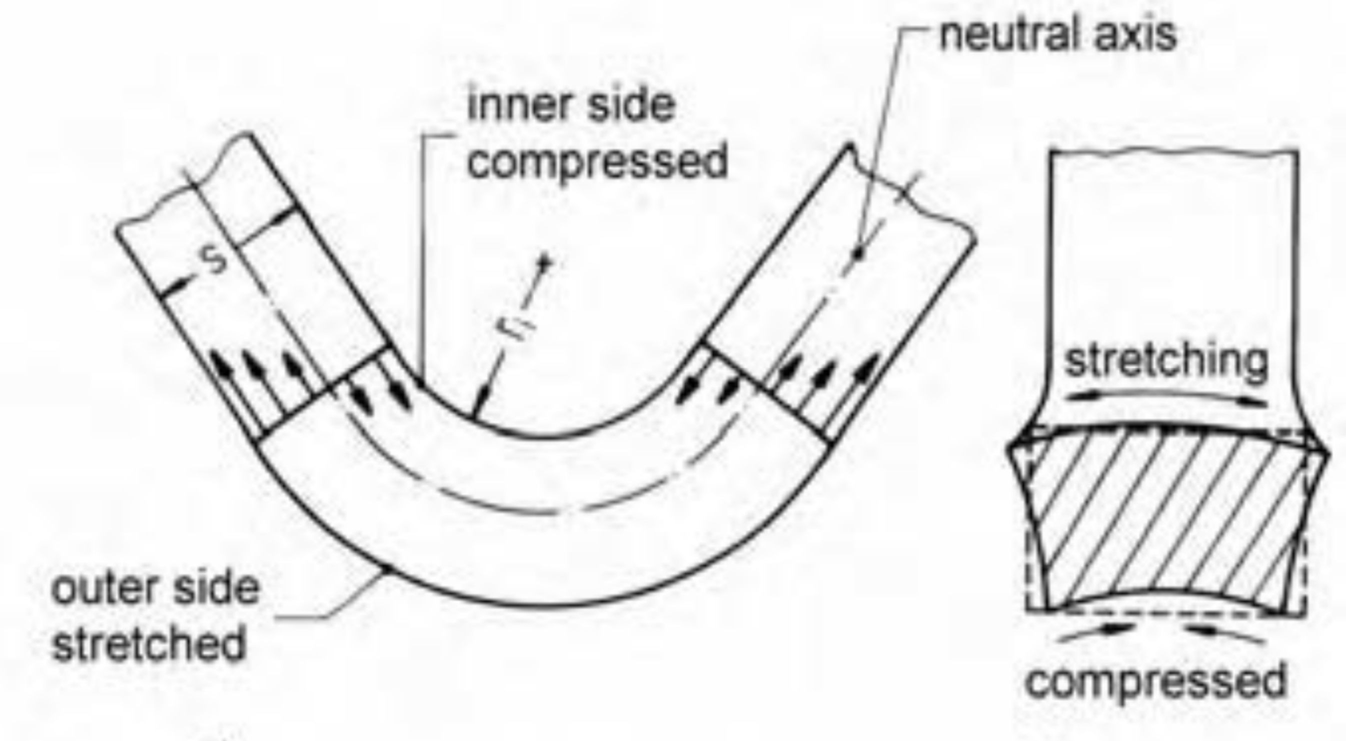
Limits of bending deformation

Strains

The inner side: compressed along the length of the workpiece
stretched across the length of the workpiece

The outer side: stretched along the length of the workpiece
compressed across the length of the workpiece

The neutral axis does not change in length (it is approximately in the center.)



Limits of bending deformation

Die bending (bottom bending)

More precise if enough pressure is applied in the die at the end of the bending operation.

The **smaller the bend (punch) radius** (r_i) **the better the accuracy** of the angle.

$$r_{i\,min} = s \cdot c$$

$r_{i\,min}$	smallest permissible bend radius
s	sheet thickness
c	material coefficient (next slide)

Roll bending

$$r_{i\,max} = \frac{s \cdot E}{2\,\sigma_f}$$

$r_{i\,max}$	maximum permissible bend radius
s	sheet thickness
E	Young's modulus
σ_f	flow stress

Limits of bending deformation

Material coefficient for the bending limit

Material	*c* values			
	soft annealed		hardened	
	transverse	longitudinal	transverse	longitudinal
Al	0.01	0.3	0.3	0.8
Cu	0.01	0.3	1.0	2.0
CuZn 37	0.01	0.3	0.4	0.8
C15 – C25	0.1	0.5	0.5	1.0
C35 – C45	0.3	0.8	0.8	1.5

See the much smaller values in the transverse direction compared to the longitudinal direction, caused by the **unisotropy** of the rolled raw material (see later slide14).

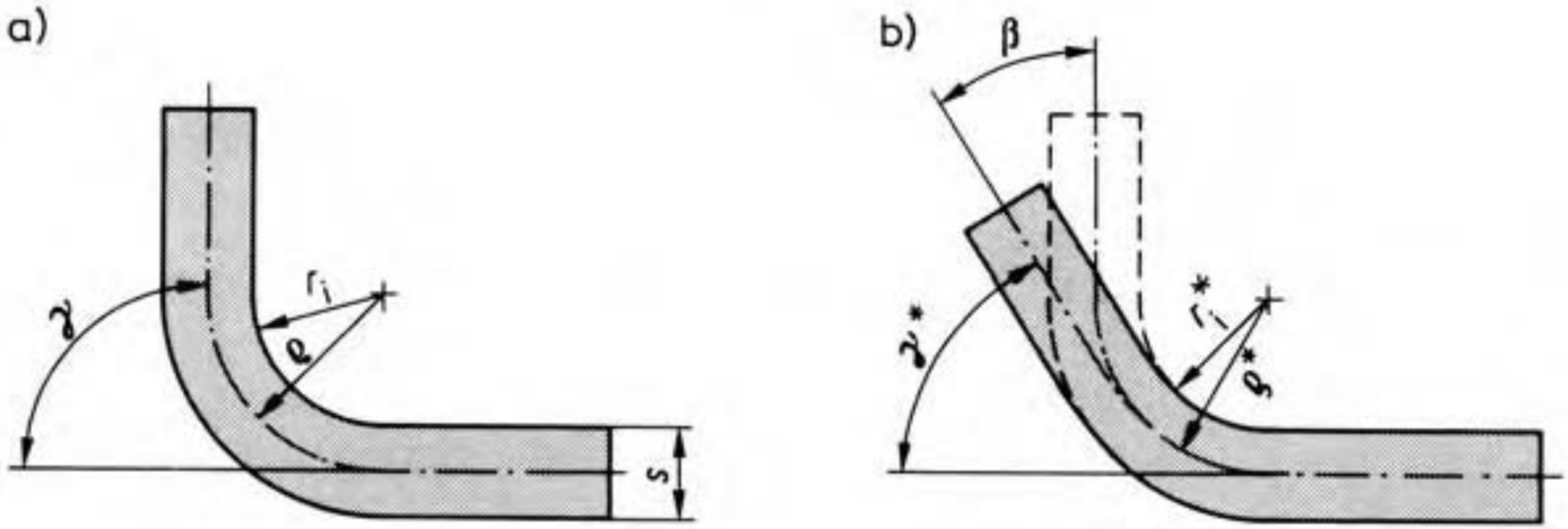
Spring back

In every bending operation **spring-back** occurs.

The extent of the spring-back depends upon

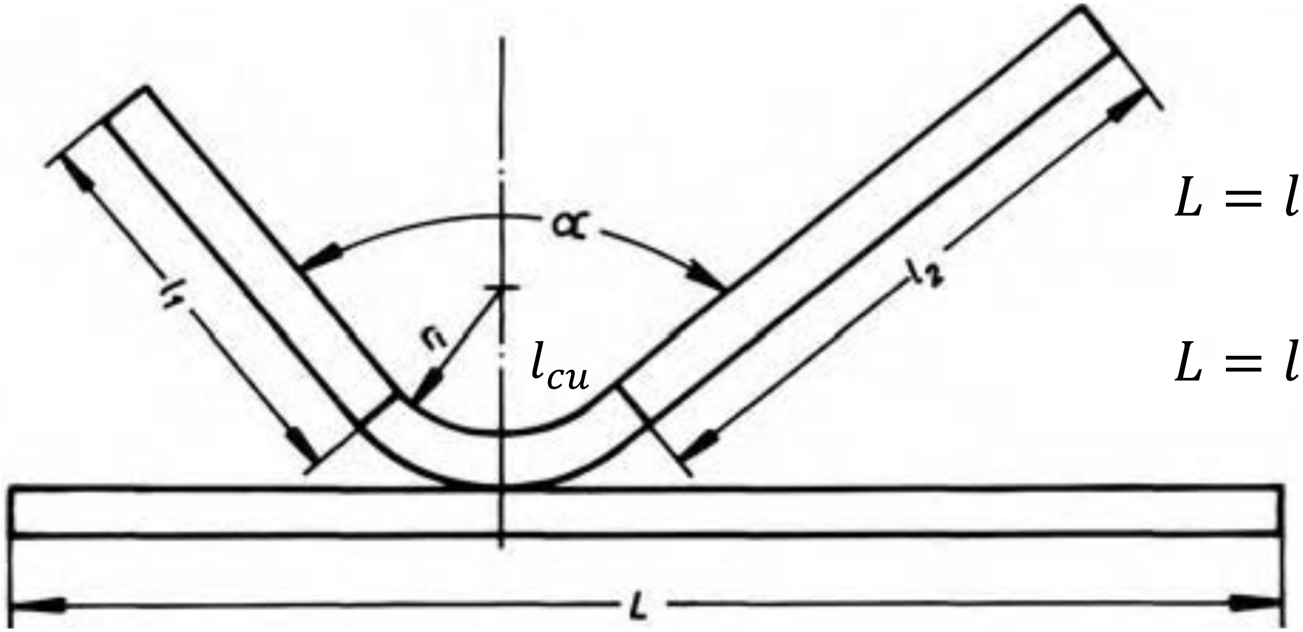
- elastic limit of the material formed
- bending type (air bending or die bending)
- bend radius:

  the **smaller the r** is, the **larger the plastic deformation zone** is, and so, the **smaller the spring-back**.



Blank length

L = effective length, the sum of all straight and curved sections



$$L = l_1 + l_{cu} + l_2$$

$$L = l_1 + \frac{\alpha \cdot \pi}{180°}\left(r_i + \frac{e \cdot s}{2}\right) + l_2$$

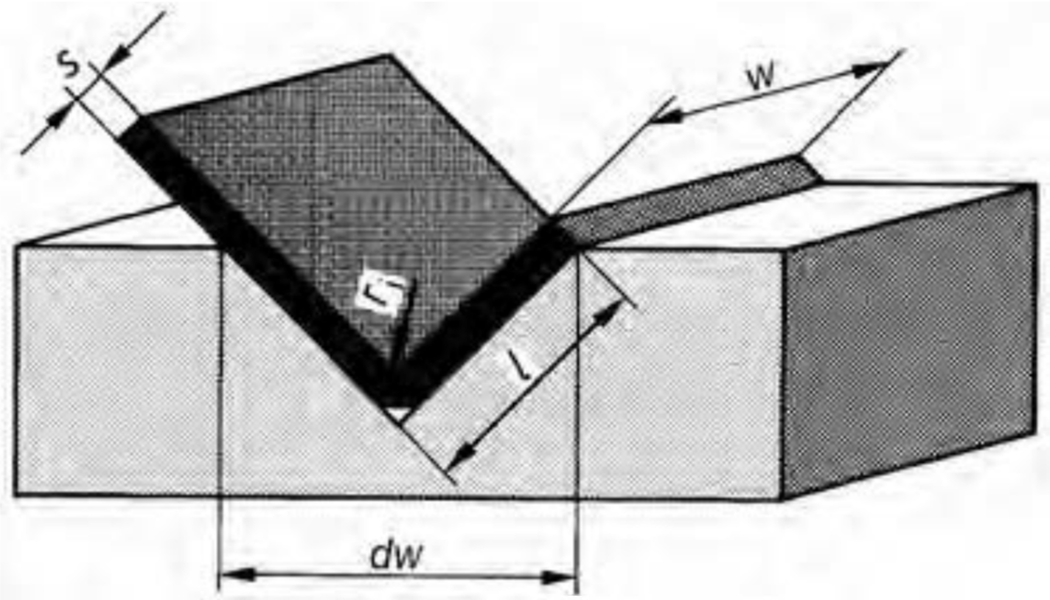
$\frac{r_i}{s}$	5.0	3.0	2.0	1.2	0.8	0.5
e	1.0	0.9	0.8	0.7	0.6	0.5

L effective length
L_{cu} length of the curve
l_1, l_2 length of the legs
r_i bend radius
s sheet thickness
α bend angle
e correction value

Bending force - example

Bending force:

$$F_b = \frac{1.2 \cdot w \cdot s^2 \cdot R_m}{dw}$$



Recommended: $l = 6 \cdot s$

F_b	bending force
w	width of the part
s	thickness of the part
R_m	tensile strength
dw	die width
r_i	bend radius
$r_{i\,min}$	smallest permissible radius

Bottoming force (for precision):

$$F_{bbot} = n \cdot F_b$$

r_i / s	> 0.7	0.7	0.5	0.35
n	2	2	2.5	3.5

Die design

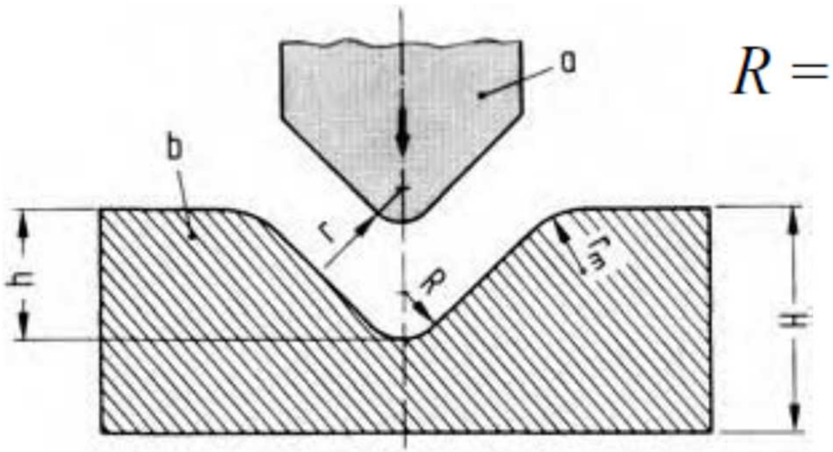
V-shaped die

$$r_m = 2.5 \cdot s$$

s - thickness of the part

$$R = 0.7\,(r + s)$$

$R < r + s$ – sharper edge



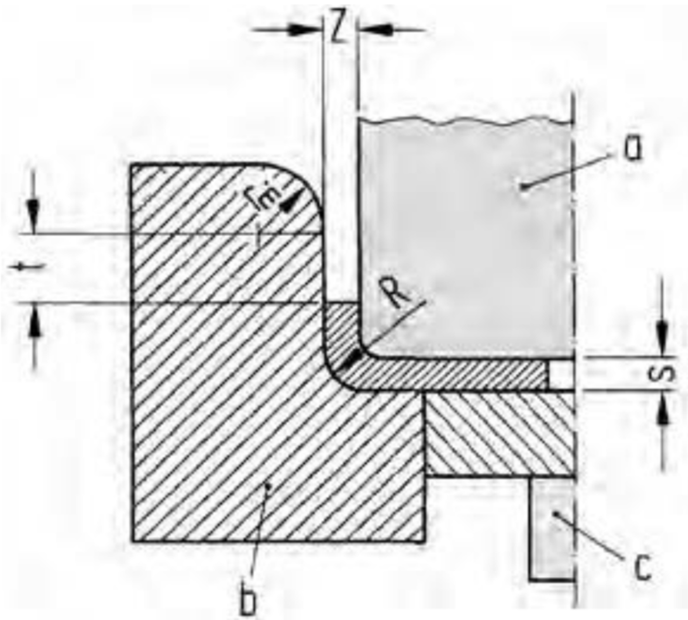
$h = f(s)$ – see literature

U-shaped die

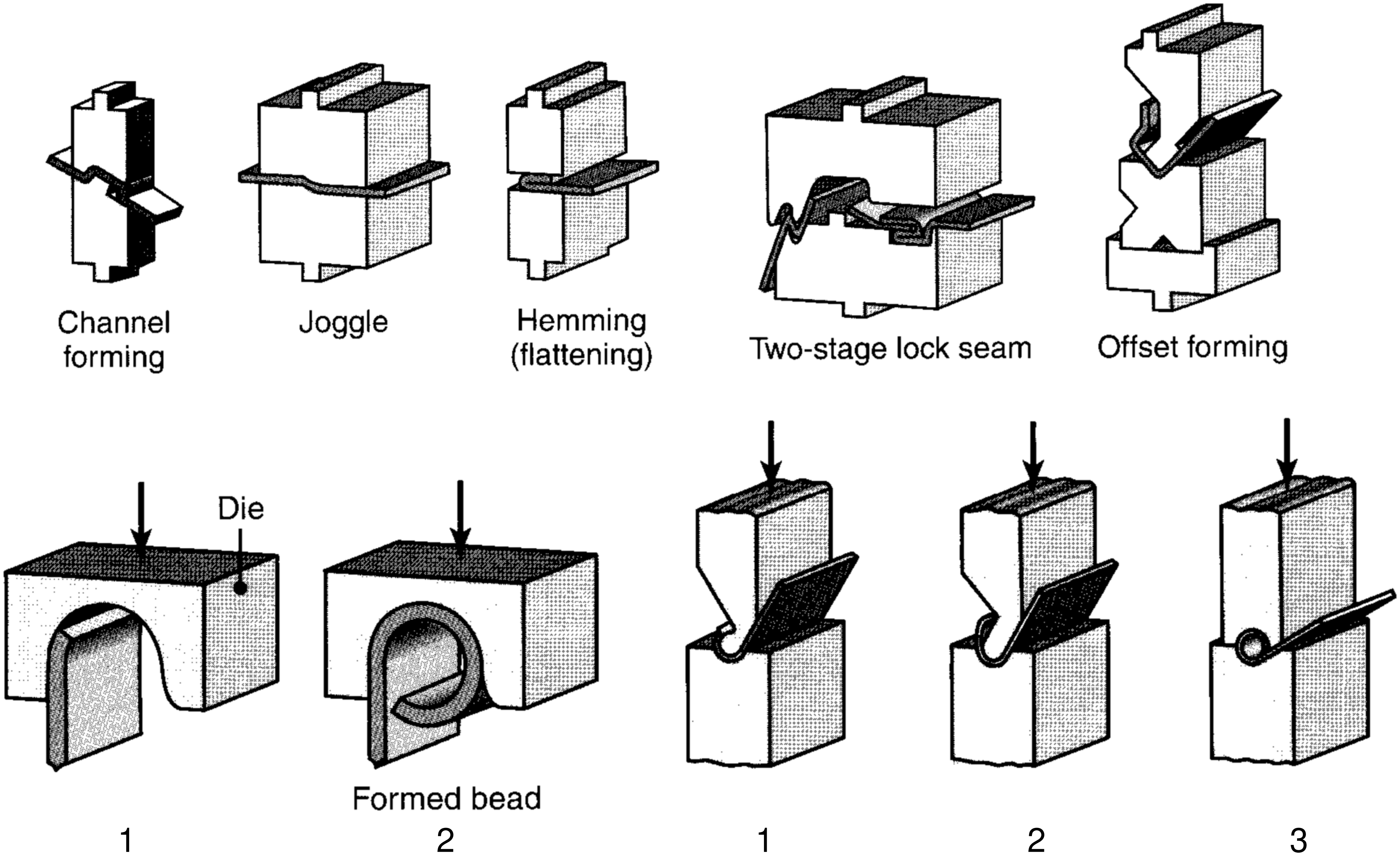
$$r_m = 2.5 \cdot s$$

$$Z_{max} = s_{max}$$

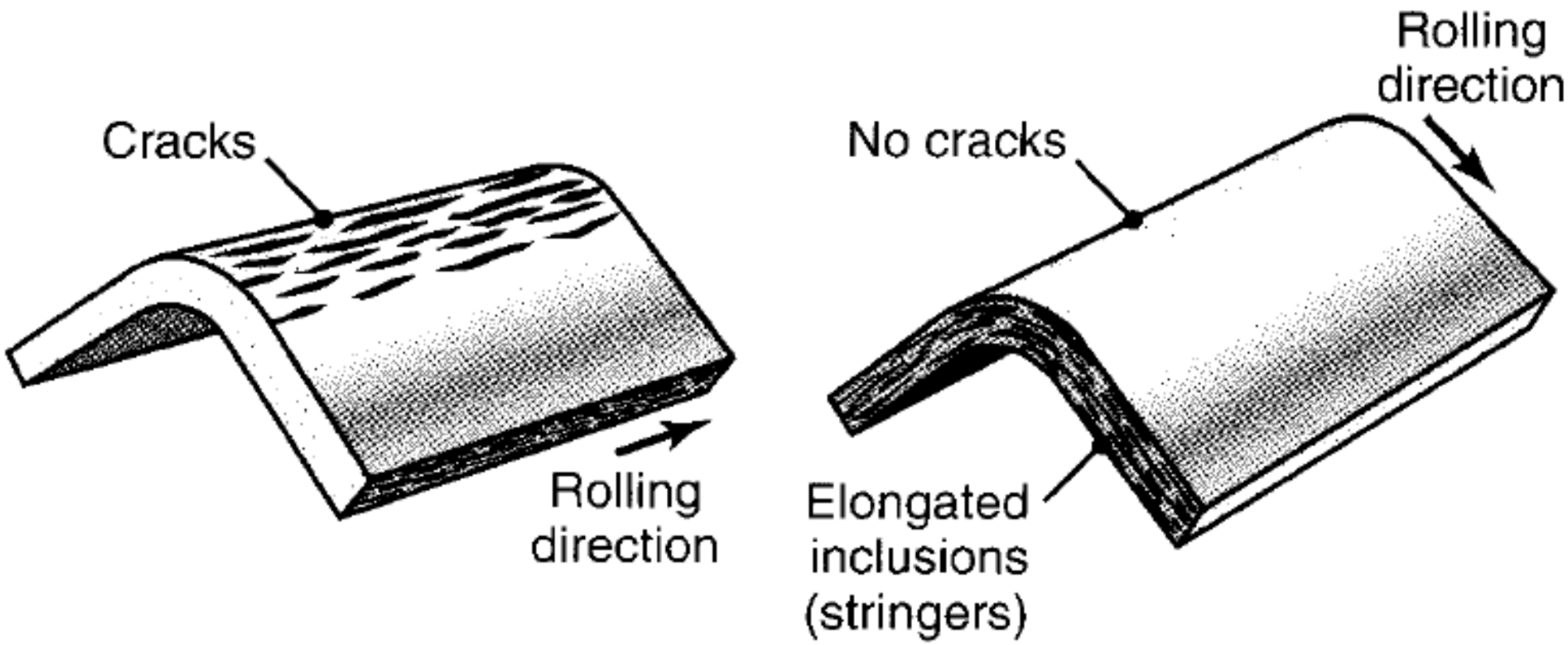
$t = f(s)$ – see literature



Bending operations

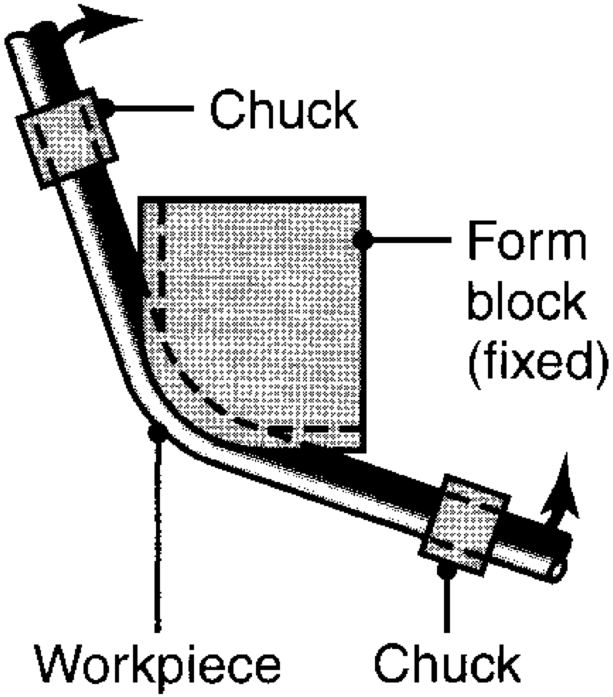


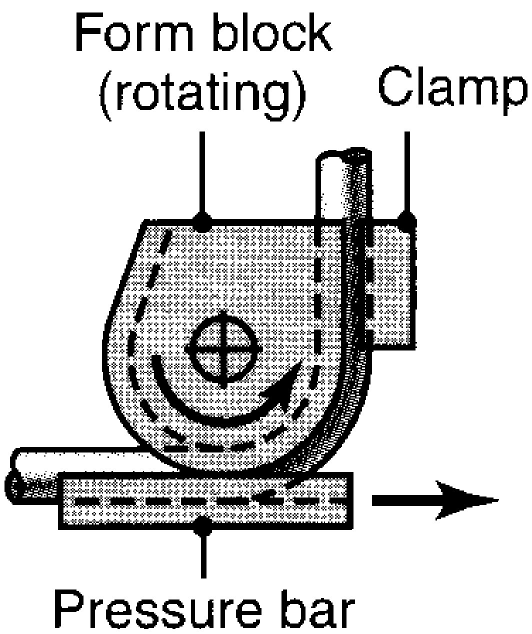
Bending defects

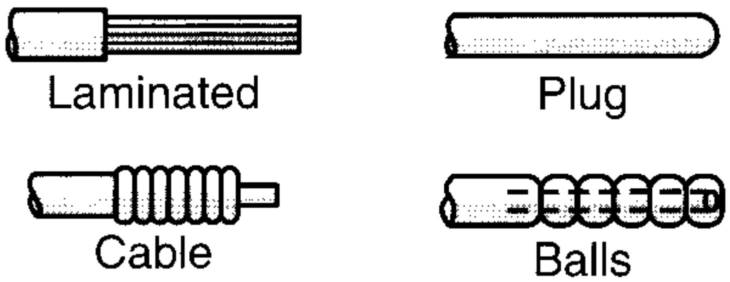


Remember for the table on slide 8.

Bending of pipes, tubes

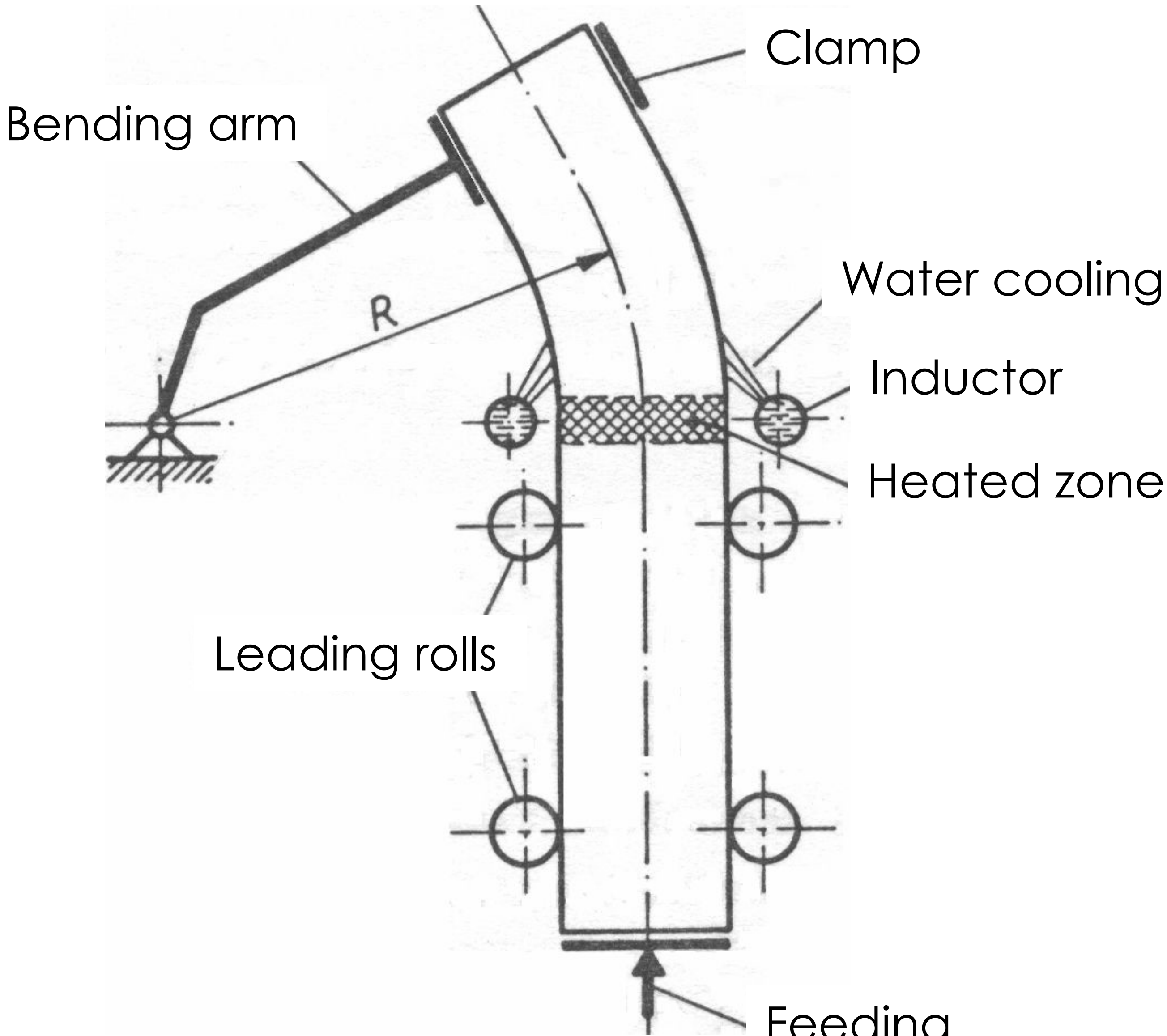






Mandrels for tube bending

Induction tube bending



Thank you for your attention!