ME361 – Manufacturing Science Technology

Bulk deformation processes

Forging

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Bulk deformation processes

- Forging
- Rolling
- Drawing
- Extrusion (if time permits)

Forging

Forging

https://www.youtube.com/watch?v=TX3uJxB1j8Q

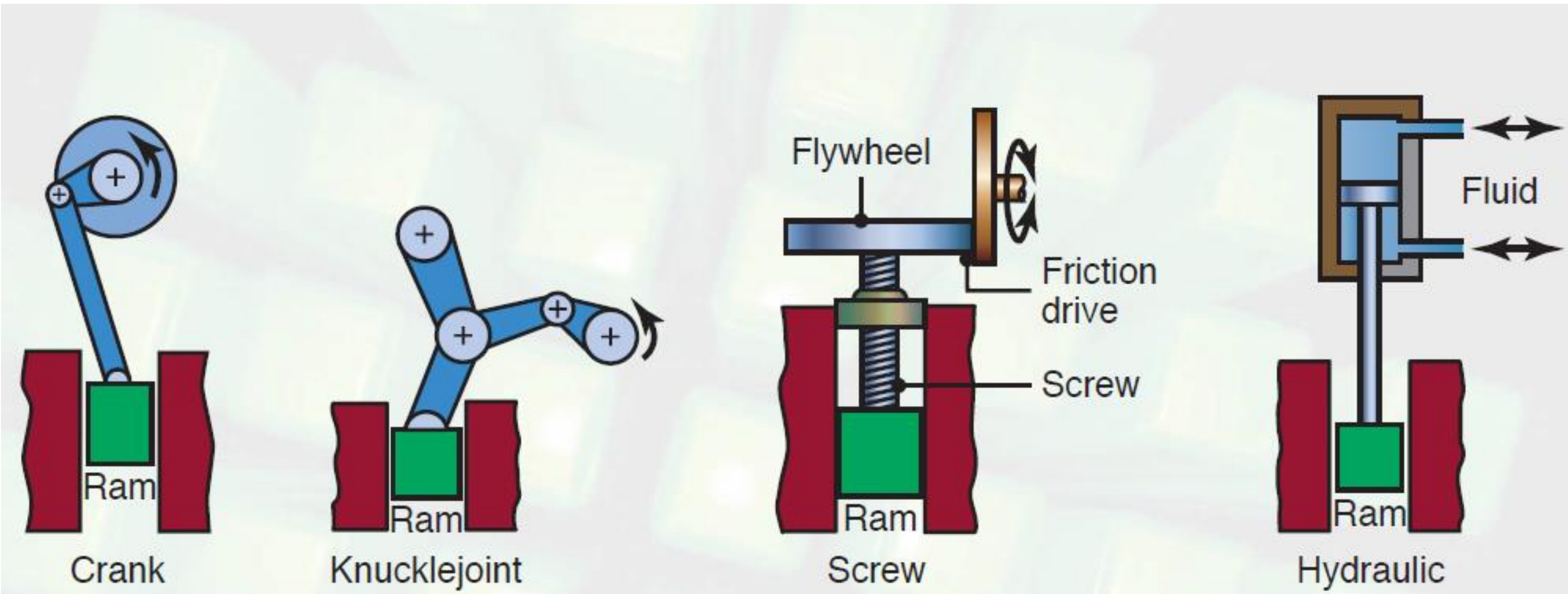
Forging, the Chinese way

https://www.youtube.com/watch?v=r41dcYUvNLk

Forging, the German way

https://www.youtube.com/watch?v=KwNwN4eRQOA

Types of mechanisms for moving forging die



Source: Kalpakjian and Schmid

Forging

FORGING IS THE OLDEST MECHANICAL METHOD OF METALWORKING KNOWN TO MAN.

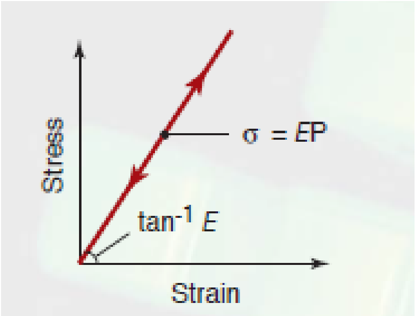
VideoScribe

https://www.youtube.com/watch?v=QwKaKP53HDI

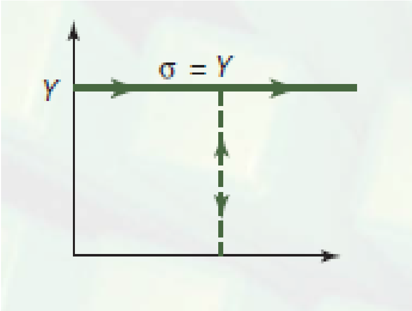
Forging analysis

Preliminaries. Stress-strain behavior.

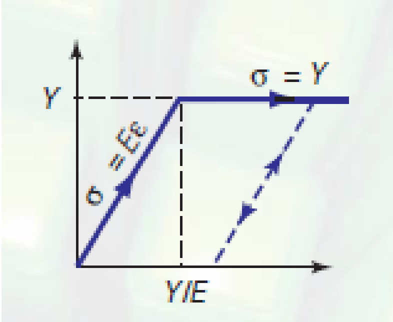
(a) Perfectly elastic



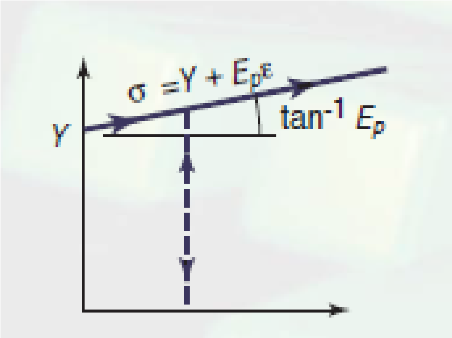
(b) Rigid, perfectly plastic



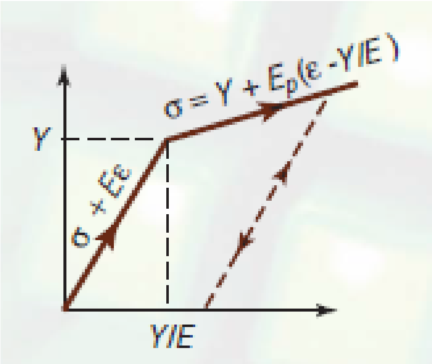
(c) Elastic, perfectly plastic



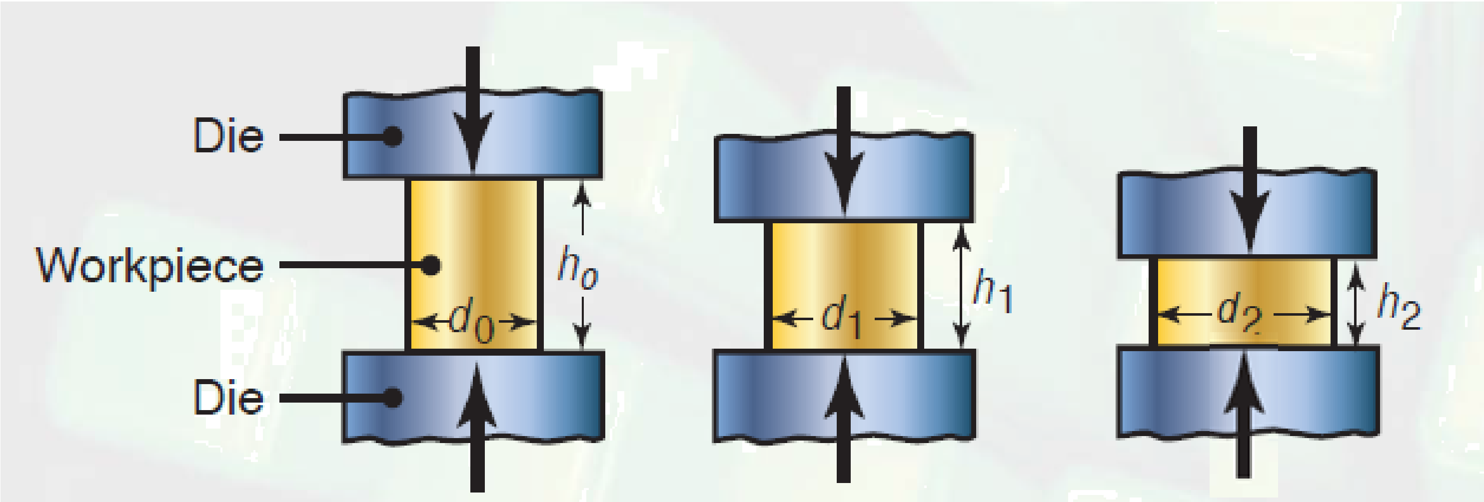
(d) Rigid, linearly strain hardening



(e) Elastic, linearly strain hardening

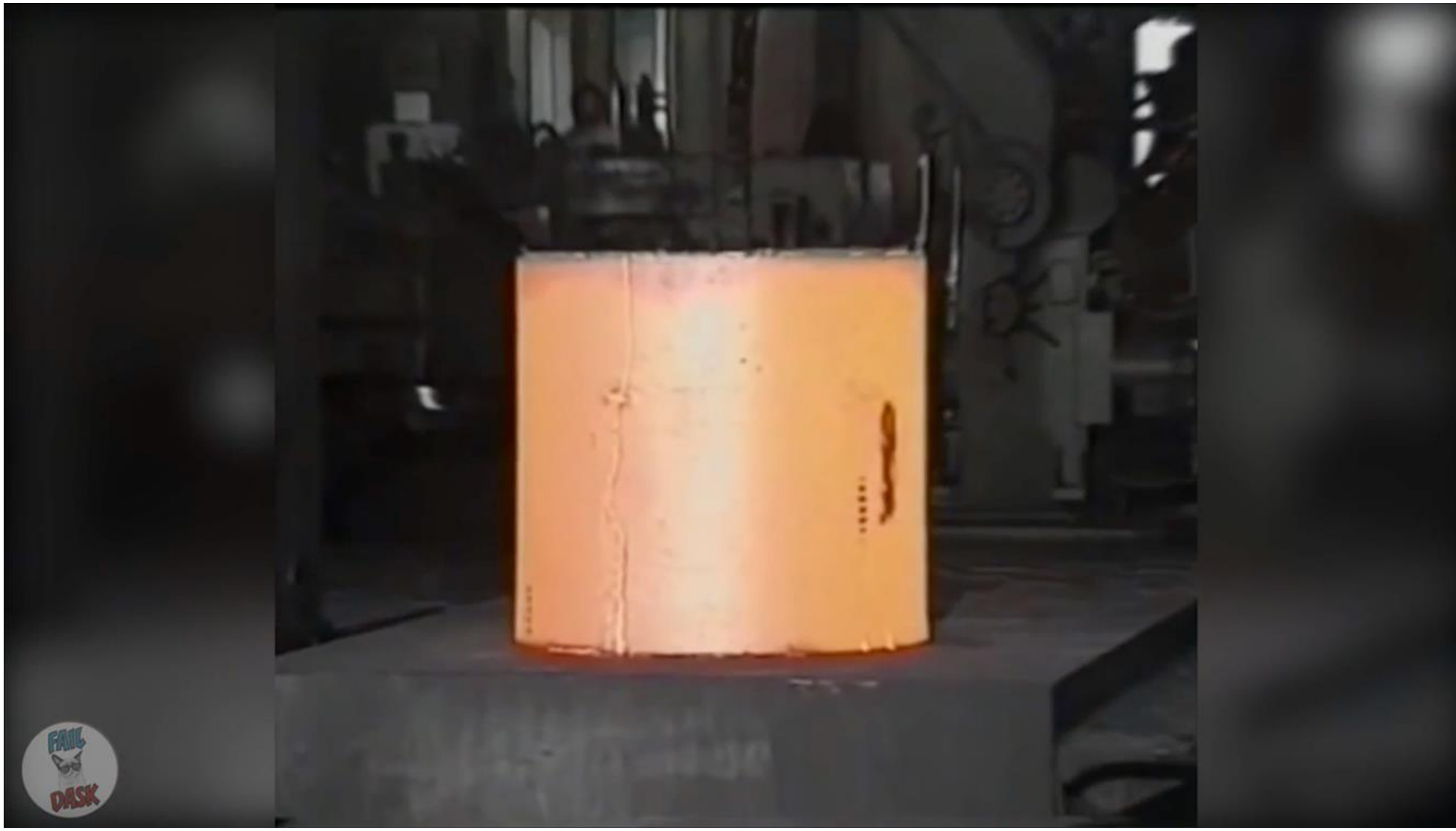


Forging. The ideal case.



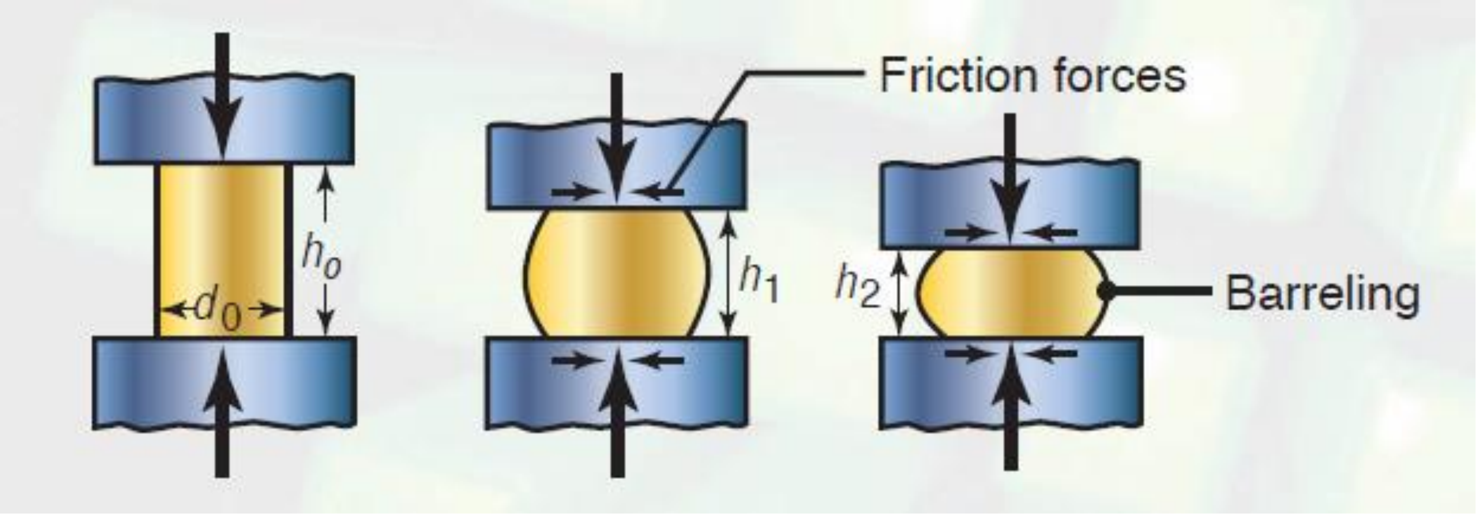
Source: Kalpakjian and Schmid

Barreling in forging

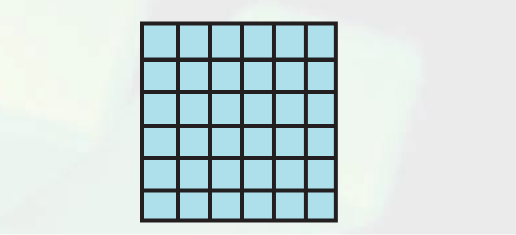


https://www.youtube.com/watch?v=MSWYbb5vWu4

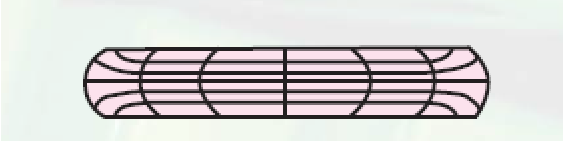
Barreling, caused by friction



Grain flow:



Original

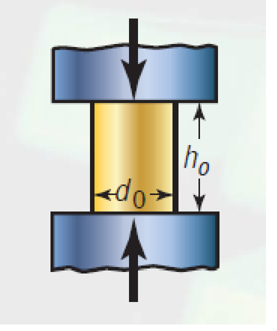


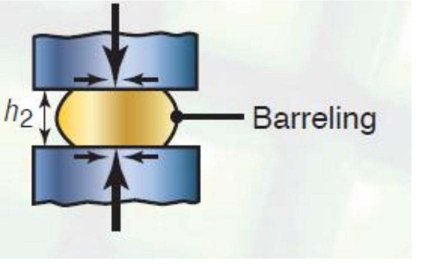
Deformed

Source: Kalpakjian and Schmid

Forging analysis: objectives and assumptions

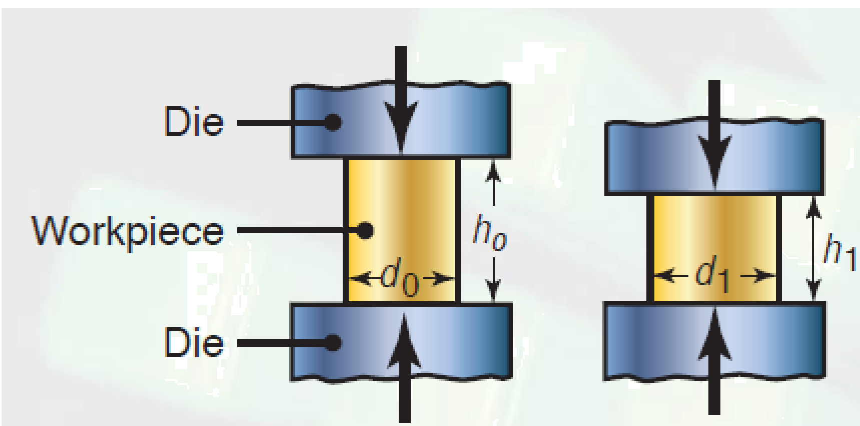
- Objective: To determine the forging force
- Assumptions:
  - Max. force is attained at the end of the operation
  - Friction between workpiece and dies is constant
  - Thickness is small compared to other dimensions, and hence variation in stress field along thickness is negligible
  - Problem is of plane strain type (length >> width)
  - Workpiece is in plastic state during the process





Forging analysis – the ideal case (no barreling)

- Consider a cylindrical specimen with initial diameter d_0
- Ideal case: friction at the interfaces is zero, i.e. no barreling
- Material is perfectly plastic with a yield stress of Y



Forging force at any height h_1:

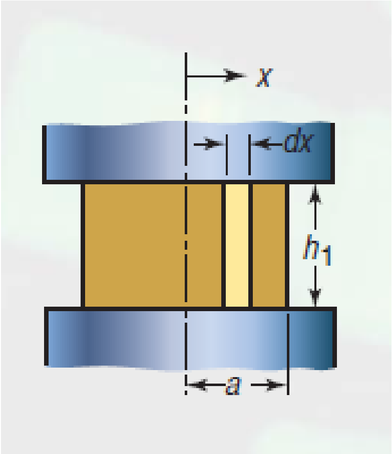
$$\boxed{F = YA_1}$$

Cross sectional area A_1 from volume constancy:

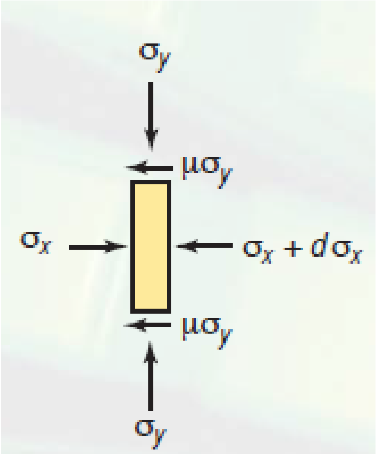
$$\boxed{A_1 = \frac{A_0 h_0}{h_1}}$$

Forging analysis: with barreling (with friction)

- Consider a rectangular workpiece
- Simple case of compression with friction
- Deformation in plane strain, i.e. no flow in the z-direction (no flow out of plane)
- Use slab method for analysis



Source: Kalpakjian and Schmid



Balance horizontal forces in this element:

$$\boxed{(\sigma_x + d\sigma_x)h + 2\mu\sigma_y dx - \sigma_x h = 0}$$

or

$$\boxed{d\sigma_x + \frac{2\mu\sigma_y}{h}dx = 0}$$

One equation, two unknowns.
Need another equation.

Forging analysis contd. with a digression for plane strain

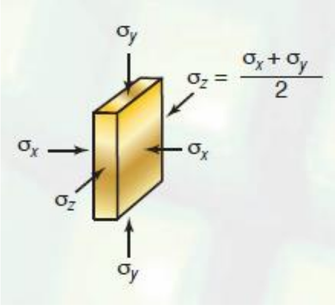
Recalling Hooke's law equations:

$$\boxed{\begin{aligned}\varepsilon_x &= \frac{1}{E}\left[\sigma_x - \nu\left(\sigma_y + \sigma_z\right)\right]\\ \varepsilon_y &= \frac{1}{E}\left[\sigma_y - \nu\left(\sigma_x + \sigma_z\right)\right]\\ \varepsilon_z &= \frac{1}{E}\left[\sigma_z - \nu\left(\sigma_x + \sigma_y\right)\right]\end{aligned}}$$

For plane strain, $\varepsilon_z = 0$;

$$\sigma_z = \frac{\sigma_x + \sigma_y}{2};$$

since $\nu = \frac{1}{2}$ in plastic deformation



Use a yield criterion (Distortion energy/ von-Mises):

$$\boxed{\left(\sigma_x - \sigma_y\right)^2 + \left(\sigma_y - \sigma_z\right)^2 + \left(\sigma_z - \sigma_x\right)^2 = 2Y^2}$$

$\sigma_x, \sigma_y, \sigma_z$ – principle stresses;

Y – the uniaxial yield stress

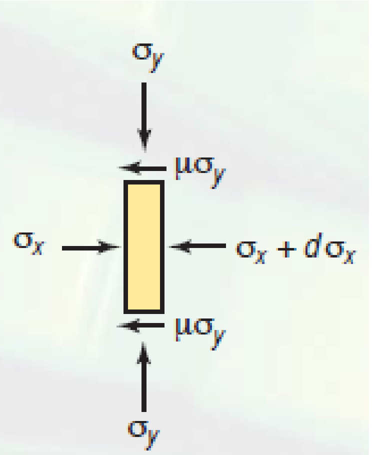
$$\boxed{\sigma_y - \sigma_x = \frac{2}{\sqrt{3}} Y = Y'}^{*} \quad \text{or} \quad \boxed{d\sigma_y = d\sigma_x} \qquad (2)$$

*σ_x and σ_y are assumed to be principle stresses, even though there is a shear component of $\mu\sigma_y$. However, since μ is usually small, this is reasonable

Forging analysis contd.

One equation, two unknowns. Need another equation.

$$\boxed{d\sigma_x + \frac{2\mu\sigma_y}{h}dx = 0} \qquad (1)$$

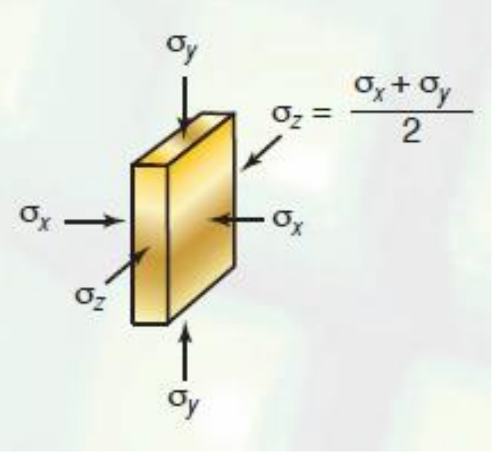


Element is subjected to triaxial compression. Using distortion energy criterion for plane strain:

$$\boxed{\sigma_y - \sigma_x = \frac{2}{\sqrt{3}}Y = Y'}$$

or

$$\boxed{d\sigma_y = d\sigma_x} \qquad (2)$$



Forging analysis contd.

From force balance and yield criterion for plane strain:

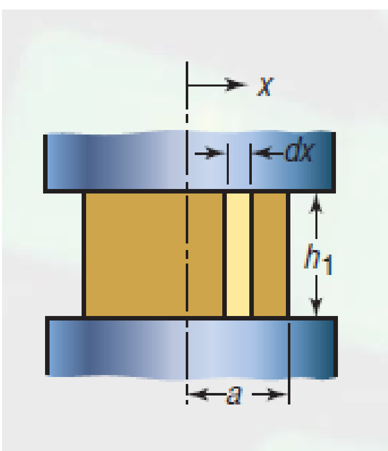
$$d\sigma_x + \frac{2\mu\sigma_y}{h}dx = 0 \qquad (1)$$

$$d\sigma_y = d\sigma_x \qquad (2)$$

$$\frac{d\sigma_y}{\sigma_y} = \frac{2\mu}{h}dx$$

Integrate

$$\sigma_y = Ce^{\frac{-2\mu x}{h}}$$



At $x = a, \sigma_x = 0 \rightarrow \sigma_y = Y'$ ($\sigma_y - \sigma_x = Y'$) at workpiece edges, hence

$$C = Y'e^{\frac{2\mu a}{h}}$$

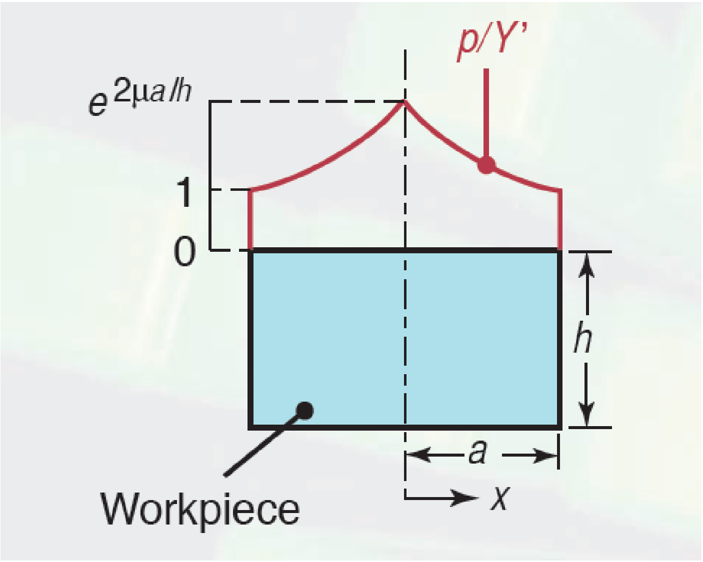
Thus, the stresses are: $p = \sigma_y = Y'\, e^{(2\mu(a-x))/h}$ and

$$\sigma_x = \sigma_y - Y' = Y'\left[e^{(2\mu(a-x))/h} - 1\right]$$

Forging analysis contd.

Distribution of die pressure in dimensionless form:

$$\frac{p}{Y'} = e^{(2\mu(a-x))/h}$$



Source: Kalpakjian and Schmid

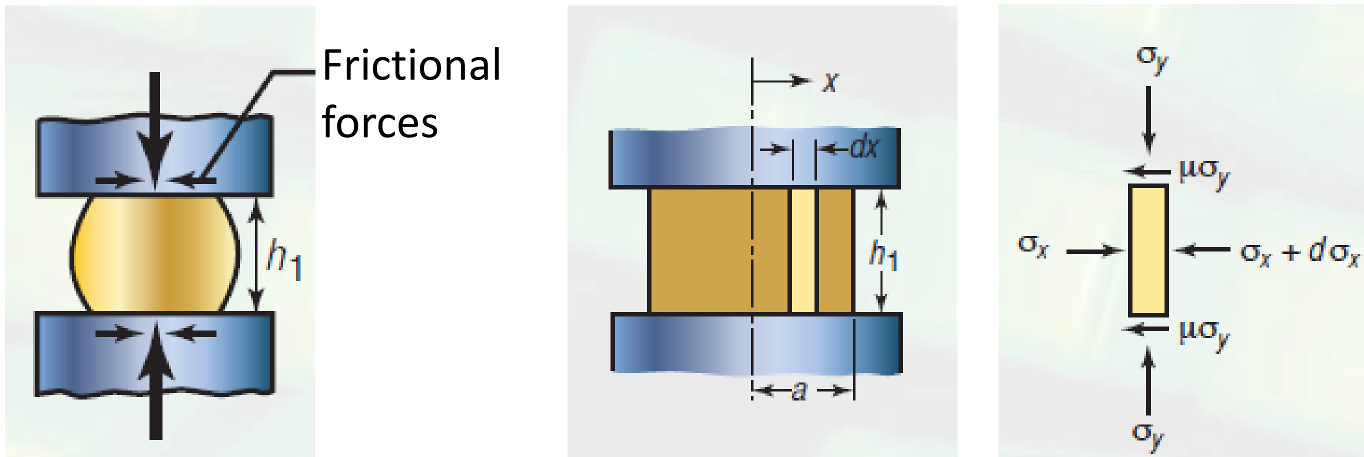
- Pressure increases exponentially towards the center
- Pressure also increases with the a/h ratio, and friction
- Area under pr. curve is the upsetting (forging) force per unit width of the workpiece. Can integrate to obtain exact force.
- Alternatively, forging force, is a product of average pressure and contact area:

$$F = (p_{av})(2a)(width)$$

$$p_{av} \simeq Y'\left(1 + \frac{\mu a}{h}\right)$$

- Force at any h during continuous forging is different, being a $f(p_{av}) \rightarrow f(h)$

Transition from sliding to sticking friction



- In plane-strain forging, product of μ and p is the frictional stress at a location x from the center.
- Since p increases towards the center, so does μp
- However, $\mu p \ngtr k$, the yield stress of the material
- Limiting case, $\mu p = k$, i.e. sticking is taking place
- At what distance does the transition from sticking to sliding take place?

Transition from sliding to sticking friction

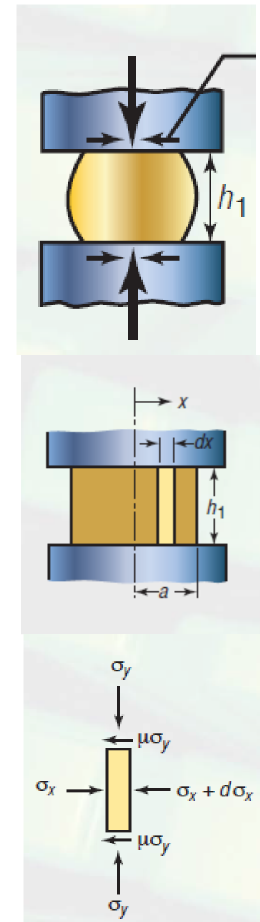
- Shear stress at interface due to friction: $\tau = \mu p$
- Since $\mu p \ngtr k$, the limiting case is $\mu p = k$, i.e. sticking is taking place
- For plane strain, $k = Y'/2$
- From pressure ($p = Y'\, e^{(2\mu(a-x))/h}$) in the limit, we get:

$$\boxed{\mu Y' e^{(2\mu(a-x))/h} = \frac{Y'}{2}} \longrightarrow \boxed{2\mu\frac{(a-x)}{h} = ln\left(\frac{1}{2\mu}\right)}$$

i.e., the location from sliding to sticking is

$$\boxed{x = a - \left(\frac{h}{2\mu}\right) ln\left(\frac{1}{2\mu}\right)}$$

- Follows that as magnitude of μ decrease, x decreases



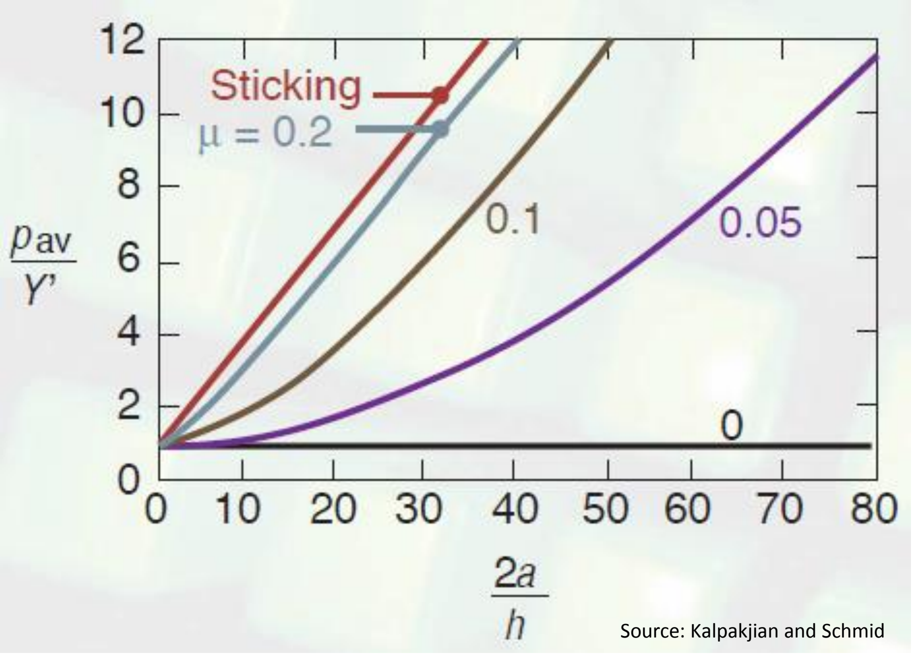
Pressure in sliding and in sticking

- Recalling normal pressure (stress) in sliding

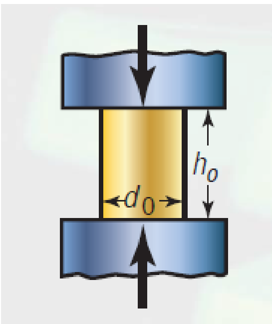
$$p = Y' e^{\frac{2\mu(a-x)}{h}}$$

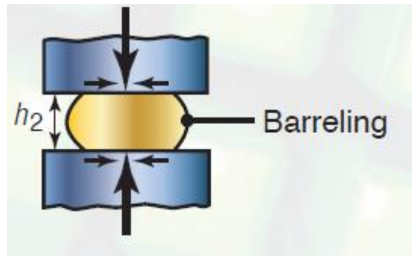
- Similarly, normal stress in sticking can be shown to be

$$p = Y'\left(1 + \frac{a-x}{h}\right)$$



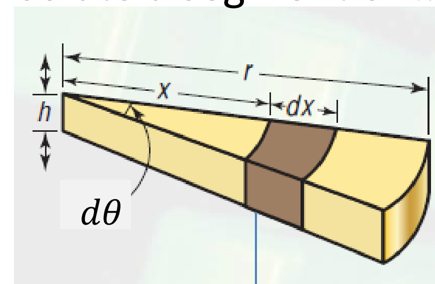
Forging of a cylindrical specimen

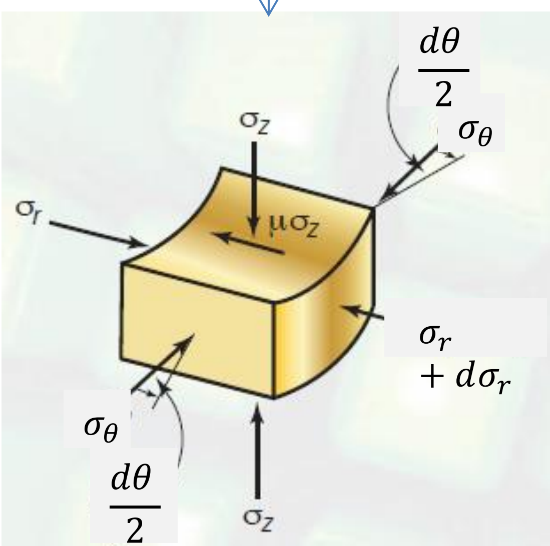




Again using the slab method

Isolate a segment of $d\theta$





Follow the same approach as for the plane strain case, the pressure p, at any radius x is:

$$\boxed{p = Ye^{\frac{2\mu(r-x)}{h}}}$$

And, the forging force can be approximated as:

$$\boxed{F = (p_{av})(\pi r^2)}$$ wherein $$\boxed{p_{av} \simeq Y\left(1 + \frac{2\mu r}{3h}\right)}$$

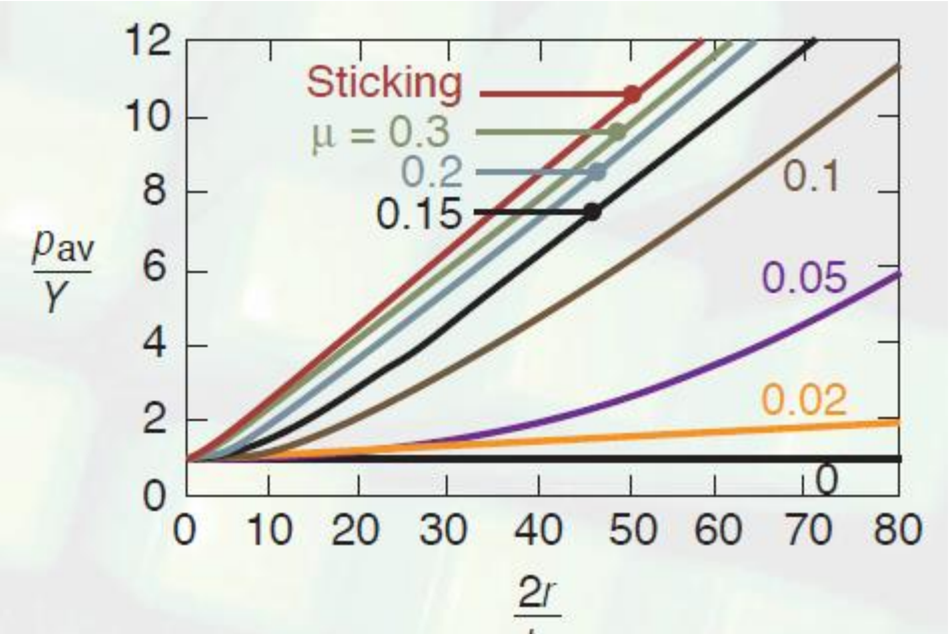
Pressure in sliding and in sticking for a cylindrical specimen

- Recalling normal pressure (stress) in sliding

$$p = Ye^{\frac{2\mu(r-x)}{h}}$$

- Similarly, normal stress in sticking can be shown to be

$$p \simeq Y'\left(1 + \frac{r-x}{h}\right)$$

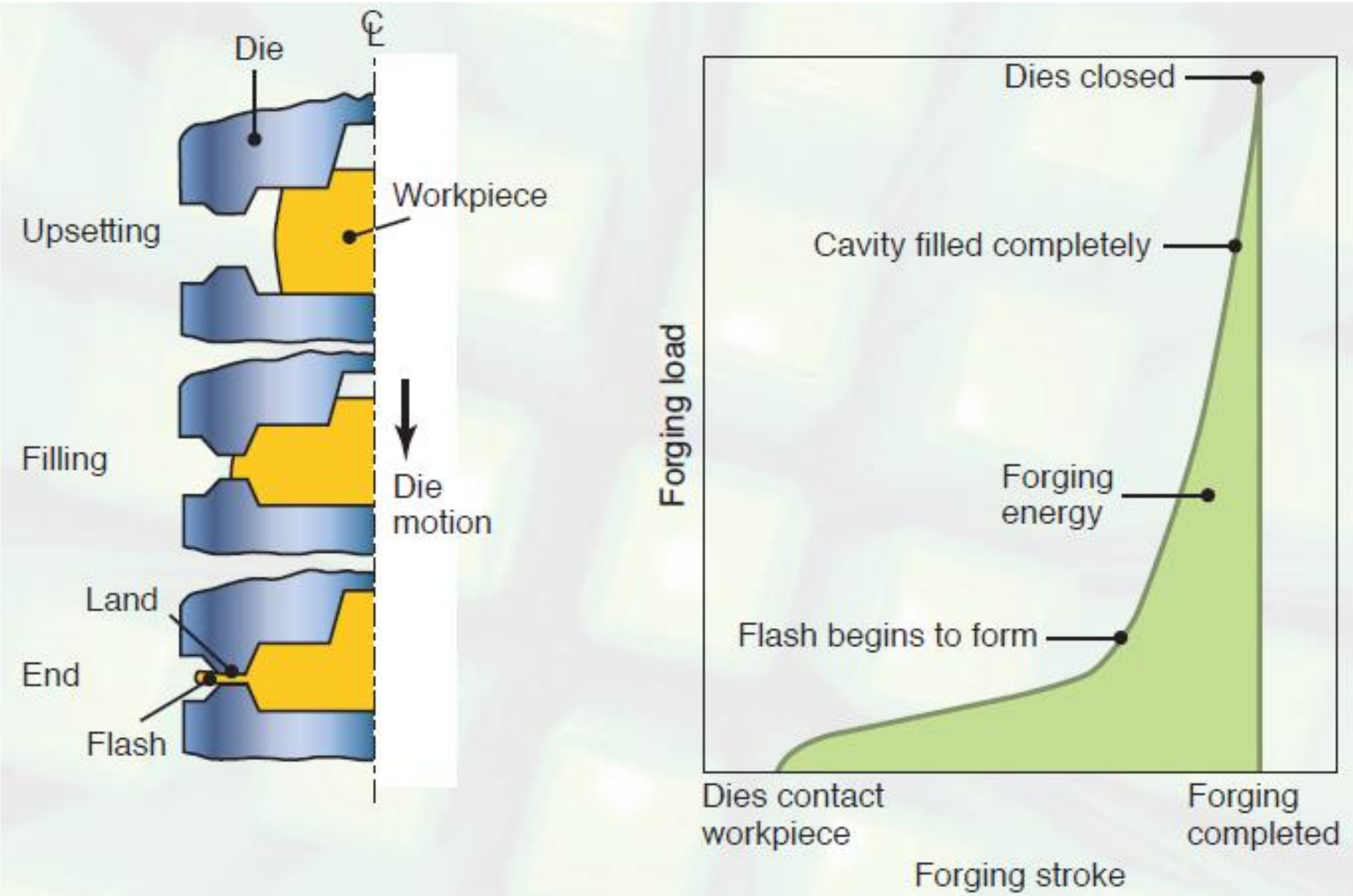


Source: Kalpakjian and Schmid

Forging, closed die

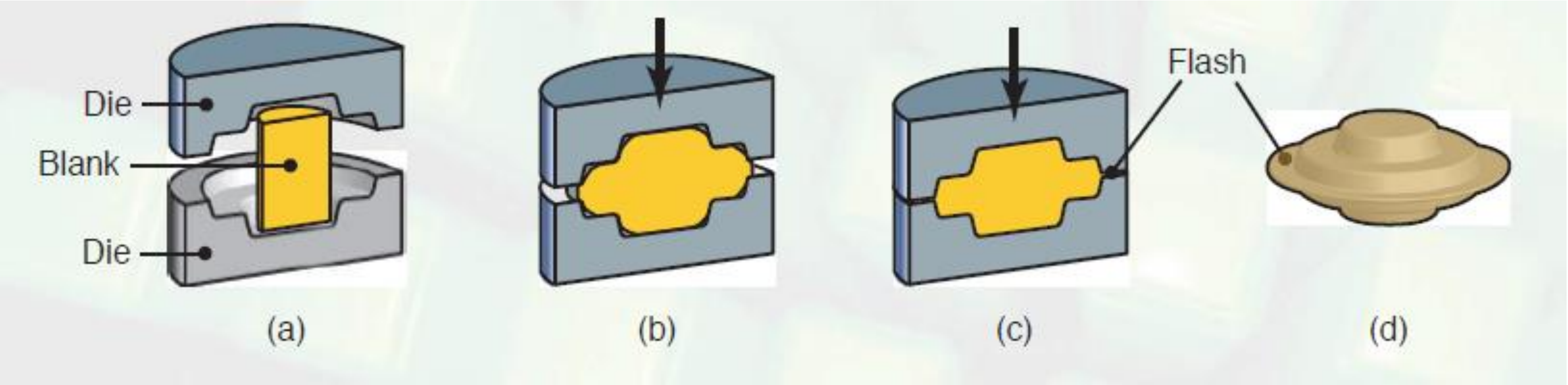
https://www.youtube.com/watch?v=E8YozBTvw3Q

Load-stroke curve for impression-die forging



Source: Kalpakjian and Schmid

Impression-die forging (closed die forging)



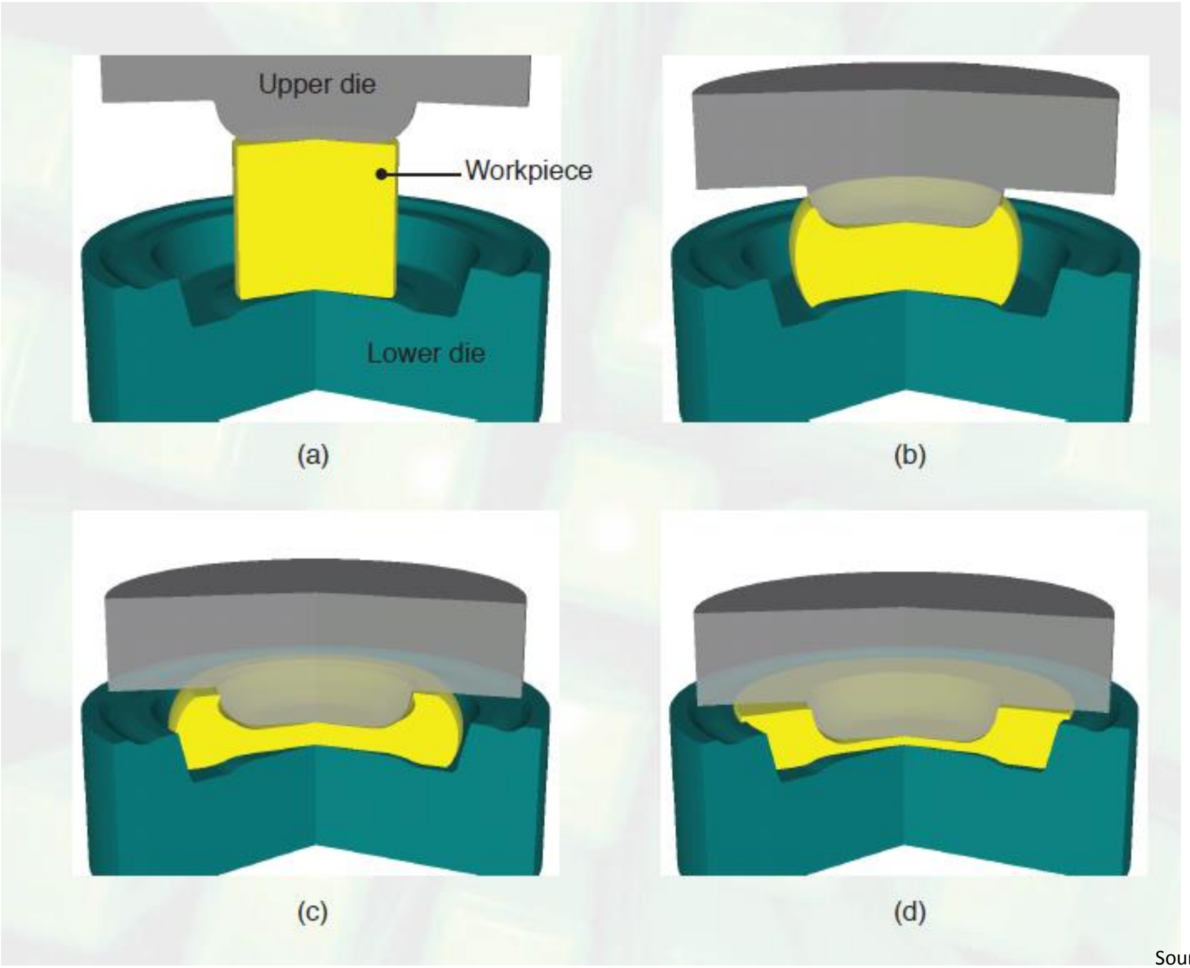
Forging force: $\boxed{F = K_p Y_f A}$

TABLE 6.2 Range of K_p values in Eq. (6.22) for impression-die forging.

Simple shapes, without flash	3-5
Simple shapes, with flash	5-8
Complex shapes, with flash	8-12

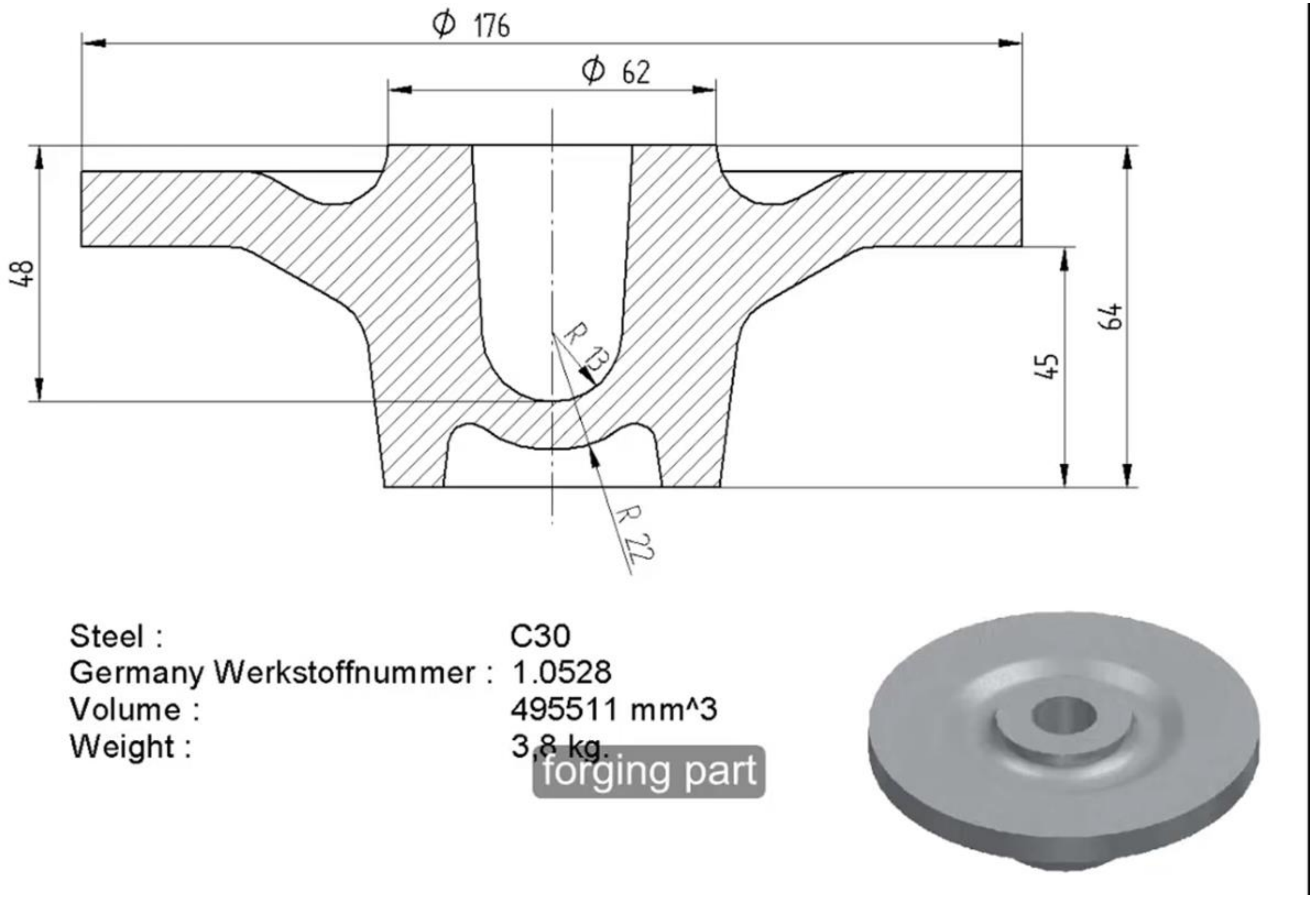
Source: Kalpakjian and Schmid

Closed die forging: numerical analysis



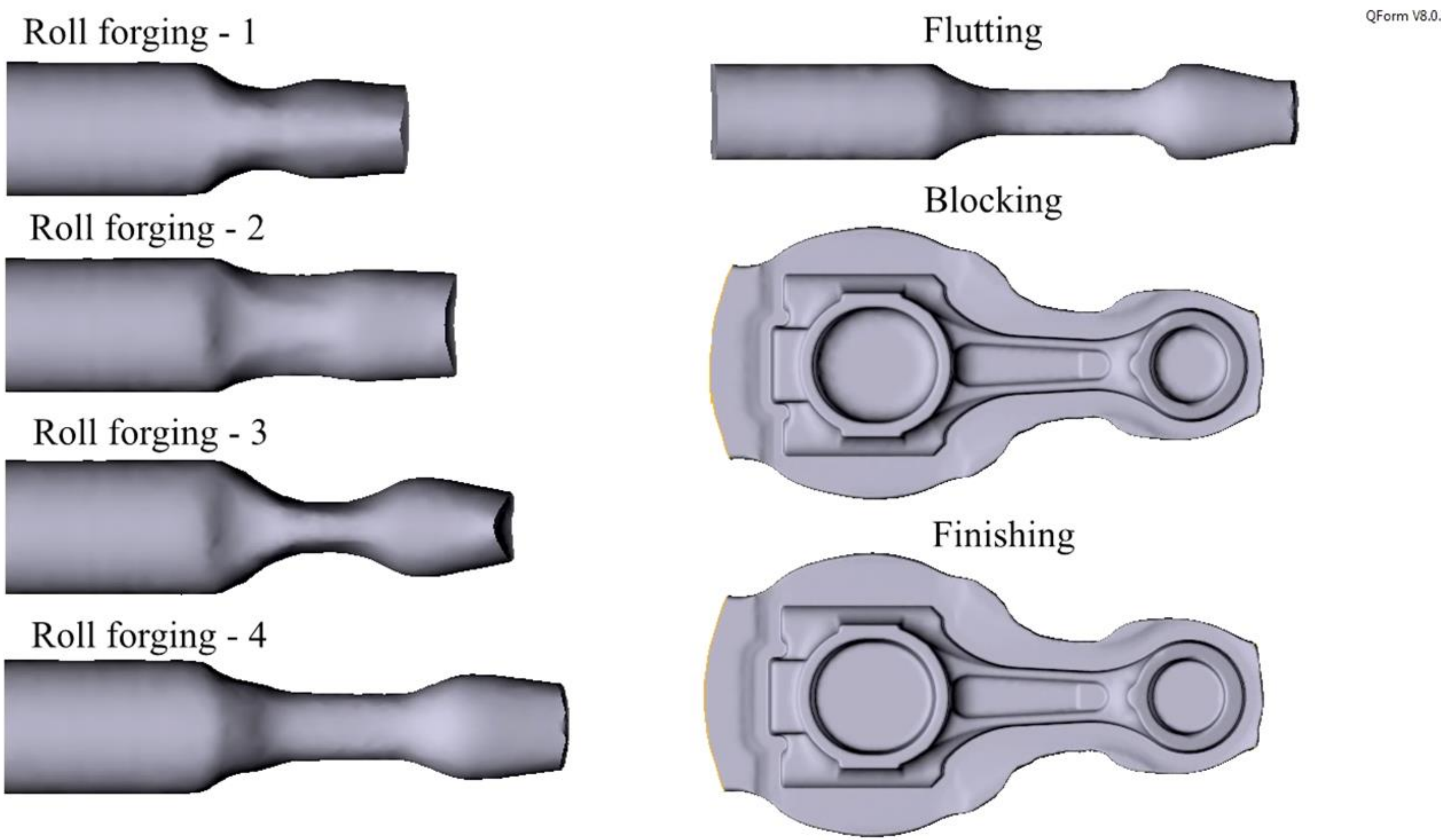
Source: Kalpakjian and Schmid

Analysis numerical (FE)



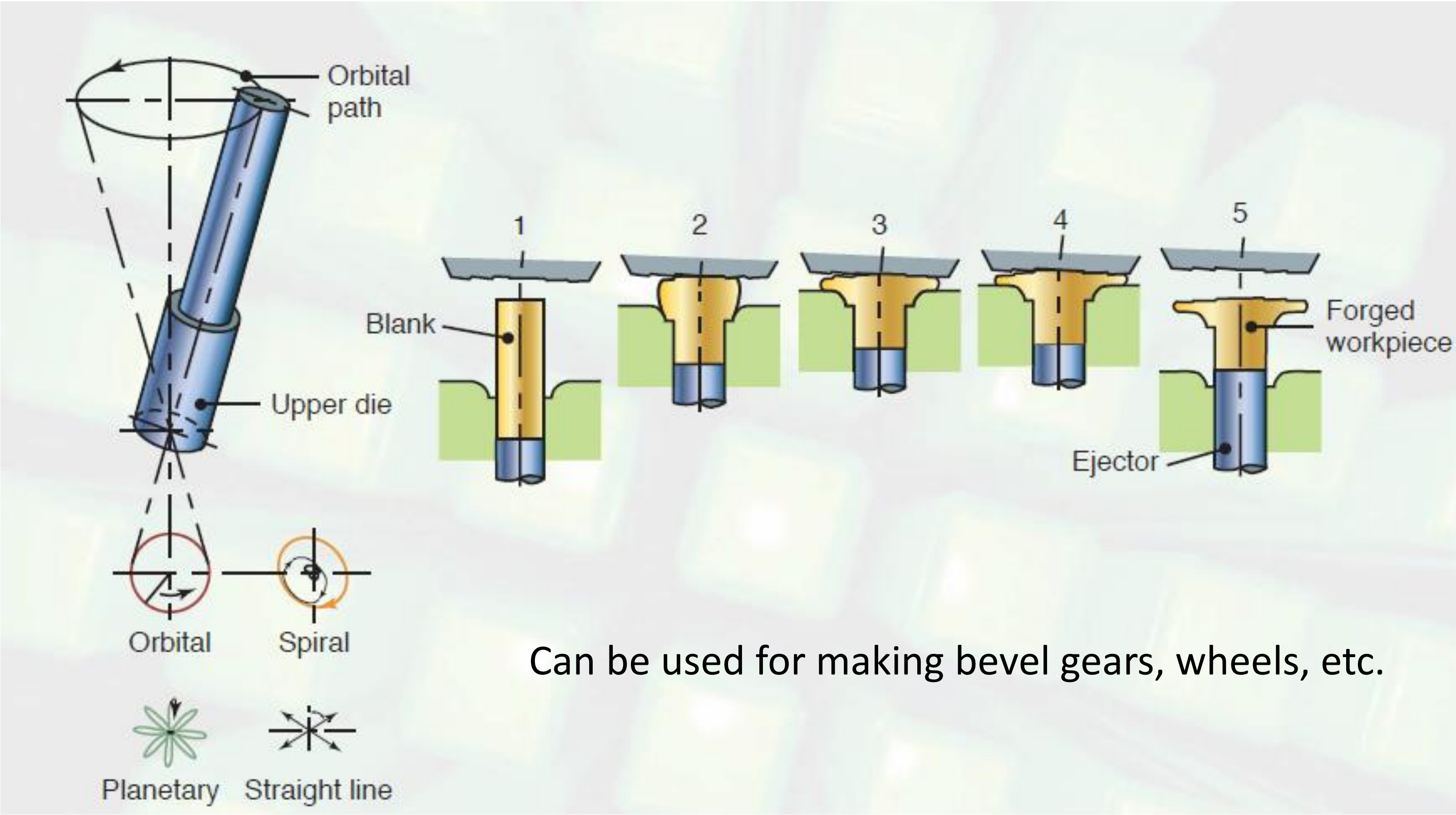
https://www.youtube.com/watch?v=G5x3s1pYrVQ

Connecting rod forging: numerical analysis



https://www.youtube.com/watch?v=bZLNKnAENbY

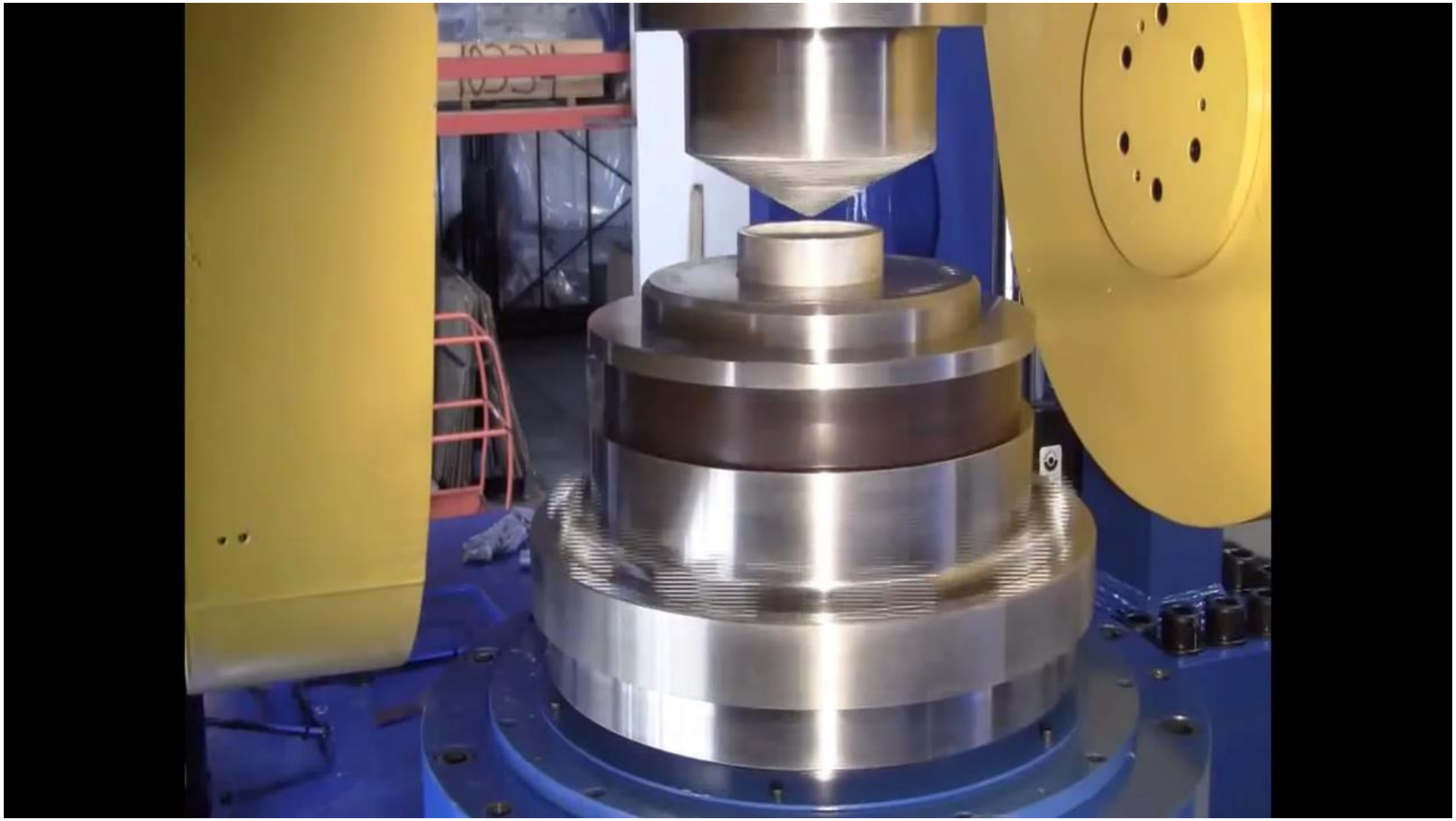
Rotary forging (swing/orbital/rocking-die)



Can be used for making bevel gears, wheels, etc.

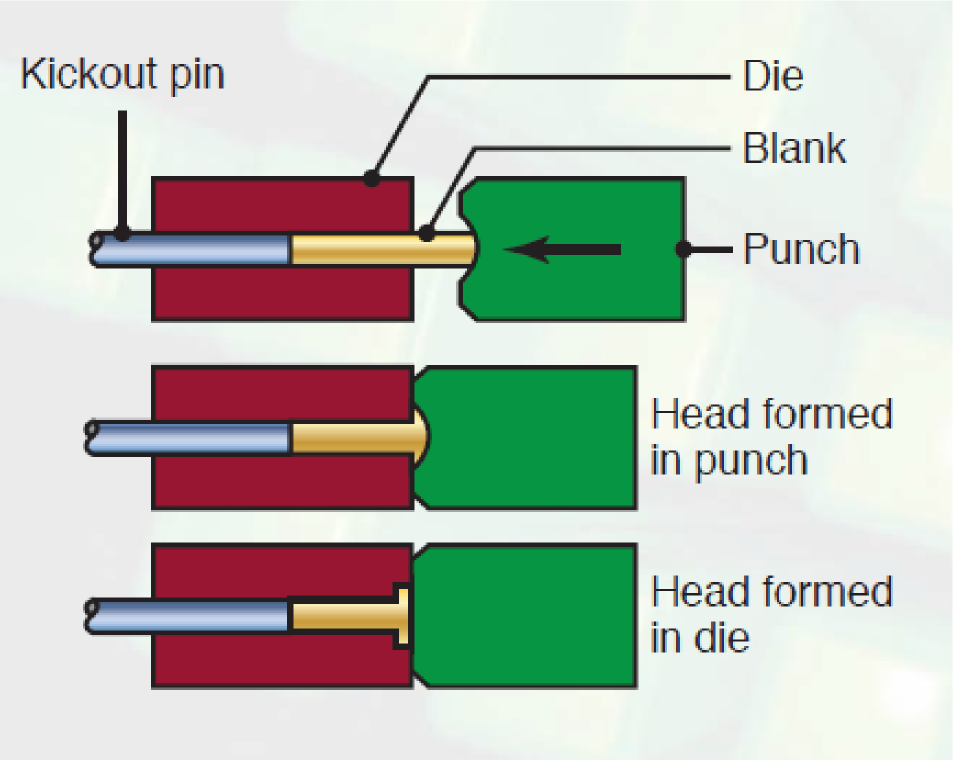
Source: Kalpakjian and Schmid

Rotary forging



https://www.youtube.com/watch?v=i7lWtWe2Kr8

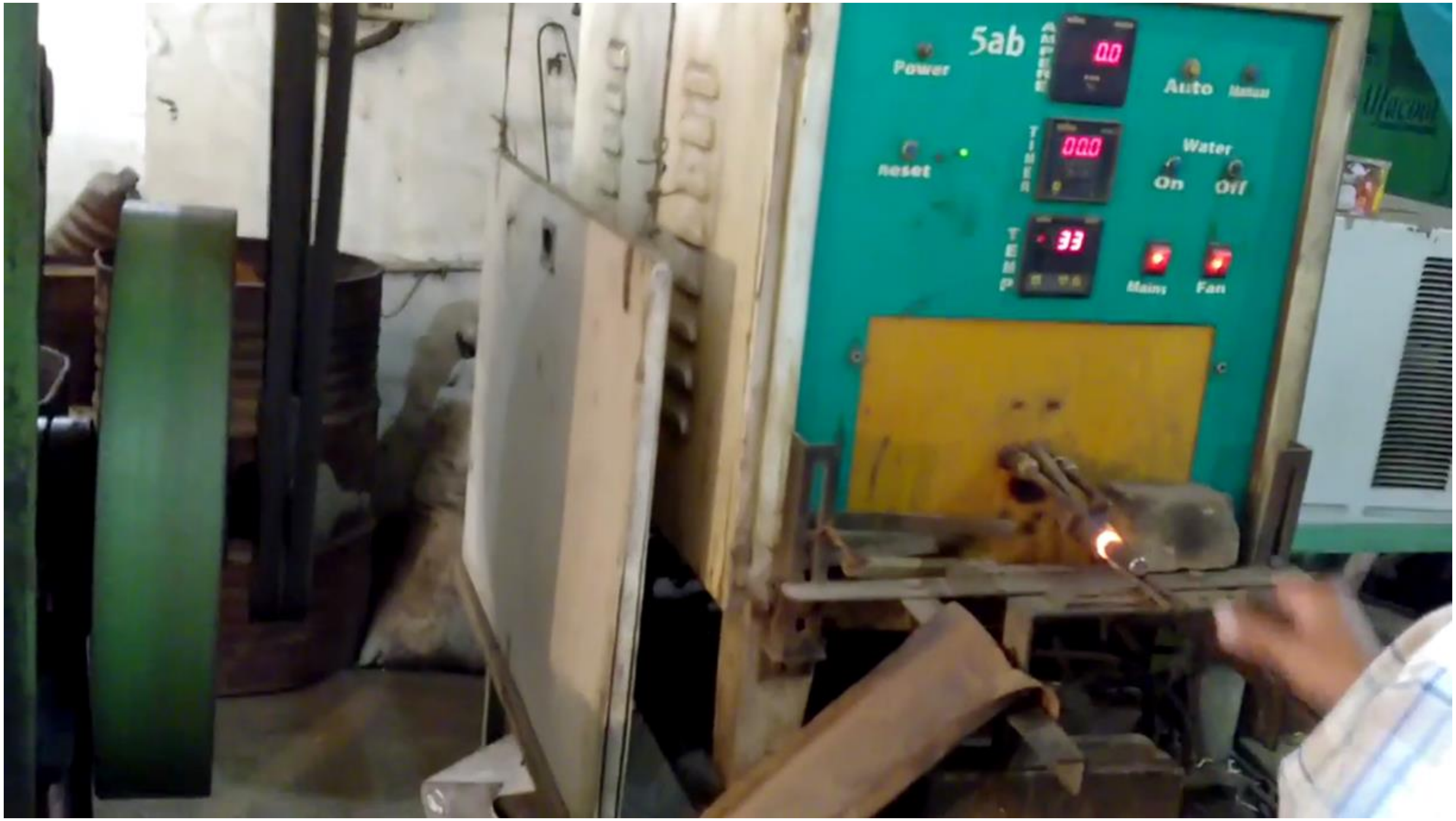
Heading



Can be used for making fasters such as bolts, rivets, etc.

Source: Kalpakjian and Schmid

Forging bolts



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