

BULK DEFORMATION PROCESSES IN METALWORKING

1. Rolling
2. Forging
3. Extrusion
4. Wire and Bar Drawing

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Introduction

- Input: bulk materials in a form of cylindrical bars and billets, rectangular billets and slabs or elementary shapes
- Process: large plastic deformation - Rolling, Forging, Extrusion and Wire and Bar drawing under cold, warm and hot working conditions
- Output: work materials for subsequent processes or final products (net shaping)

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1. Rolling

- Thickness of a work material is reduced by the compressive forces exerted by two opposing rolls.
 - plates (>6mm or 1/4 in) - ship hull, bridge
 - sheets (<6mm) - car bodies, appliance
 - foil (<0.1mm) - aluminum foil
- Flat (typical) and shape rolling
- Equipment: roll mills (expansive)
- Hot rolling - large deformation, low force, no residual stress and isotropic properties but problems with tolerance and surface finish
- Cold Rolling - strengthen, tight tolerance, better surface

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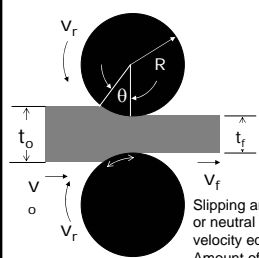
Process Information

- Ingot casting
 - Input: Molten metal
 - Output: Ingot
- Soaking
 - Input: Ingot
 - Output: heated Ingot
- Rolling
 - Input: Heated Ingot
 - Output: bloom, billet or slab
- Cold Rolling
 - tight tolerance, better surface and mechanical properties
- Hot Rolling
 - above recrystallization temp. (450C for Al alloy, 1250C for steel alloy and 1650C for refractory alloy) converts the cast structure to a wrought structure
 - Heavy scale forms on the surface.

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Flat rolling

Spreading: Conservation of Mass



$$t_o w_o L_o = t_f w_f L_f$$

OR $t_o w_o v_o = t_f w_f v_f$

Draft: $d = t_o - t_f$

Reduction: $r = \frac{d}{t_o}$

True strain: $\epsilon = \ln \frac{t_o}{t_f}$

Average Flow stress: $\bar{Y}_f = \frac{K \epsilon^n}{1+n}$

Slipping and friction on the contact arc except on no-slip or neutral point - One point along the arc where work velocity equals roll velocity.

Amount of slip between the work and the rolls: Forward slip

$$s = \frac{v_f - v_r}{v_r}$$

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Rolling Analysis I

- Friction at the entrance controls the maximum possible draft.
 - d_{max} = maximum draft (mm);
 - μ = the coefficient of friction;
 - R = Roll Radius (mm)
$$d_{max} = \mu^2 R$$
- It however depending on lubrication, work and roller materials and temperature.
 - $\mu = \begin{cases} 0.1 & \text{for coldworking} \\ 0.2 & \text{for warmworking} \\ 0.3-0.4 & \text{for hotworking} \end{cases}$
- When sticking occurs, μ can be as high as 0.7
- Higher the friction and larger the roll radius, the greater the maximum draft and reduction in thickness become.

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Rolling Analysis II

- Roll force: $F = w \int_0^L p dL = \bar{Y}_f w L$
 - Newton or lb, L is in meter or ft and N is in rpm
- Contact length: $L = \sqrt{R(t_o - t_f)}$
- Torque for each roll: $T = 0.5FL$

$$P = 2\pi NFL$$
- Power: $= 2\pi NFL / 60,000kW$
 $= 2\pi NFL / 33000hp$

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Problem 19.11

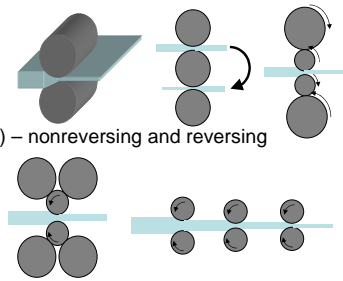
A single-pass rolling operation reduced a 20mm thick plate to 18mm. The starting plate is 200mm wide. Roll radius=250mm and rotational speed=12rev/min. The work material has a strength=600MPa and a strain hardening coefficient=0.22. Determine (a) roll force (b) roll torque and (c) power required for this operation.

- (a) Assuming a typical friction coefficient for cold rolling of 0.1
- | | |
|---------------------|---|
| Draft | $d = 20 - 18 = 2\text{mm} < d_{\max} = 0.1^2(250) = 2.5\text{mm}$ |
| Contact length | $L = (250 \times 2)^{0.5} = 11.18\text{mm} = 0.0112\text{m}$ |
| True Strain | $\epsilon = \ln(20/18) = 0.1054$ |
| Average flow stress | $\bar{Y}_f = 600(0.1054)^{0.22} / 1.22 = 300\text{MPa}$ |
| Rolling force | $F = \bar{Y}_f w L = 300(0.0112)(0.2) = 0.672\text{MN}$ |
| (b) Torque | $T = 0.5(672,000)(0.0112) = 3,720\text{ N.m}$ |
| (c) Power | $P = 2\pi(12/60)(672,000)(0.0112) = 37,697\text{W}$ |

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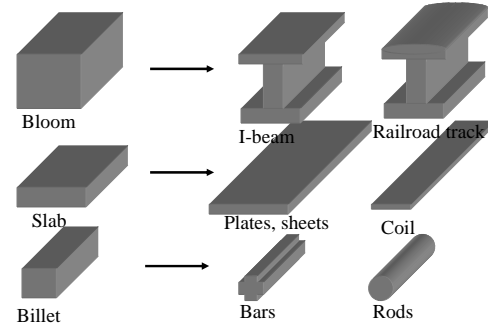
Rolling

- Rolling mills
 - Two-high (basic) – nonreversing and reversing
 - Three-high
 - Four-high
 - Cluster
 - Tandem
- Shape Rolling
 - I-beam, L-beam and U-channels, railroad track, round and square bars.
 - Roll-pass design
 - Designing the intermediate shapes and rolls



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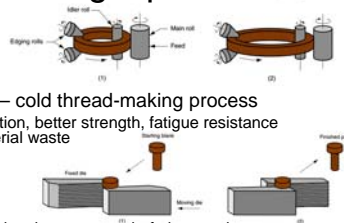
Intermediate & final rolled form



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Other Rolling Operations

- Ring rolling
 - higher production, better strength, fatigue resistance and less material waste
- Thread rolling – cold thread-making process
 - higher production, better strength, fatigue resistance and less material waste
- Gear rolling
 - higher production, better strength, fatigue resistance and less material waste
- Roll piercing – making seamless thick-walled tubes



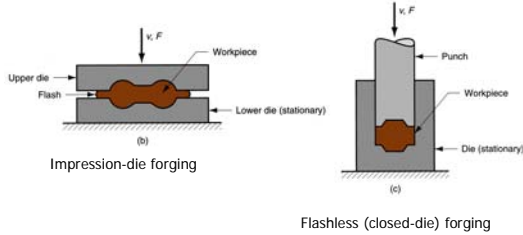
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2. Forging

- Dating from about 5000 B C
- A deformation process achieved by gradual and certain movement of two dies. (forging press or forging hammer)
- Hot or warm forging and sometime cold forging
- Three types
 - Open-die forging – no lateral constraints
 - Impression-die forging – the die surface contains the material but not completely
 - Flashless (closed-die) forging – the material is completely constrained within the die

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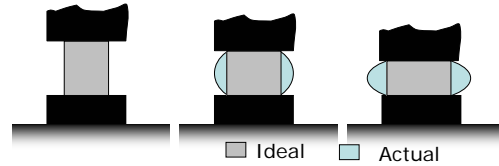
Impression-die & Flashless



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Analysis on Open-die forging

- The true strain for the process: $\epsilon = \ln \frac{h_o}{h}$
- Force required: $F = K_f Y_f A$
 where $K_f = 1 + \frac{0.4\mu D}{h}$
 Y_f is the flow stress, not average flow stress



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Impression and Flashless

- Force required: $F = K_f Y_f A$

| | |
|-----------------------|------|
| Impression | |
| Simple w/ flash | 6.0 |
| Complex w/ flash | 8.0 |
| Very complex w/ flash | 10.0 |
| Flashless | |
| Coining | 6.0 |
| Complex shape | 8.0 |

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Impression-die Forging

- Impression-die forging can achieve Close tolerance
- Advantages compared to machining from solid stock:
 - Higher production rates, less waste, Greater strength
 - Favorable grain orientation in the metal
- Limitations:
 - Not capable of close tolerances
 - Machining often required to achieve accuracies and features needed, such as holes, threads, and mating surfaces that fit with other components Need machining afterward

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Problem 19.14

A cylindrical part is warm upset forged in an open die. $D_o=50\text{mm}$ and $h_o=40\text{mm}$. Coefficient of friction $=0.2$. The work materials has a flow curve defined by $K=600\text{MPa}$ and $n=0.12$. Determine the force in the operation (a) just as the yield point reached(0.002), and (b) $h=20\text{mm}$.

- (a) $V = \pi D^2 L / 4 = \pi (50)^2 40 / 4 = 78,540\text{mm}^3$
 For a small strain, $\epsilon = e = \Delta h / h_o = h_o - h_f / h_o = 40 - h_f / 40 = 0.002$
 Therefore, $h_f = 39.92\text{mm}$ and $Y_f = 600(0.002)^{0.12} = 284.5\text{MPa}$
 $A = V / h_f = 78,540 / 39.92 = 1963.5\text{mm}^2$; $D_f = 50.0000637\text{mm}$
 $K_f = 1 + 0.4(0.2)(50) / 39.92 = 1.1$
 $F = 1.1(284.6)(1963.5) = 614,693\text{N}$
- (b) $h_f = 20\text{mm}$; $\epsilon = \ln(40/20) = 0.693$
 $Y_f = 600(0.693)^{0.12} = 574.2\text{MPa}$
 Because the volume stays constant, $D_f = 70.7\text{mm}$
 $K_f = 1 + 0.4(0.2)(70.7) / 20 = 1.283$
 $F = 1.283(574.2)(3927) = 2,892,661\text{N}$

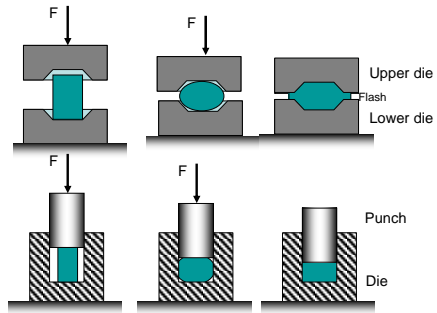
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Flashless forging

- Flashless (closed-die) forging
 - A *precision forging* process
 - Process control more demanding than impression-die forging
 - Best suited to part geometries that are simple and symmetrical
- Forging dies
- *Gravity* or *Power drop* hammers
- *Mechanical, Hydraulic & Screw* Presses

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Sequence in impression-die forging



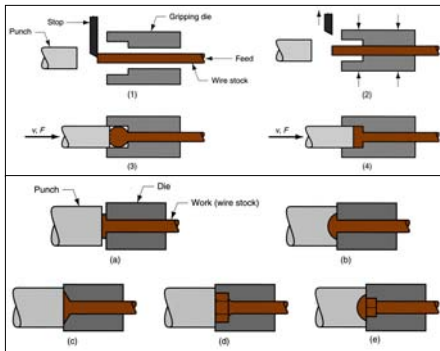
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Other Deformation Processes

- Upset and Heading
- Swaging and Radial Forging
- Roll Forging
- Orbital Forging
- Hobbing
- Isothermal and Hot Die Forging
- Trimming

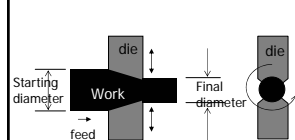
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Upsetting and Heading



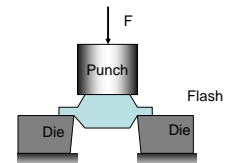
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Swaging



- Used to reduce diameter of tube or solid rod stock
- Mandrel sometimes required to control shape and size of internal diameter of tubular parts

Trimming



Cutting operation to remove flash from a work part while work is still hot in impression-die forging. Alternatively grinding or sawing operation is used.

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