

Rolling of Metals

IME240/340

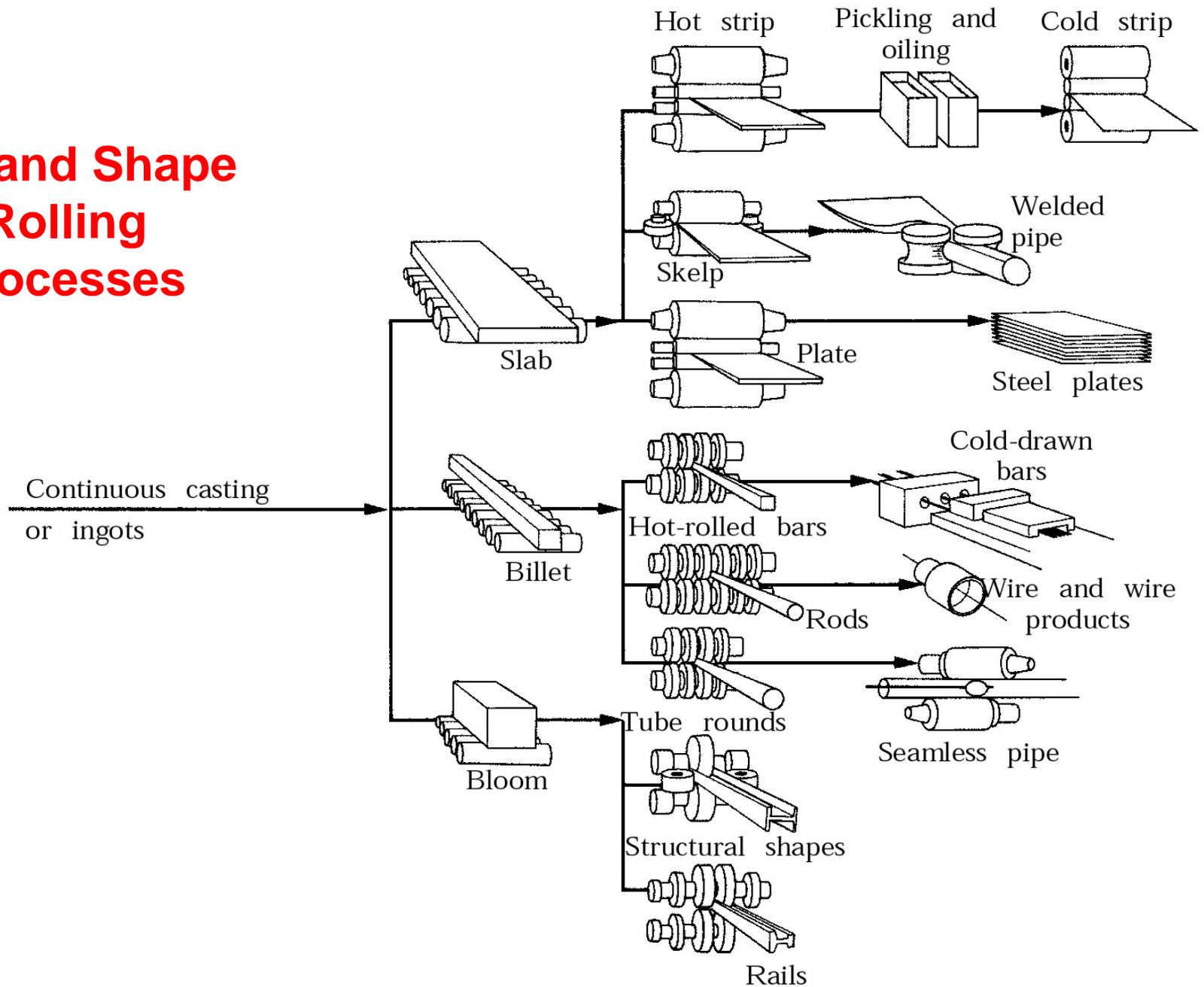
Rolling of Metals

- Rolling – reducing the thickness or changing the cross-section of a long workpiece by compressive forces applied through a set of rolls
- Developed in late 1500s
- Accounts for 90% of all metals produced by metal working processes
- Often carried out at elevated temperatures first (hot rolling) to change coarse-grained, brittle, and porous ingot structures to wrought structures with finer grain sizes and enhanced properties

Rolled Metal Thicknesses

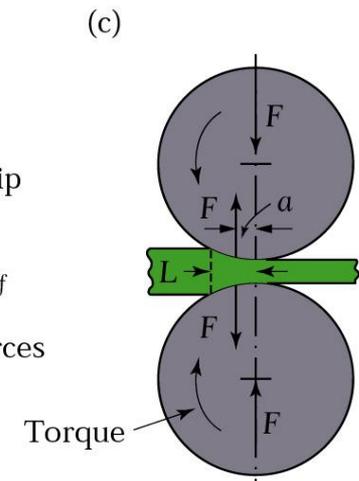
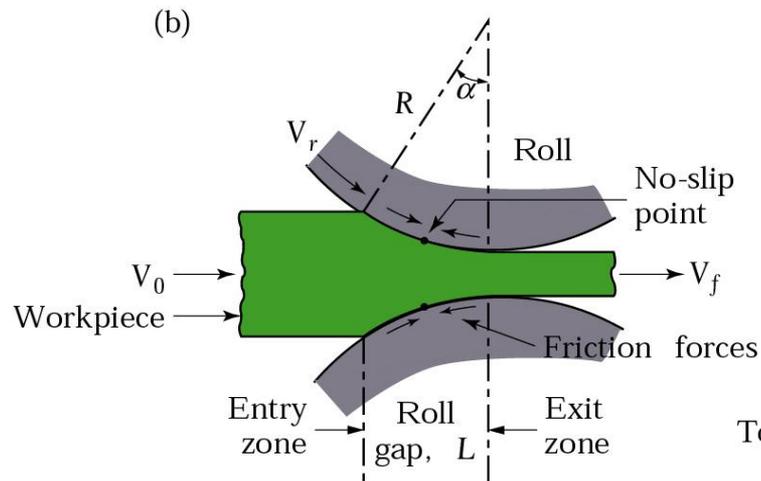
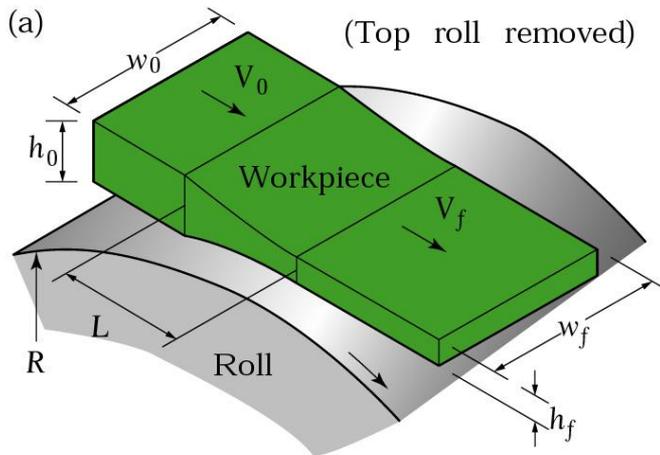
- Plates – thickness greater than 6 mm (1/4 inch);
 - boiler supports (0.3 m, 12 inch)
 - reactor vessels (150 mm, 6 inch)
 - battleships and tanks (100-125 mm, 4-5 inch)
- Sheets – less than 6 mm thick; flat pieces, strips, and coils for beverage containers, automobile and aircraft bodies, appliances, kitchen and office equipment
 - Boeing 747 skin thickness – 1.8 mm (0.071 inch)
 - Lockheed L1011 skin thickness – 1.9 mm (0.075 inch)
 - Aluminum beverage cans – start as sheets that are 0.28 mm (0.011 inch) thick; later reduced to 0.1 mm (0.004 inch) by deep drawing
 - Aluminum foil – 0.008 mm (0.0003 inch)

Flat and Shape Rolling Processes



Flat Rolling

- Initial thickness h_0
- Final thickness h_f
- Roll gap L
- Surface speed of rolls V_r
- Entry velocity of strip V_0
- Final velocity of the strip V_f
- Neutral point, no-slip point – point along contact length where velocity of the strip equals velocity of the roll



Flat Rolling

- Draft: $h_o - h_f$
- Maximum draft possible: $h_o - h_f = \mu^2 R$
 - Coefficient of friction μ
 - Roll radius R
- The strip thickness is reduced at each rolling pass and the strip width increases slightly (around 2%)
- $h_o V_o w_o = h_f V_f w_f$. Typically $w_f = 1.02 w_o$

Flat Rolling

- Roll Force: $F = LwY_{avg}$
 - Roll-strip contact length L
 - Average strip width w – despite the fact that spreading, or an increase in width, may actually occur if edger mills are not used
 - Average true stress of the strip in the roll gap Y_{avg}
 - Assumes no friction and thus predicts lower roll force than the actual value
- Power per roll (SI units) = $\pi FLN / 60,000$ kW
 - Where F is in Newtons, L is in meters, and N is rpm of roll
- Power per roll (English units) = $\pi FLN / 33,000$ hp
 - Where F is in lbs, L is in ft

Flat Rolling

- Contact length $L = \sqrt{R(h_0 - h_f)}$
- Average flow stress:

$$Y = k\varepsilon^n$$

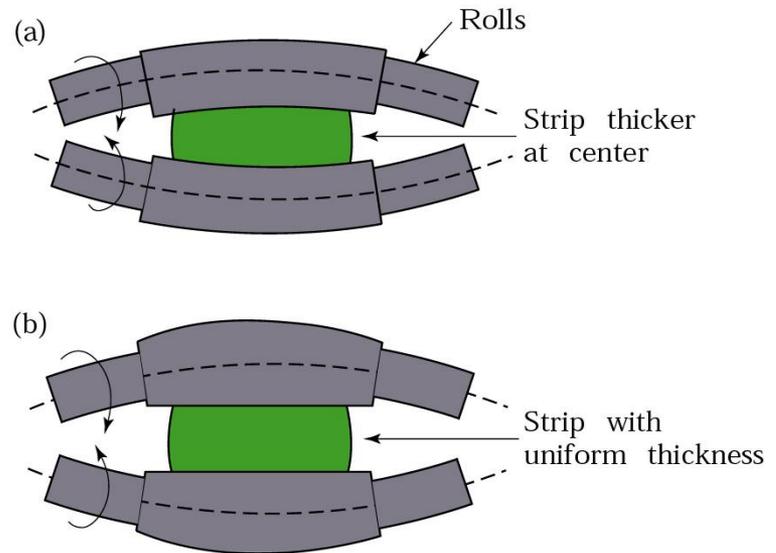
$$Y_{ave} = \frac{\int_0^{\varepsilon_f} k\varepsilon^n d\varepsilon}{\varepsilon_f} = \left[\frac{k\varepsilon^{n+1}}{\varepsilon_f(n+1)} \right]_0^{\varepsilon_f} = k \frac{\varepsilon_f}{n+1}$$

- In rolling:

$$\varepsilon_f = \ln \frac{h_0}{h_f}$$

Reducing Roll Forces that Deflect and Flatten the Rolls

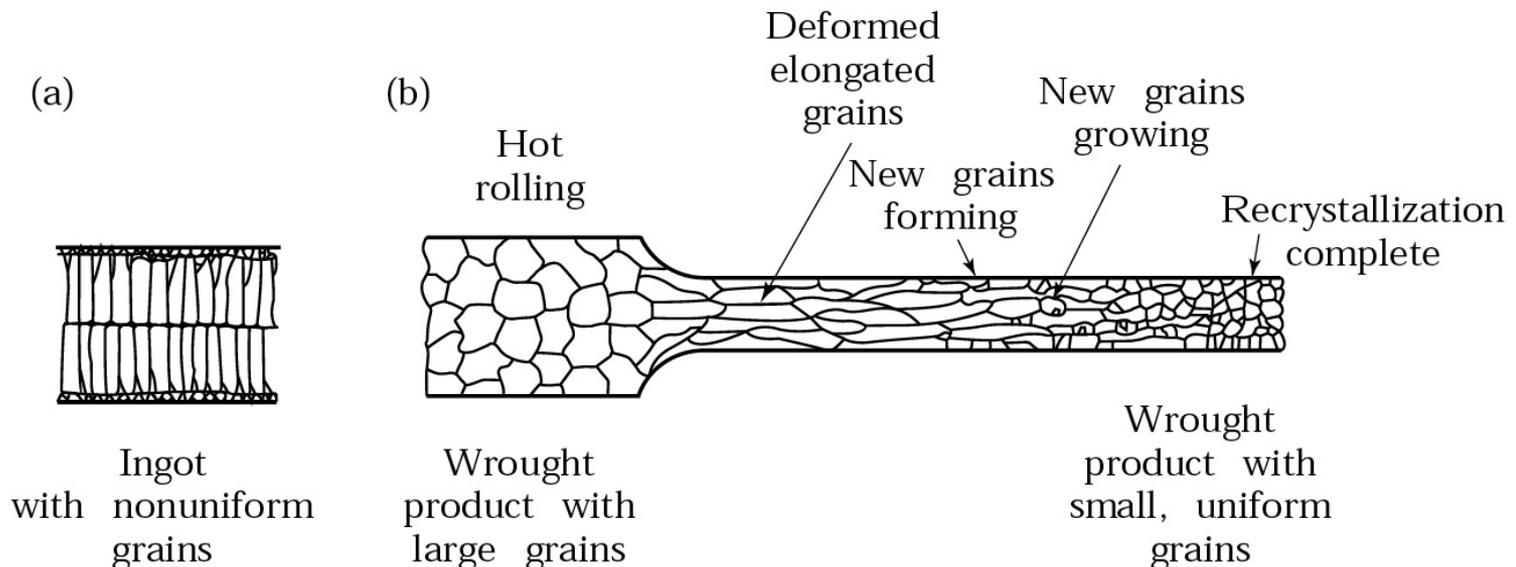
- Reduce rolling forces by
 - Reducing friction
 - Using smaller diameter rolls to reduce the contact area
 - Taking smaller reductions per pass (also to reduce the contact area)
 - Rolling at elevated temperatures to lower the strength of the material
 - Apply longitudinal tension to the strip during rolling – back tension on the pay-off reel or front tension on the take-up reel



- Grind rolls with a camber to prevent crowning of the rolled strip
- Radius of maximum camber point generally 0.25 mm greater than at roll edges
- Simulate camber by bending the rolls with applied moments

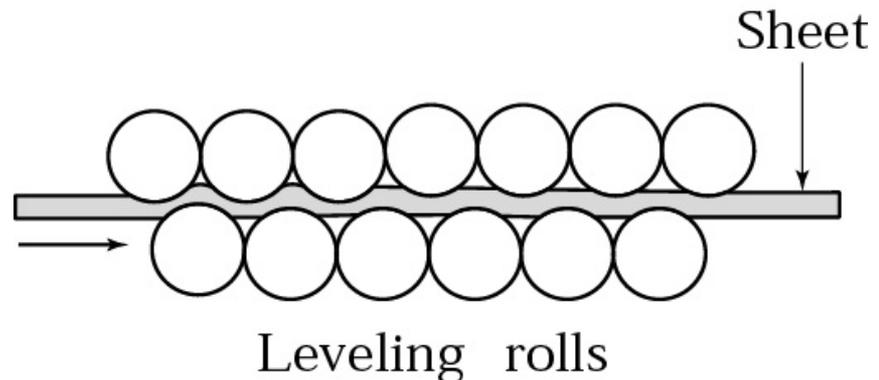
Flat Rolling Stages

- Hot rolling of *ingot* or a continuously cast slab converts it to a wrought structure called a *bloom* (square) or *slab* (rectangular)
- Bloom may next go to shape rolling
- Slabs may be rolled into plates and sheet



Other Rolling Processes

- Cold rolling at room temperature to produce better surface finish
- Pack rolling of two or more layers of metal
- Temper rolling to correct surface irregularities from stretching operations on mild steel
- Leveling rolls to increase flatness after previous rolling operations



Defects in Rolling

- Surface defects – scale, rust, scratches, gouges, pits, and cracks
- Wavy edges – due to roll bending
- Alligatoring – complex phenomenon that may be due to non-uniform deformation or defects in the billet

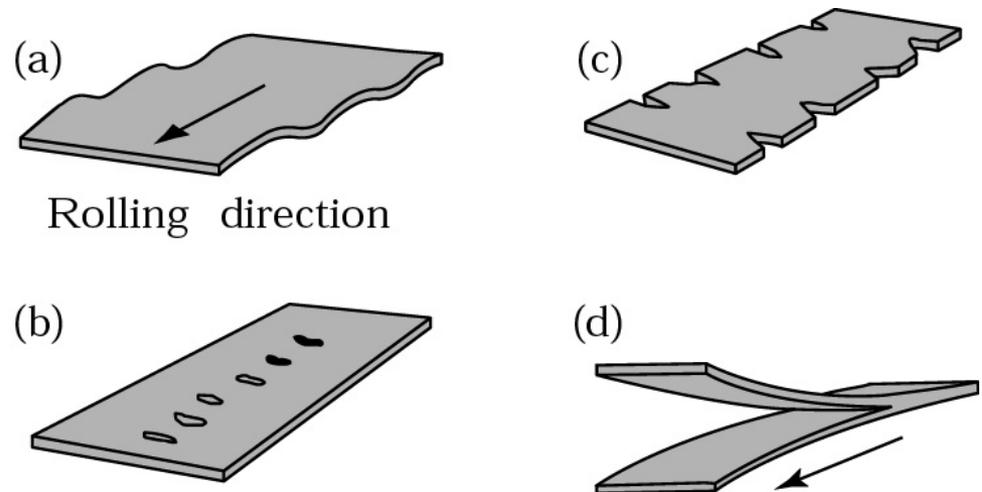


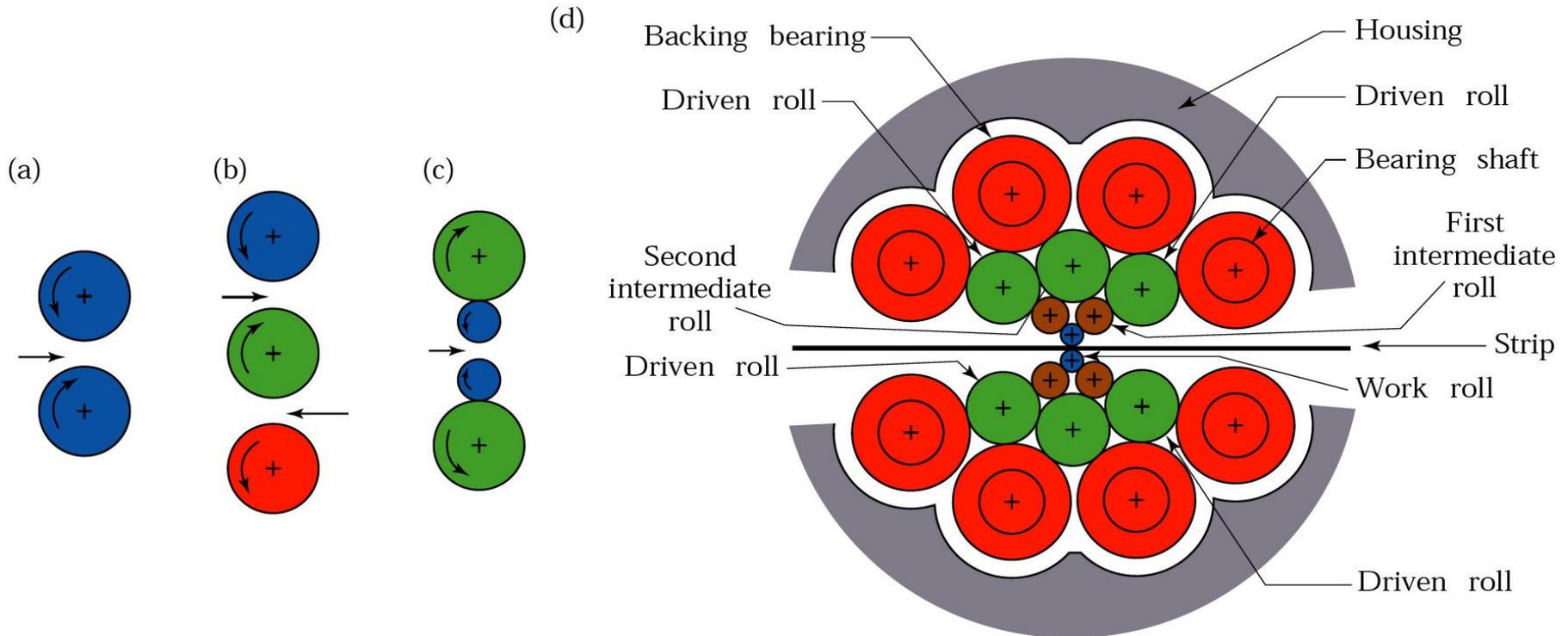
Figure 13.8 Schematic illustration of typical defects in flat rolling: (a) wavy edges; (b) zipper cracks in the center of the strip; (c) edge cracks; and (d) alligatoring.

Rolled Metal Characteristics

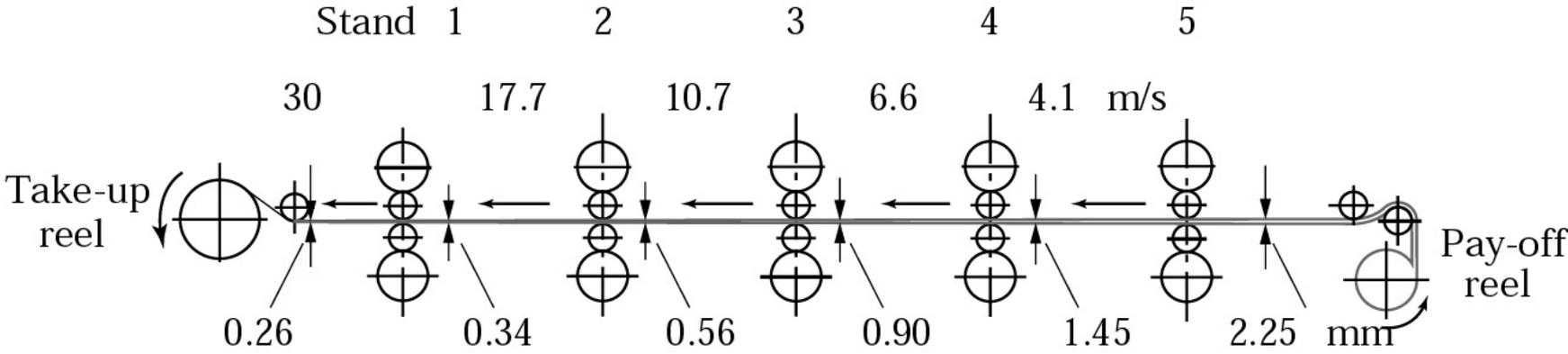
- Residual stresses
- Dimensional tolerances for cold-rolled sheet thicknesses +/- 0.1 mm to 0.35 mm (0.004 to 0.014 inch)
- Flatness tolerances to within +/- 15 mm/m (3/16 inch/foot) for cold rolling, +/- 55 mm/m (5/8 inch/foot) for hot rolling
- Hot rolling and sand casting produce similar ranges for surface finish
- Cold rolling produces a very fine surface finish
- Gage number identifies standard thicknesses of sheet (the smaller the number, the thicker the sheet)

Rolling Mills

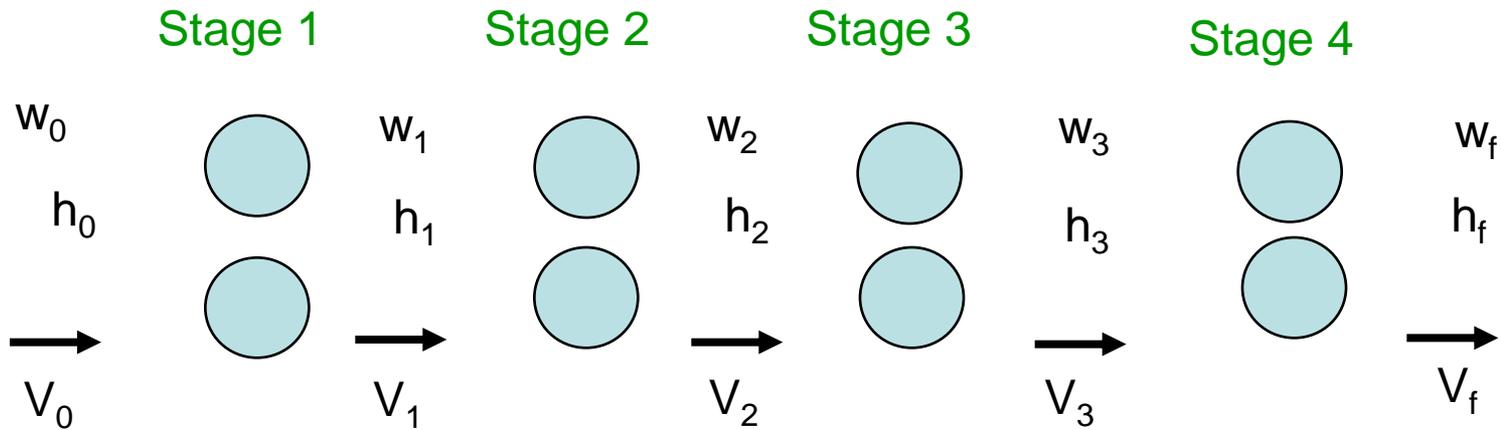
Figure 13.11 Schematic illustration of various roll arrangements: (a) two-high; (b) three-high; (c) four-high; (d) cluster (Sendzimir) mill.



Tandem Rolling



Tandem Rolling



Volume conserved

$$h_0 V_0 w_0 = h_1 V_1 w_1 = h_2 V_2 w_2 = h_3 V_3 w_3 = h_f V_f w_f$$

Rolling schedules

Equal drafts

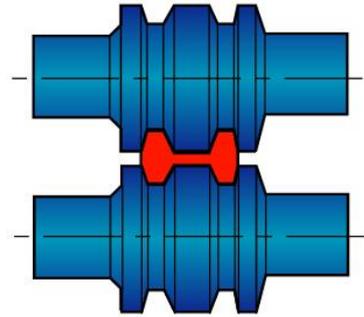
$$h_0 - h_1 = h_1 - h_2 = h_2 - h_3 = h_3 - h_f$$

Equal strains

$$\ln \frac{h_0}{h_1} = \ln \frac{h_1}{h_2} = \ln \frac{h_2}{h_3} = \ln \frac{h_3}{h_f}$$

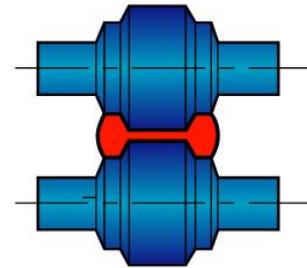
Shape Rolling

Stage 1



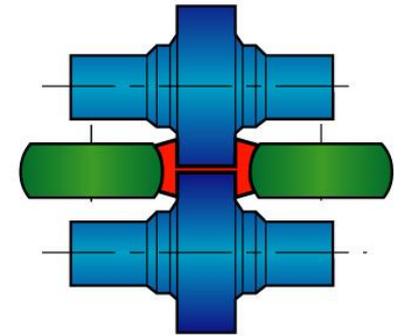
Blooming rolls

Stage 2



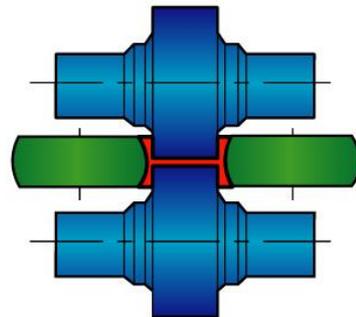
Edging rolls

Stage 3



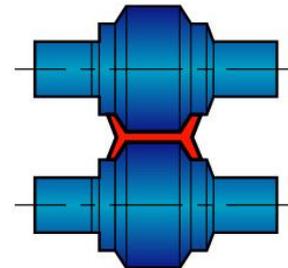
Roughing horizontal
and vertical rolls

Stage 4



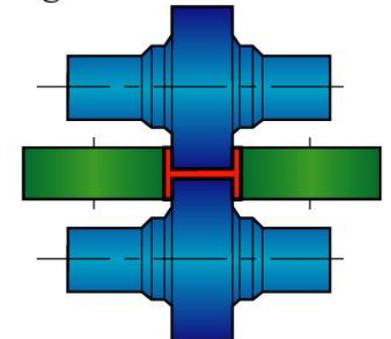
Intermediate horizontal
and vertical rolls

Stage 5



Edging rolls

Stage 6



Finishing horizontal
and vertical rolls

Ring Rolling

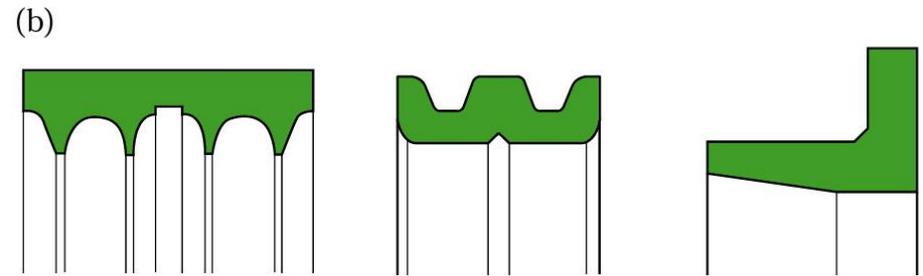
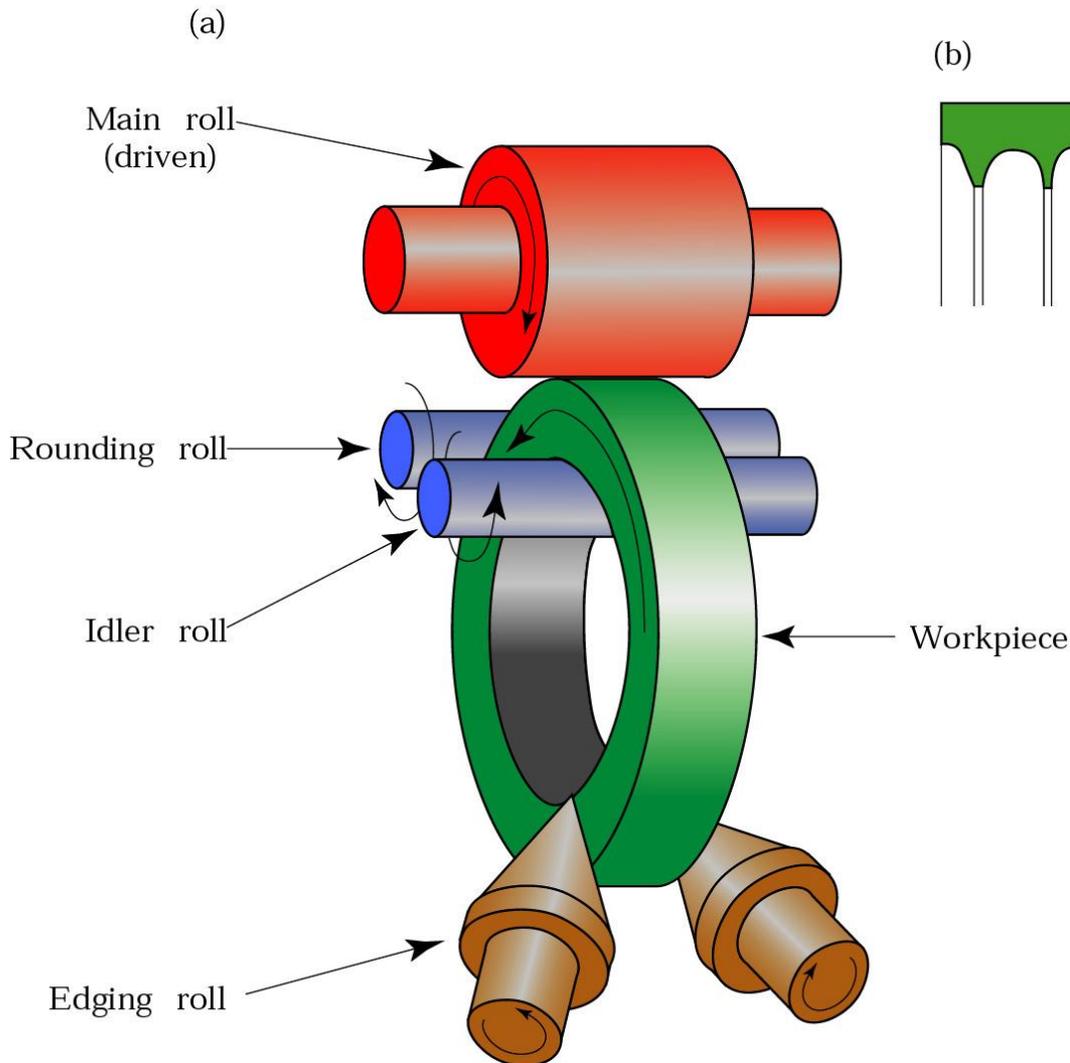


Figure 13.14 (a) Schematic illustration of a ring-rolling operation. Thickness reduction results in an increase in the part diameter. (b) Examples of cross-sections that can be formed by ring rolling.

Thread Rolling

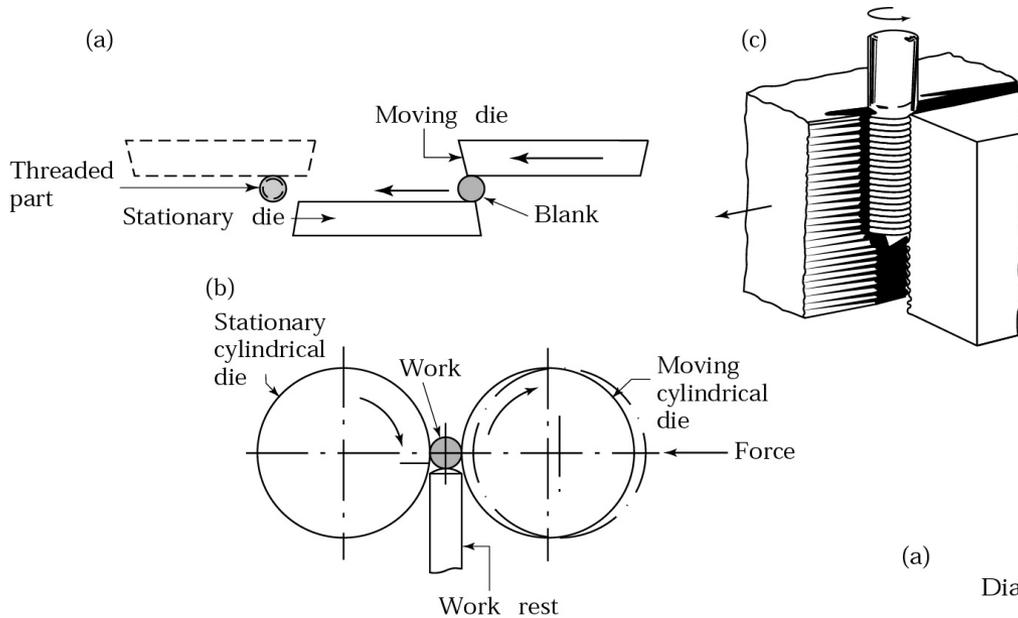
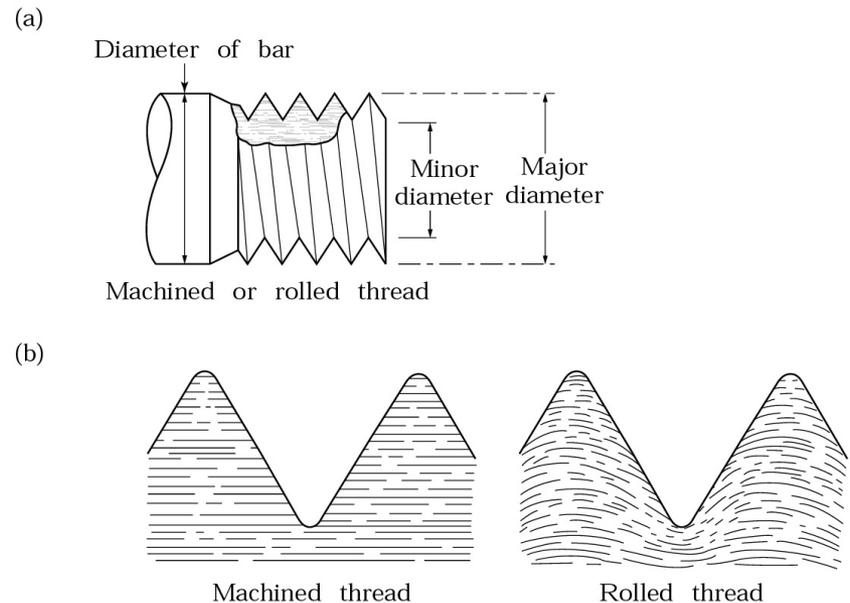


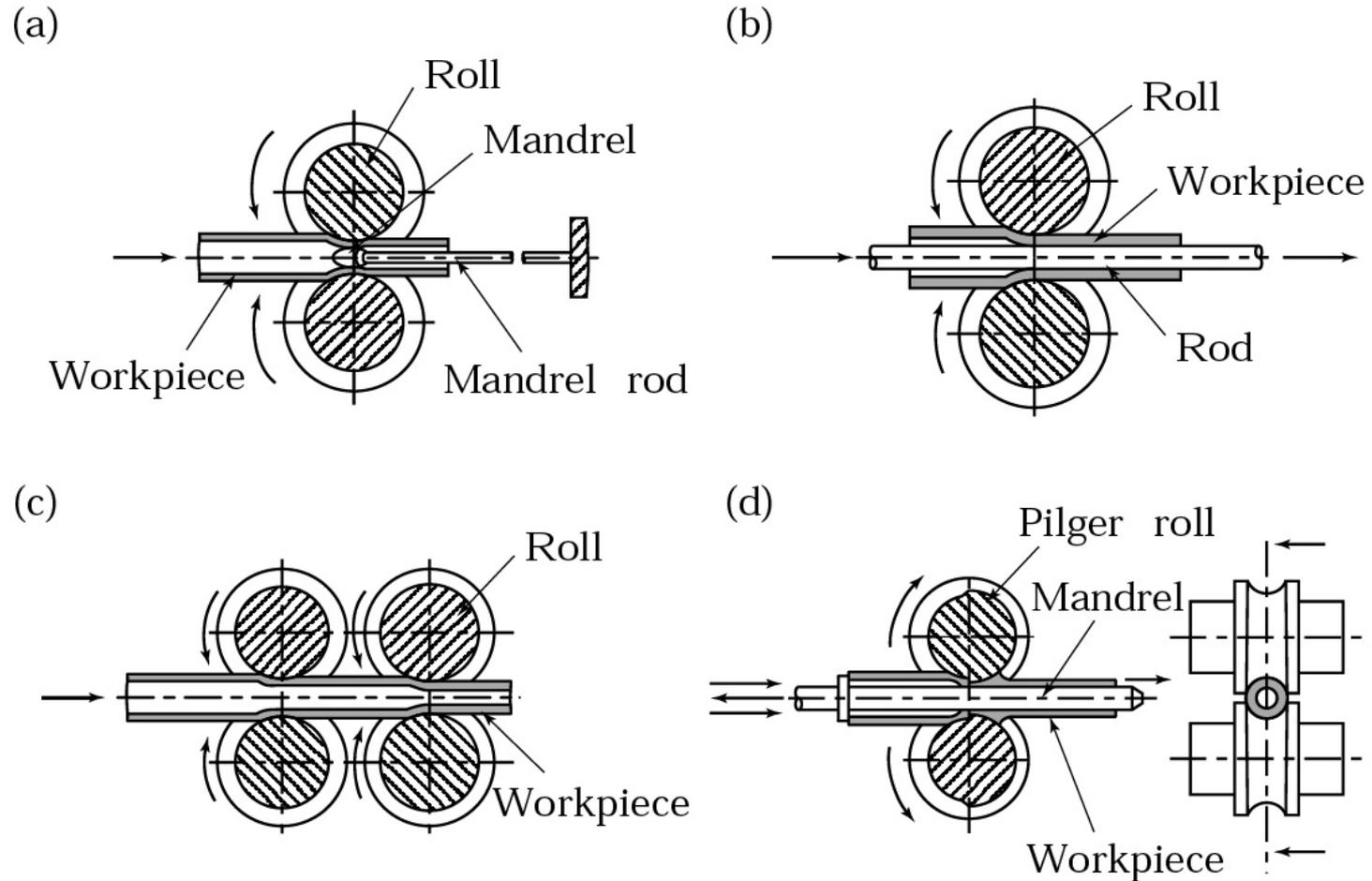
Figure 13.15 Thread-rolling processes: (a) and (c) reciprocating flat dies; (b) two-roller dies. Threaded fasteners, such as bolts, are made economically by these processes, at high rates of production.

Figure 13.16 (a) Features of a machined or rolled thread. (b) Grain flow in machined and rolled threads. Unlike machining, which cuts through the grains of the metal, the rolling of threads causes improved strength, because of cold working and favorable grain flow.



Tube Rolling

Figure 13.18
Schematic illustration
of various tube-rolling
processes: (a) with
fixed mandrel; (b)
with moving mandrel;
(c) without mandrel;
and (d) pilger rolling
over a mandrel and a
pair of shaped rolls.
Tube diameters and
thicknesses can also
be changed by other
processes, such as
drawing, extrusion,
and spinning.



Roll Piercing (The Mannesmann Process)

Figure 13.17 Cavity formation in a solid round bar and its utilization in the rotary tube piercing process for making seamless pipe and tubing. (The Mannesmann mill was developed in the 1880s.)

