روشهاي توليد و كارگاه
PRODUCTION TECHNIQUES

ACADEMIC YEAR 94-95, SEMESTER ONE

FORMING AND SHAPING PROCESSES
ROLLING OF METALS

DEPARTMENT OF MECHANICAL ENGINEERING
ISFAHAN UNIVERSITY OF TECHNOLOGY

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Forming and shaping processes

- ✓ *Forming* indicates “changing” the shape of an existing solid body
  - ✓ Plate, sheet, rod, wire, or tubing of various cross-sections as starting material (wire hanger is made from piece of wire)
- ✓ Shaping processes involve the molding and casting of soft or molten materials
  - ✓ The finished product is net or near net shape (a plastic coat hanger is made by forcing molten plastic into a two-piece mold with a cavity in the shape of the hanger)
- ✓ Products:
  - ✓ Long continuous products, such as plates, sheets and tubing (by rolling, extrusion, and drawing processes)
  - ✓ Discrete products (forging, sheet metal, powder metallurgy, ceramics and glasses, and plastic processes)

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Forming and shaping processes

- ✓ Rolling
- ✓ Forging
- ✓ Extrusion
- ✓ Drawing
- ✓ Sheet-metal forming
- ✓ Powder metallurgy
- ✓ Processing of plastics and composite materials
- ✓ Forming and shaping of ceramics

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Rolling process

- ✓ Reducing the thickness or changing the cross-section of a long workpiece by compressive forces applied through a set of **rolls**
- ✓ Accounts for about 90% of all metals produced by metalworking processes
- ✓ Modern steelmaking practices and the production of various ferrous and nonferrous metals and alloys combine continuous casting with rolling processes
- ✓ Rolling of nonmetalic materials to reduce their thickness and enhance their properties

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Rolling process

- ✓ Primary rolling (hot rolling) is carried out at elevated temperature that is above the recrystallization temperature of the metal
  - ✓ The coarse-grained and brittle structure of the ingot is broken down into a wrought structure having a finer grain size and enhance properties
  - ✓ Large amount of deformation
  - ✓ Generally free of residual stresses, and isotropic
  - ✓ Cannot be held to close tolerances, the oxide scale of the surface
  - ✓ Typical temperature range: ~450°C for aluminum alloys, up to 1250°C for alloy steels, and up to 1650°C for refractory alloys
- ✓ Cold rolling is carried out at room temperature
  - ✓ Product with higher strength and hardness and better surface finish
  - ✓ Requires more energy and results in a product with anisotropic properties

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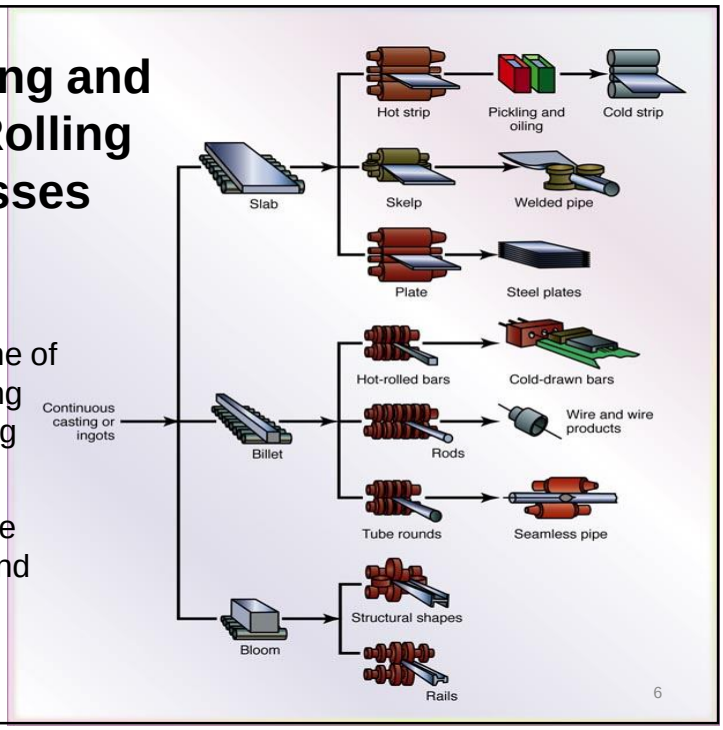
Flat-Rolling and Shape-Rolling Processes



Schematic outline of various flat-rolling and shape-rolling processes.

Source: After the American Iron and Steel Institute.

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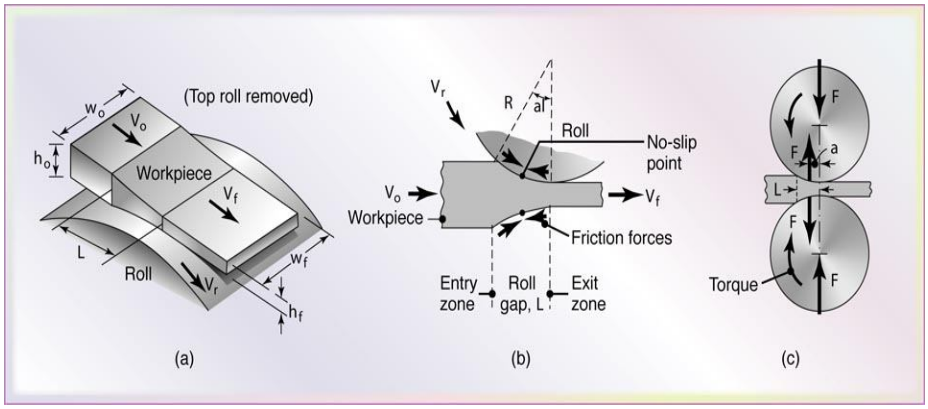
Flat-Rolling Process



(a) Schematic illustration of the flat-rolling process.

(b) Friction forces acting on strip surfaces

(c) Roll force, *F*, and the torque, *T*, acting on the rolls. The width of the strip, *w*, usually increases during rolling

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Flat rolling equations

Draft: the reduction of thickness $d = h_0 - h_f$

Maximum draft: $d_{\max} = \mu^2 R$ forward slip $s = \dfrac{V_f - V_r}{V_r}$

Roll-strip contact length: $L = \sqrt{R(h_0 - h_f)}$

Rolling force: $F = LwY_{avg}$ $Y_{avg} = \dfrac{K\varepsilon^n}{1+n}$

Rolling torque:

$$T = 0.5FL$$

The total power:

$$P = \frac{2\pi FLN}{60{,}000}\,(\text{kW}) \qquad P = \frac{2\pi FLN}{33000}\,(\text{hp})$$

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Reducing roll force

- ✓ Roll force can cause significant deflection and flattening of the rolls
- ✓ The roll stand may deflect to such an extent that the roll gap can open significantly
- ✓ Reducing roll force
  - ✓ Using hot rolling rather than cold rolling to lower the strength of material
  - ✓ Taking smaller reductions-per-pass to reduce the contact area
  - ✓ Using smaller-diameter rolls to reduce contact area
  - ✓ Using a lower rolling speed to reduce power
  - ✓ Reducing friction at the roll-workpiece interface
  - ✓ Applying tensions to the strip (back tension, front tension, or both)
    - ✓ Back tension is applied by applying a braking action to the reel that supplies the sheet into the roll gap by suitable means
    - ✓ Front tension is applied by increasing the rotational speed of the take-up reel

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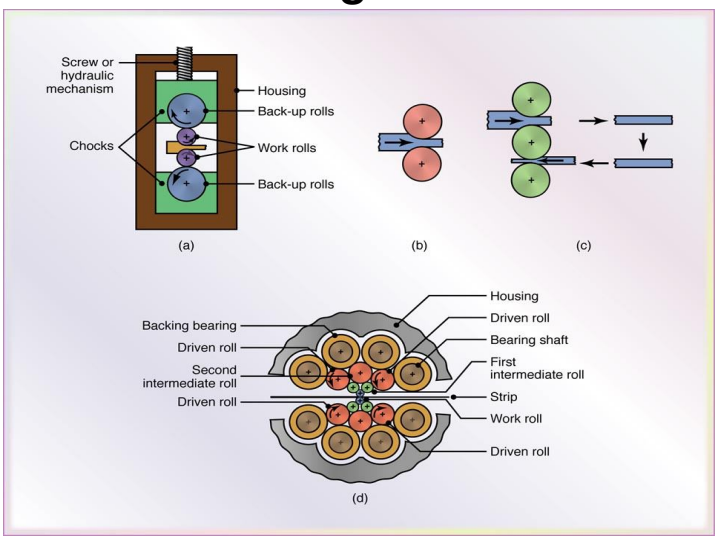
Roll Arrangements



Schematic illustration of various roll arrangements: (a) four-high rolling mill showing various features (b) two-hill mill; (c) three-high mill; and (d) cluster (or Sendzimir) mill.

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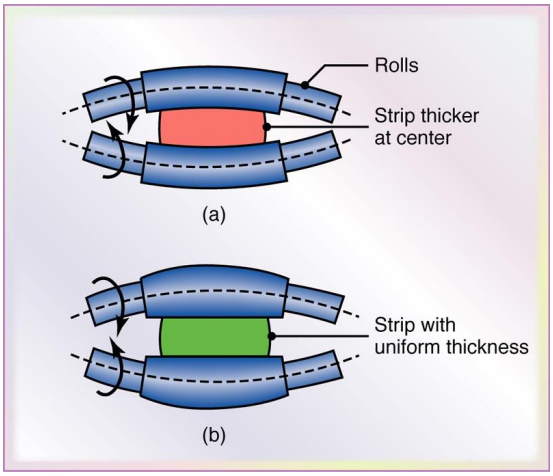
Bending of Rolls



(a) Bending of straight cylindrical rolls caused by roll forces.

(b) Bending of rolls ground with camber, producing a strip with uniform thickness through the strip width. Deflections have been exaggerated for clarity.

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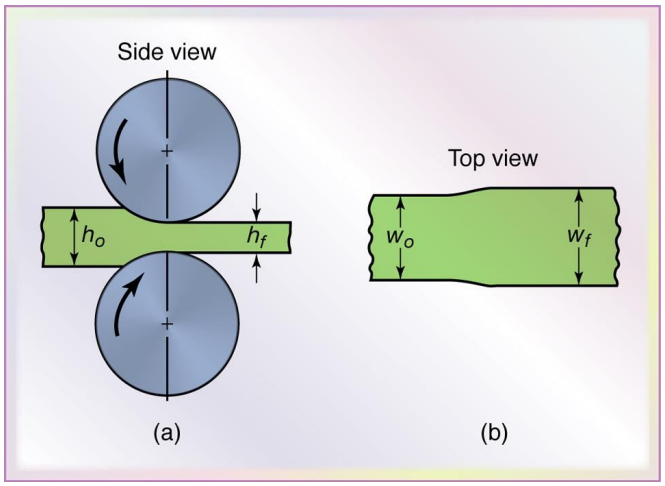
Spreading in Flat Rolling



Increase in strip width (spreading) in flat rolling. Note that similar spreading can be observed when dough is rolled with a rolling pin.

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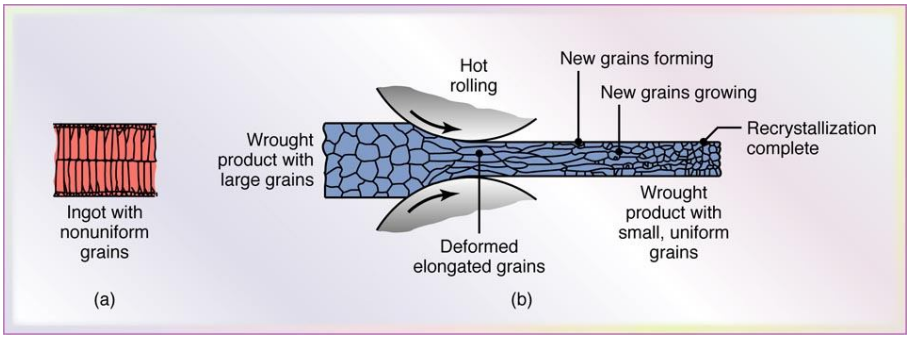
Effects of Hot Rolling



Changes in the grain structure of cast or of large-grain wrought metals during hot rolling.

Hot rolling is an effective way to reduce grain size in metals for improved strength and ductility.

Cast structures of ingots or continuous castings are converted to a wrought structure by hot working.

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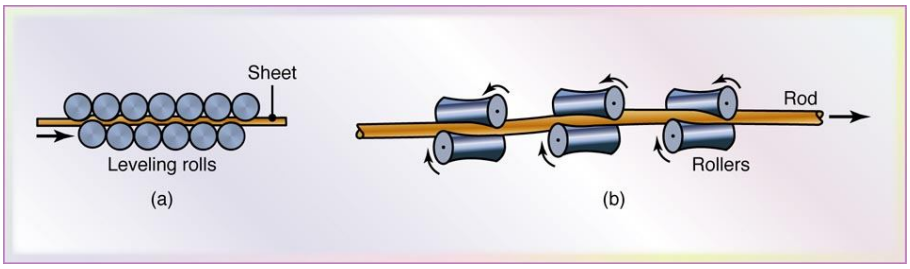
Roller Leveling



(a) A method of roller leveling to flatten rolled sheets.

(b) Roller leveling to straighten drawn bars. The workpiece is flexed in opposite directions as it passes through the sets of rollers, where each roll usually is driven by an individual electric motor

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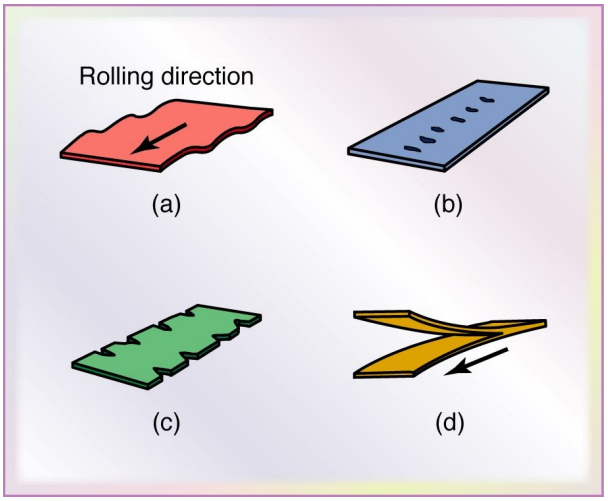
Defects in Flat Rolling



(a) wavy edges: as a result of roll bending;

(b) zipper cracks in the center of the strip and (c) edge cracks: as a result of poor material ductility at the rolling temperature;

(d) alligatoring: a complex phenomenon and typically is caused by nonuniform bulk deformation of the billet during rolling or by the presence of defects in the original cast material

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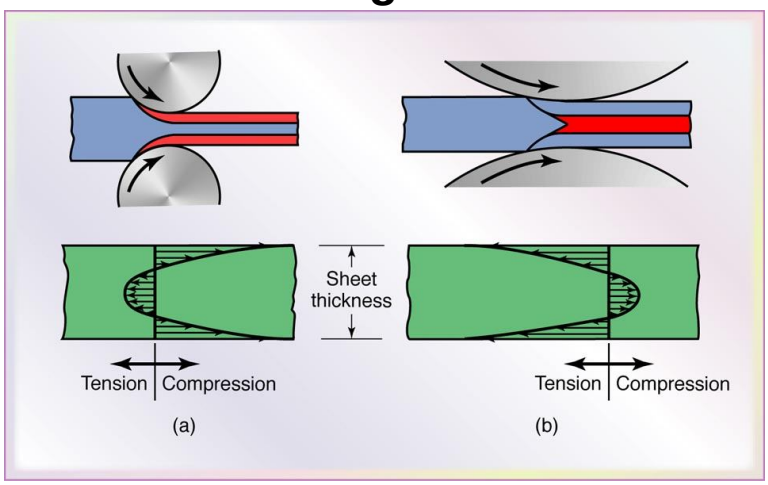
Residual Stresses Developed in Rolling



(a) Residual stresses developed in rolling with small-diameter rolls or at small reductions in thickness per pass.

(b) Residual stresses developed in rolling with large-diameter rolls or at high reductions per pass

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Rolling Mills

- ✓ Two-high rolling mills:
  - ✓ For hot rolling in initial passes (cogging mills)
  - ✓ Roll diameter from 0.6 to 1.4 m
- ✓ Three-high mill (reversing mill):
  - ✓ The direction of material movement is reduced after each pass
  - ✓ The plate being rolled is raised and lowered repeatedly
- ✓ Four-high mills & cluster mill:
  - ✓ Reduced roller diameters to lower roll forces, power requirements and reduce spreading
  - ✓ Lower cost for changing the milling rolls
  - ✓ More deflection on rollers: to be supported by larger-diameter rolls
  - ✓ Cluster mills (Sendzimir or Z mill) suitable for cold rolling of plates
- ✓ Tandem rolling:
  - ✓ Rolling continuously through a number of stands to thinner gages with each pass

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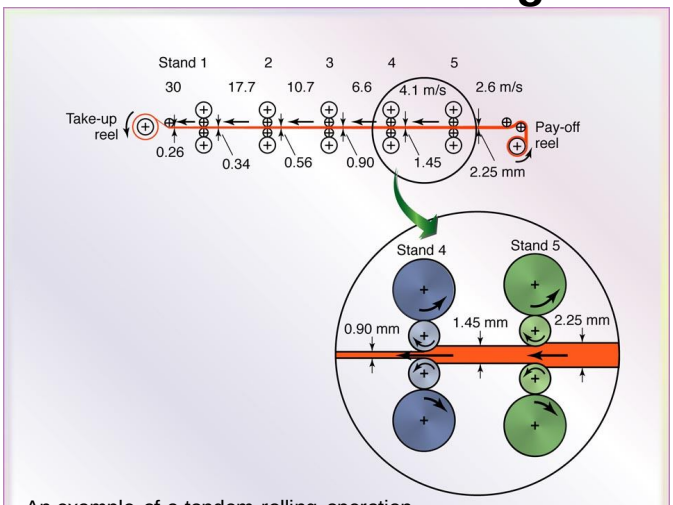
Tandem-Rolling



An example of a tandem-rolling operation.

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Rolling Mills

- ✓ Roll materials:
  - ✓ Strength and resistance to wear are basic requirements
  - ✓ Common materials: cast iron, cast steel, and forged steel
  - ✓ Tungsten carbides for small-diameter rolls in cluster mill
  - ✓ Separate cold and hot rolling mills; rolls for cold rolling may crack from thermal cycling
- ✓ Lubricants:
  - ✓ Hot rolling of ferrous alloys usually is carried without lubricants, although graphite may be used
  - ✓ Water-based solutions to cool the rolls and to break up the scale on the rolled material
  - ✓ Nonferrous alloys are hot rolled with oils, emulsions, and fatty acids
  - ✓ Water-soluble oils or low-viscosity lubricants for cold rolling (mineral oils, paraffin, and fatty oils)
  - ✓ The heating medium, such a that used in heat treating billets and slabs, may also act as a lubricant

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Various rolling processes

- ✓ Shape rolling:
  - ✓ Straight and long structural shapes (such as I-beams, railroad rails, and solid bars) are formed at elevated temperature by *shape rolling (profile rolling)*
  - ✓ Wire with various cross-sections also can be shaped by cold shape rolling
  - ✓ Nonuniformity of the process requires considerable experience in designing a series of rolls (roll-pass design)
- ✓ Roll forging:
  - ✓ The cross section of a round bar is shaped by passing through a pair of rolls with profiled grooves
  - ✓ Production of tapered shafts, table knives, and hand tools
- ✓ Skew rolling:
  - ✓ Similar to roll forging for production of ball bearing
  - ✓ Roughly spherical blanks are formed continuously by the action of rotating rolls

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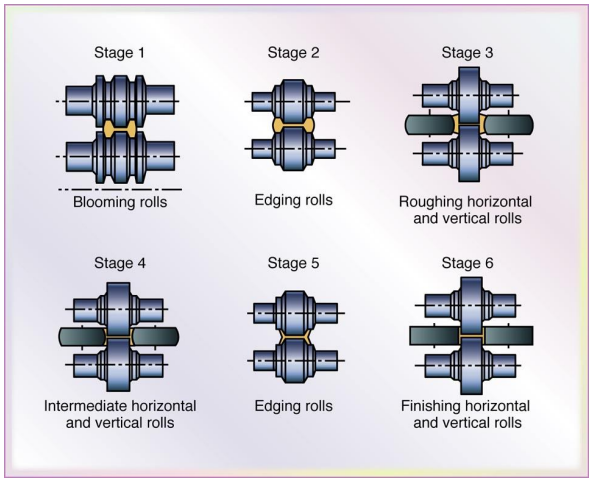
Shape Rolling of an H-section part



Steps in the shape rolling of an H-section part. Various other structural sections, such as channels and I-beams, also are rolled by this kind of process.

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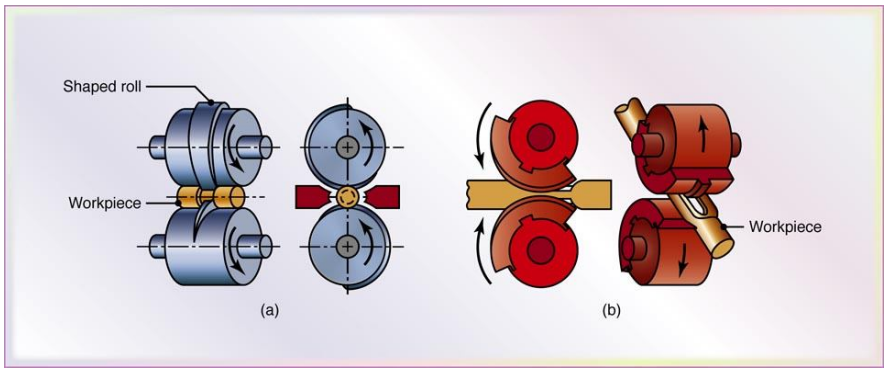
Roll-Forging



Two examples of the roll-forging operation, also known as *cross-rolling.* Tapered leaf springs and knives can be made by this process. *Source*: After J. Holub.

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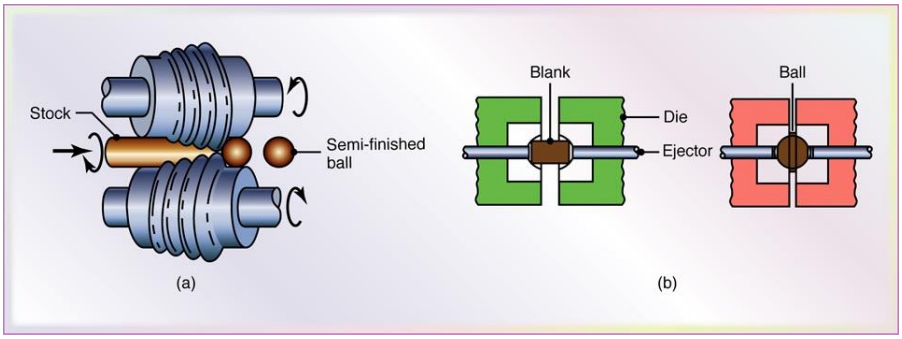
Production of Steel Balls



(a) Production of steel balls by the skew-rolling process.

(b) Production of steel balls by upsetting a cylindrical blank. Note the formation of flash. The balls made by these processes subsequently are ground and polished for use in ball bearings.

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Various rolling processes

- ✓ Ring rolling:
  - ✓ A thick ring is expanded into a large-diameter thinner one
  - ✓ Sets of two rolls, one of which is driven while the other is idle
  - ✓ The thickness is reduced by bringing the rolls closer together as they rotate
  - ✓ Various shapes can be ring rolled using shaped rolls
  - ✓ Applications include rings for rockets and turbines, jet engine cases, gearwheel rims, ball-bearing and roller-bearing races, flanges
  - ✓ At room or an elevated temperature depending on the size, strength, and ductility of the workpiece
  - ✓ Advantages are short production times, material savings, close dimensional tolerances, and favorable grain flow in the product
- ✓ Thread rolling
- ✓ Rotary tube piercing
- Tube rolling

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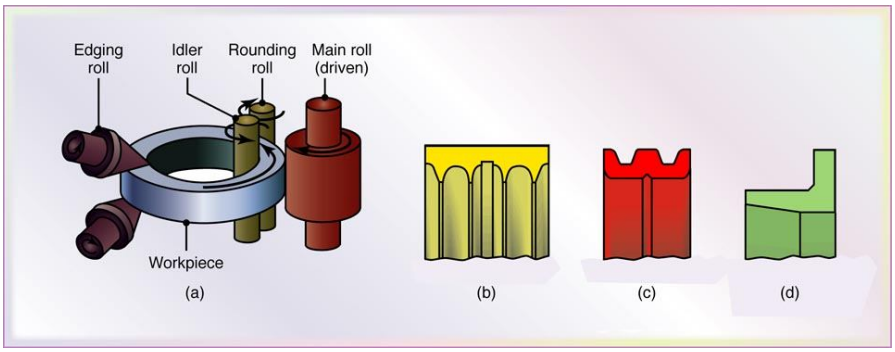
Ring-Rolling



(a) Schematic illustration of a ring-rolling operation. Thickness reduction results in an increase in the part diameter.

(b-d) Examples of cross-sections that can be formed by ring-rolling.

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Thread rolling

- ✓ Forming straight or taper threads on round rods or wire by passing them between dies
- ✓ Cold forming process with reciprocate or rotary dies
- ✓ Capable to generate other shapes such as grooves and gear forms
- ✓ Good strength, without loss of material, very smooth surface finish, improved fatigue life due to compressive residual stresses on the part surfaces, high production rate (as high as 80 pieces per seconds)
- ✓ Lubricant must be used to obtain good surface finish and to minimize the defects
- ✓ Rolling dies are made from hardened steel

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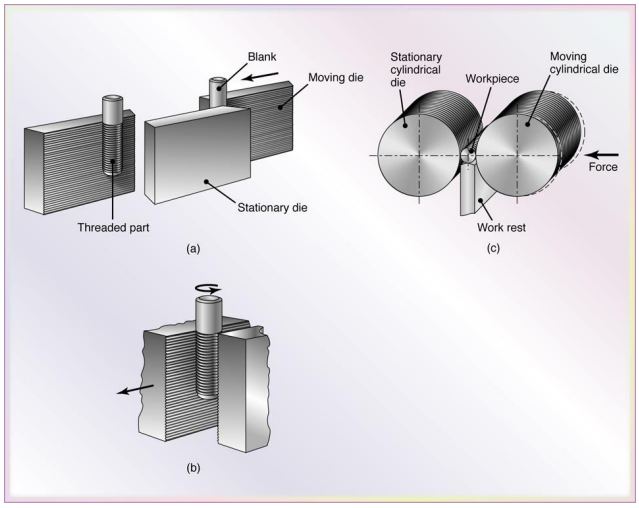
Thread-Rolling Processes



Thread-rolling processes: (a) and (b) reciprocating flat dies; (b) two-roller dies

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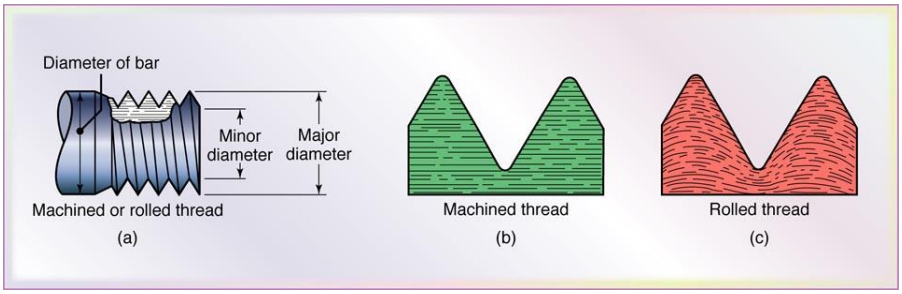
Machined and Rolled Threads



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

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Rotary tube piercing

- ✓ Known as the *Mannesmann process*
- ✓ Hot-working operation for making long, thick-walled pipe and tubing
- ✓ Based on the developing a tensile stress in a round bar subjected to radial compressive forces
- ✓ Carried out using skewed axes rotating rolls to pull the round bar through the rolls by the axial component of the rotary motion
- ✓ Internal mandrel expands and sizes the inside diameter (placed or floating mandrel)
- ✓ Due to severe deformation of the part, the material must be high in quality and free from defects

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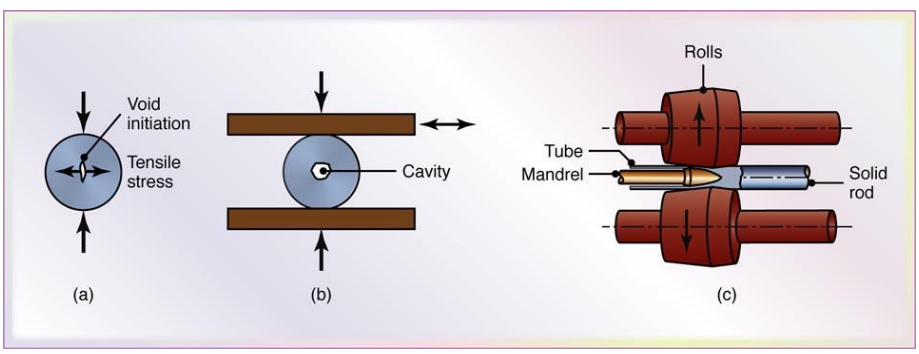
Cavity Formation in Bar



Cavity formation in a solid, round bar and its utilization in the rotary tube-piercing process for making seamless pipe and tubing

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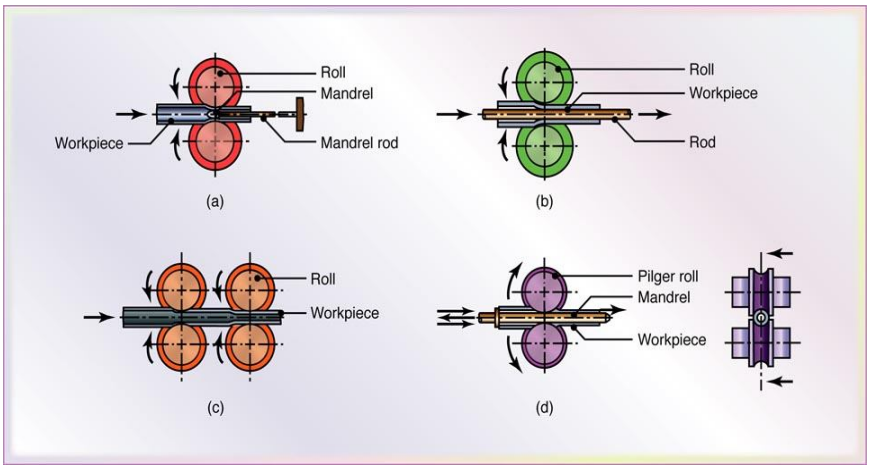
Various Tube-Rolling Processes



Tube-rolling processes: (a) with a fixed mandrel; (b) with a floating mandrel; (c) without a mandrel; and (d) pilger rolling over a mandrel and a pair of shaped rolls.

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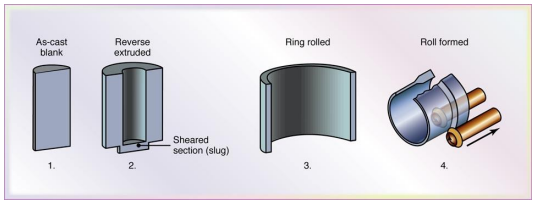
Forming of Solid Rocket Casings

The Space Shuttle *U.S.S. Atlantis* is launched by two strapped-on solid-rocket boosters. *Source*: Courtesy of NASA.

The forming processes involved in the manufacture of solid rocket casings for the Space Shuttles.



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