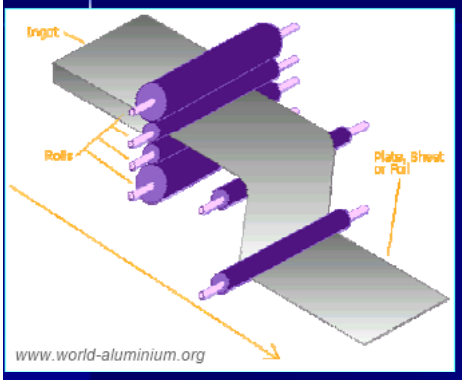
METAL FORMING - 2

Rolling of Metals

Rolling Process

1. Introduction
2. Basics of rolling
   - Rolling mechanism
3. Types of rolling mills
4. Pelbagai operasi menggelek: Ciri-ciri proses, kelebihan dan kekurangan dan aplikasi
   - Menggelek rata
   - Menggelek bentuk
   - Menggelek gelang
   - Menggelek ulir dan gear

1. Introduction



Rolling process

- ***Definition of Rolling*** : The process of plastically deforming metal by passing it between rolls.
- Rolling is the ***most widely used*** forming process, which provides high production and close control of final product.
- The metal is subjected to high ***compressive stresses*** as a result of the friction between the rolls and the metal surface.

Note: *rolling processes can be mainly divided into 1) hot rolling and 2) cold rolling.*

Introduction- Hot and cold rolling processes

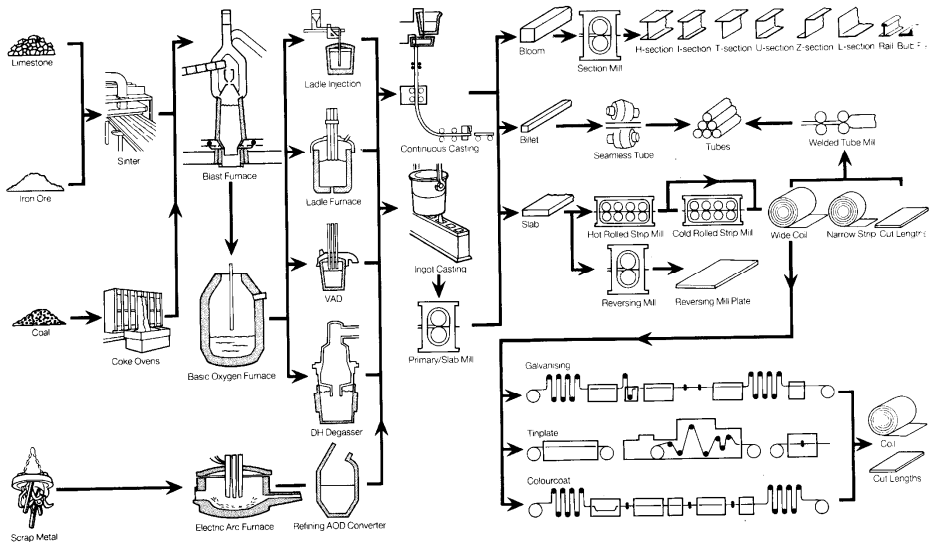
Hot rolling

- The initial ***breakdown of ingots*** into ***blooms*** and ***billets*** is generally done by ***hot-rolling***. This is followed by further hot-rolling into plate, sheet, rod, bar, pipe, rail.

Cold rolling

- The ***cold-rolling*** of metals has played a major role in industry by providing sheet, strip, foil with ***good surface finishes*** and ***increased mechanical strength*** with close control of product ***dimensions***.

Primary working



Terminology

Semi-finished products

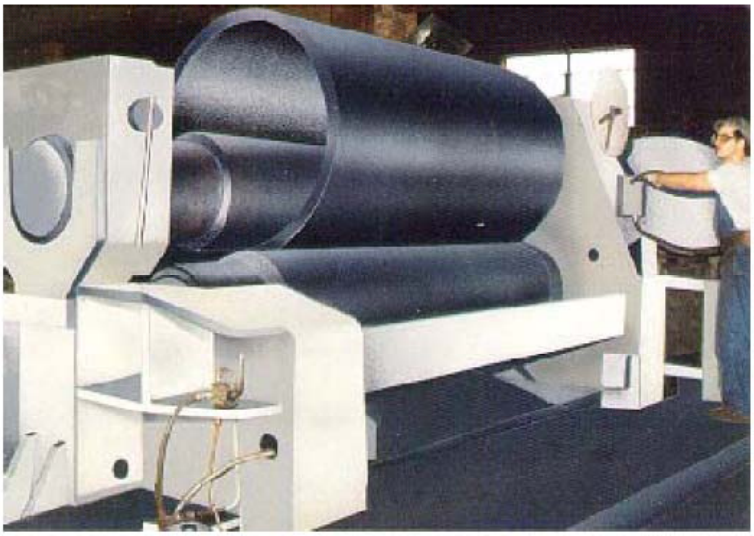
- ***Bloom*** is the product of first breakdown of ingot (cross sectional area > 230 cm^2).
- ***Billet*** is the product obtained from a further reduction by hot rolling (cross sectional area > 40x40 mm^2).
- ***Slab*** is the hot rolled ingot (cross sectional area > 100 cm^2 and with a width ≥ 2 x thickness).

Further rolling steps

Mill products

- ***Plate*** is the product with a thickness > 6 mm.
- ***Sheet*** is the product with a thickness < 6 mm and width > 600 mm.
- ***Strip*** is the product with a thickness < 6 mm and width < 600 mm.

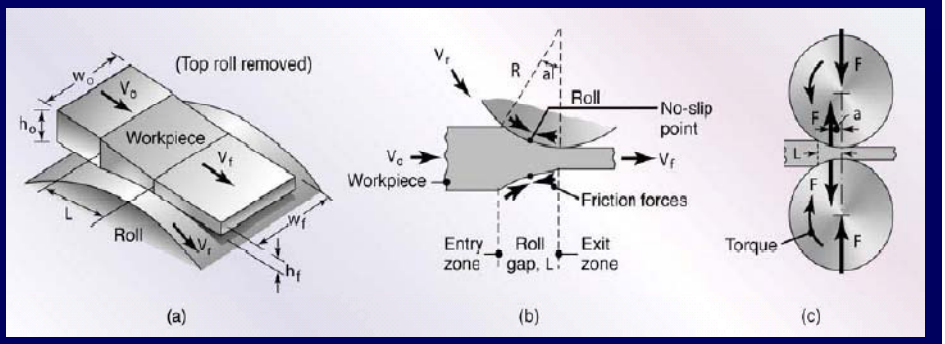
Rolling



2. Basics of Rolling process

- Rolling mechanism
  - Roller size
  - Roller speed
  - Surface friction of rollers
  - Gap difference before and after rolling (size reduction)
  - Materials – types (mechanical properties)
  - Rolling temperature
  - Types of lubrication

Flat rolling process parameters



Effects of Hot Rolling

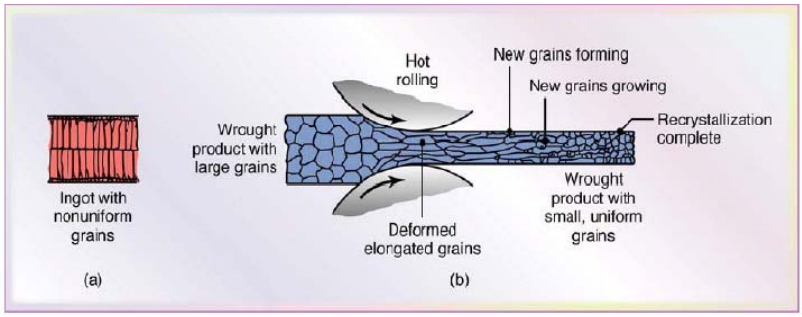


Figure 13.6 Changes in the grain structure of cast or of large-grain wrought metals during hot rolling. Hot rolling is an effective way to reduce grain size in metals for improved strength and ductility. Cast structures of ingots or continuous castings are converted to a wrought structure by hot working.

3. Rolling Mills

Rolling mills

Rolling mill is a machine or a factory for shaping metal by passing it through rollers

A rolling mill basically consists of

- rolls
- bearings
- a housing for containing these parts
- a drive (motor) for applying power to the rolls and controlling the speed

Modern rolling mill ➡

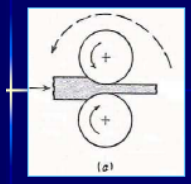
- Requires very rigid construction, large motors to supply enough power (MN).

Successive stands of a large continuous mill

- skills
- engineering design
- construction

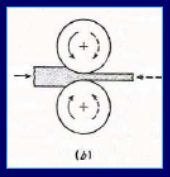
\+ **Huge capital investment**

Typical arrangement of rollers for rolling mills



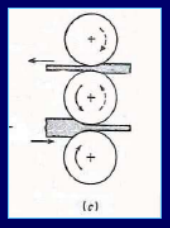
Two-high mill, pullover

The stock is returned to the entrance for further reduction.



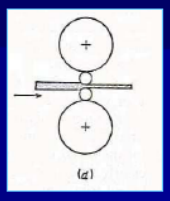
Two-high mill, reversing

The work can be passed back and forth through the rolls by reversing their direction of rotation.



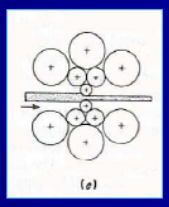
Three-high mill

Consist of upper and lower driven rolls and a middle roll, which rotates by friction.



Four-high mill

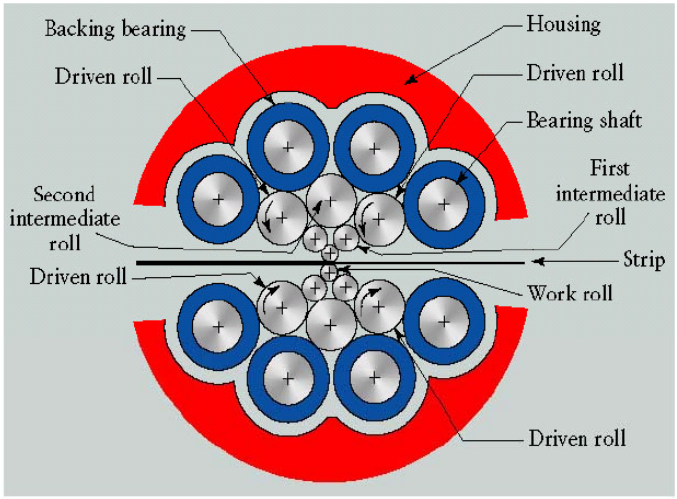
Small-diameter rolls (less strength & rigidity) are supported by larger-diameter backup rolls



Cluster mill or Sendzimir mill

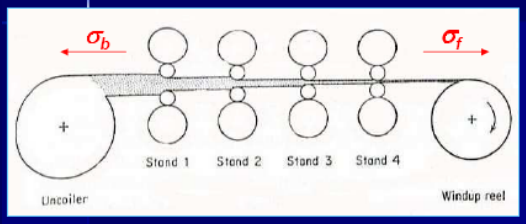
Each of the work rolls is supported by two backing rolls.

Method to reduce roll deflection



Typical arrangement of rollers for rolling mills

Continuous rolling

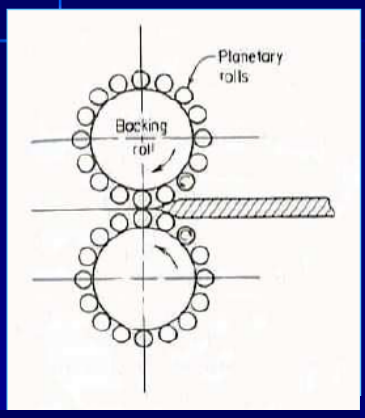


A four stand continuous mill or tandem mil.

- Use a series of rolling mill and each set is called a ***stand***.
- The strip will be moving at ***different velocities*** at each stage in the mill.
- The speed of each set of rolls is ***synchronised*** so that the input speed of each stand is equal to the output speed of preceding stand.
- The uncoiler and windup reel not only feed the stock into the rolls and coiling up the final product but also provide ***back tension*** and ***front tension*** to the strip.

Typical arrangement of rollers for rolling mills

Planetary mill



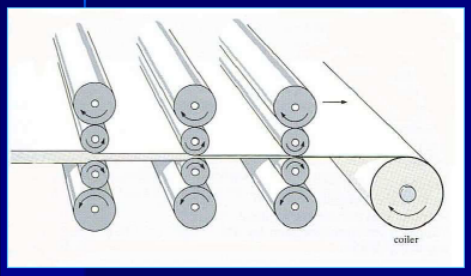
- Consist of a pair of ***heavy backing rolls*** surrounded by a large number of planetary rolls.
- Each planetary roll gives an ***almost constant reduction*** to the slab as it sweeps out a circular path between the backing rolls and the slab.
- As each pair of ***planetary rolls*** ceases to have contact with the work piece, another pair of rolls makes contact and repeat that reduction.
- The overall reduction is the summation of a series of small reductions by each pair of rolls. Therefore, the ***planetary mill*** can hot reduces a slab directly to strip in one pass through the mill.
- The operation requires ***feed rolls*** to introduce the slab into the mill, and a pair of ***planishing rolls*** on the exit to improve the surface finish.

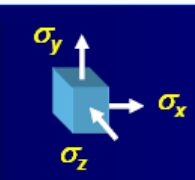
4. Different types of rolling processes

- Continuous rolling
  - Hot rolling
  - Cold rolling
- Shaped or section rolling
- Transverse rolling
- Ring rolling
- Powder rolling
- Continuous casting and hot rolling
- Thread and gear rolling

Conventional hot or cold-rolling

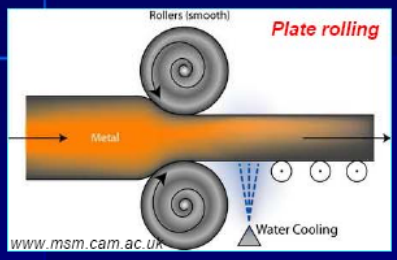
The objective is to ***decrease the thickness*** of the metal with an ***increase in length*** and with little increase in width.





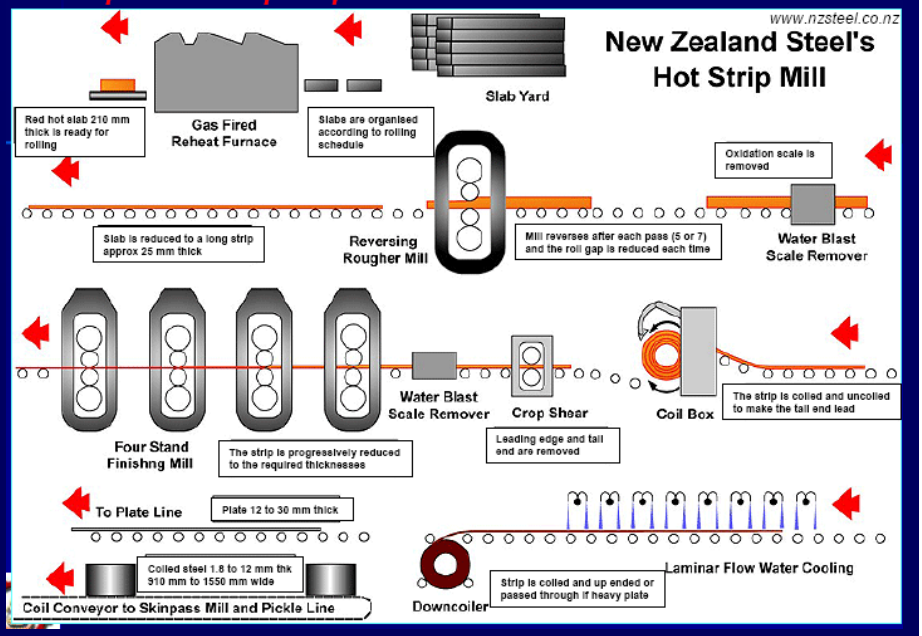
- The material in the centre of the sheet is constrained in the ***z*** direction (across the width of the sheet) and the ***constraints of undeformed shoulders of material*** on each side of the rolls prevent extension of the sheet in the width direction.
- This condition is known as ***plane strain***. The material therefore gets longer and not wider.
- Otherwise we would need the width of a ***football pitch*** to roll down a steel ingot to make tin plate!

Hot-rolling



- The first hot-working operation for most steel products is done on the ***primary roughing mill*** (blooming, slabbing or cogging mills).
- These mills are normally two-high reversing mills with 0.6-1.4 m diameter rolls (designated by size).
- The objective is to breakdown the cast ingot into ***blooms*** or ***slabs*** for subsequent finishing into bars, plate or sheet.
- In ***hot-rolling steel***, the slabs are heated initially at 1100 -1300 ^{o}C. The temperature in the last finishing stand varies from 700 - 900 ^{o}C, but should be above the upper ***critical temperature*** to produce uniform equiaxed ferrite grains.

Example for hot strip mill process



- ***Flat plate*** of large thickness (10-50 mm) is passed through different set of ***working rolls***, while each set consecutively reduces thickness.

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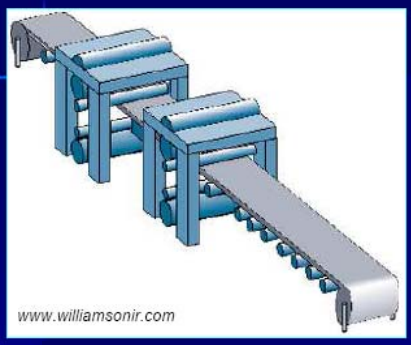
Plate rolling

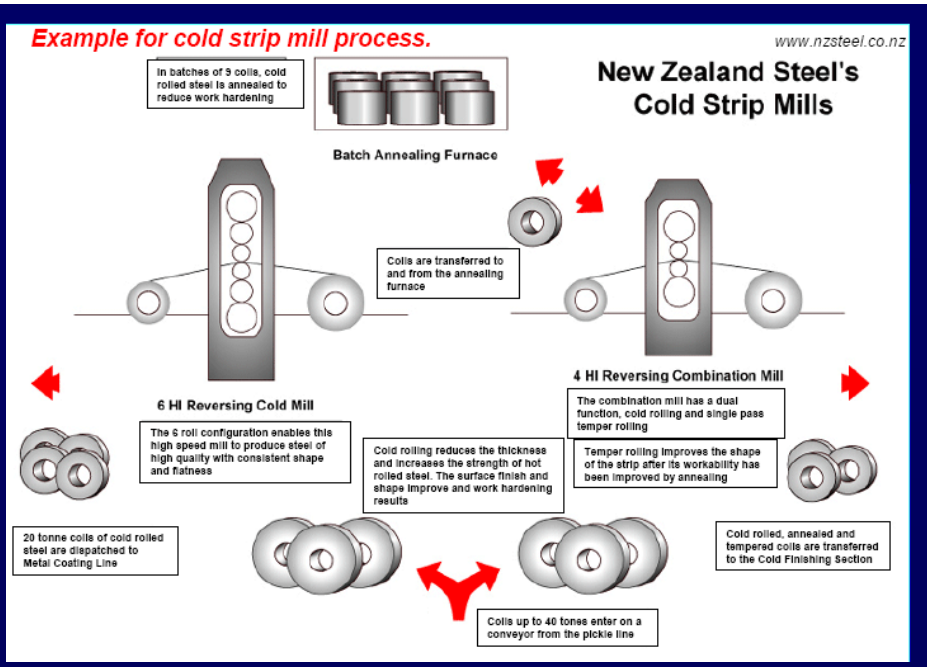
- ***Hot strip*** is coiled to reduce its increasing length due to a reduction of thickness.
- Reducing the complication of controlling strips of ***different speeds*** due to different thicknesses. (***thinner section moves faster***)

Cold-rolling

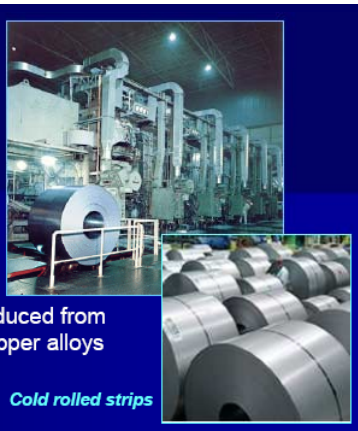


- Cold rolling is carried out under recrystallisation temperature and introduces work hardening.
- The starting material for cold-rolled steel sheet is pickled hot-rolled breakdown coil from the continuous hot-strip mill.
- The ***total reduction*** achieved by cold-rolling generally will vary from about 50 to 90%.
- The reduction in each stand should be distributed uniformly without falling much below the ***maximum reduction*** for each pass.
- Generally the lowest percentage reduction is taken place in the last pass to permit better control of flatness, gage, and surface finish.

Example for cold strip mill process.



Cold-rolling



Cold rolled strips

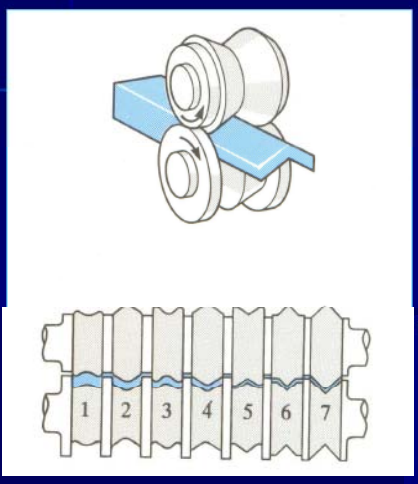
- Cold rolling provide products with ***superior surface finish*** (due to low temperature → no oxide scales)
- Better ***dimensional tolerances*** compared with hot-rolled products due to less thermal expansion.
- Cold-rolled nonferrous sheet may be produced from hot-rolled strip, or in the case of certain copper alloys it is cold-rolled directly from the cast state.

Cold rolled metals are rated as 'temper'

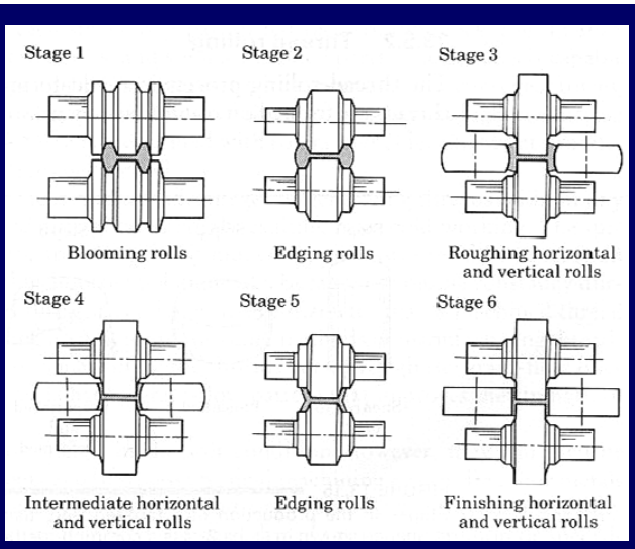
- ***Skin rolled*** : Metal undergoes the least rolling ~ 0.5-1% harden, still more workable.
- ***Quarter hard :*** Higher amount of deformation. Can be bent normal to rolling direction without fracturing
- ***Half hard*** : Can be bent up to 90°.
- ***Full hard*** : Metal is compressed by 50% with no cracking. Can be bent up to 45°.

Rolling

Shaped rolling or section rolling



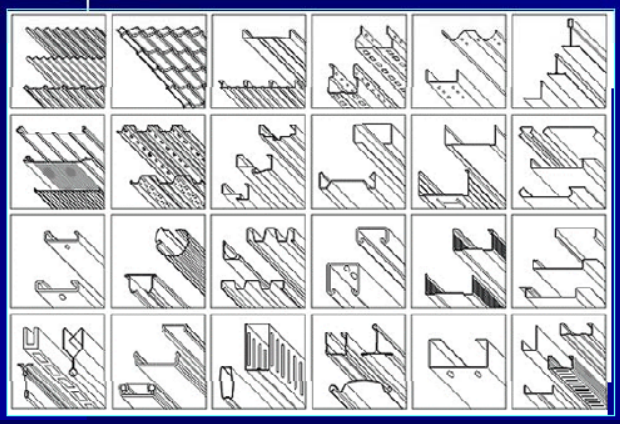
- A special type of cold rolling in which flat slap is progressively bent into ***complex shapes*** by passing it through a series of ***driven rolls***.
- No appreciable change in the thickness of the metal during this process.
- Suitable for producing moulded sections such as irregular shaped channels and trim.



Peringkat-peringkat yang dilalui semasa menggelek bentuk keratan berbentuk-H. Pelbagai bentuk lain seperti U, I dan sebagainya juga menggunakan proses yang serupa

Shaped rolling or section rolling

A variety of sections can be produced by roll forming process using a series of forming rollers in a continuous method to roll the metal sheet to a specific shape

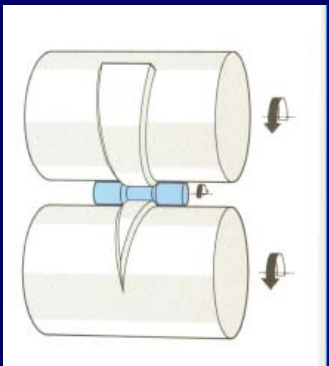


Applications:

- construction materials,
- partition beam
- ceiling panel
- roofing panels.
- steel pipe
- automotive parts
- household appliances
- metal furniture,
- door and window frames
- other metal products.

Transverse rolling

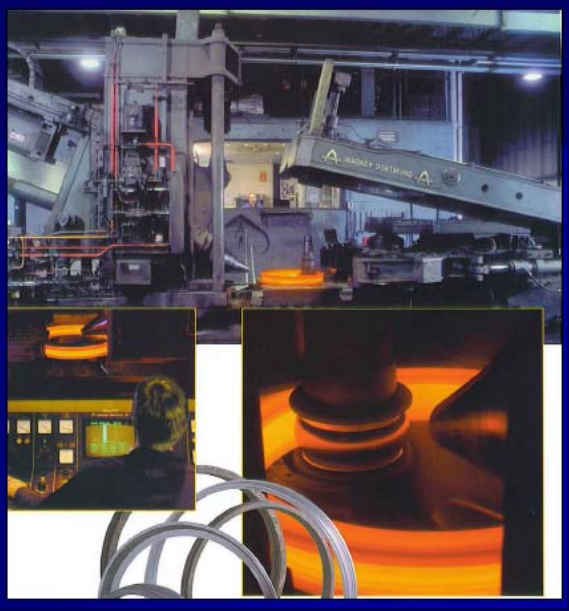
- Also known as roll forging



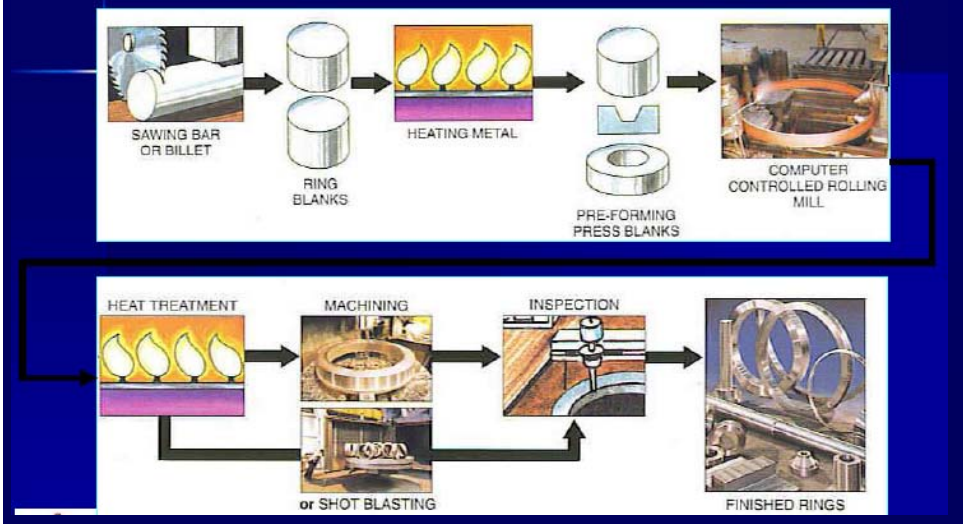
- Using circular wedge rolls.
- Heated bar is cropped to length and fed in transversely between rolls.
- Rolls are revolved in one direction.

Ring rolling

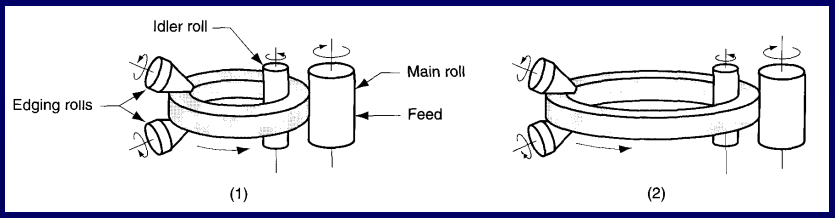
Seamless rings



Seamless ring rolling



Ring Rolling



- To make a larger and thinner ring from the original ring
- Usually a hot rolling process for large rings and cold rolling for small rings
- Typical applications: bearing races, steel tires, rings for pressure vessel.

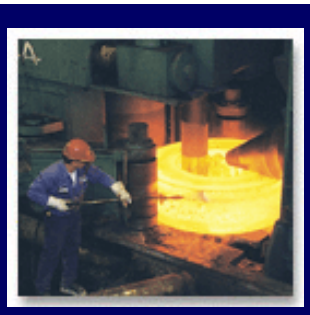
Open Die Rings Process Highlights

To produce open die rings, material is first upset, then pierced to form an inside diameter. The ring is then drawn over a mandrel if necessary to achieve desired dimension.

1. Breaking corners on starting billet stock
2. Upsetting the material for reduction and grain flow
3. Rounding the O.D. of the workpiece
4. Piercing the workpiece
5. Finishing the ring by opening the I.D. to size on a mandrel





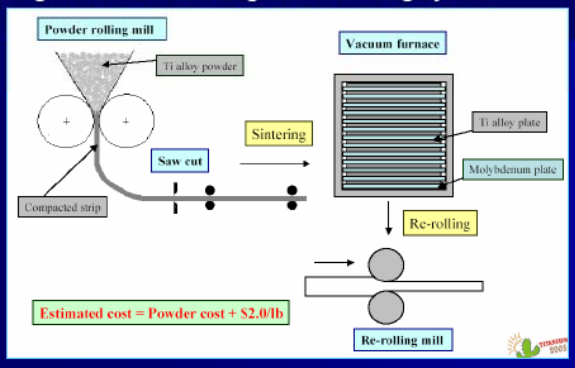
- Rolled Rings Process Highlights

  To produce a rolled ring, a preform is first produced. This preform is then placed on a ring mill, and through radial and axial pressure, is opened up to desired dimensions.

  1. A hot ring "preform" has been placed on the ring mill
  2. The I.D. and O.D. begin opening up in the early rolling stage
  3. A thin-wall ring takes shape
  4. The finished rolled ring is measured for accuracy

Powder rolling

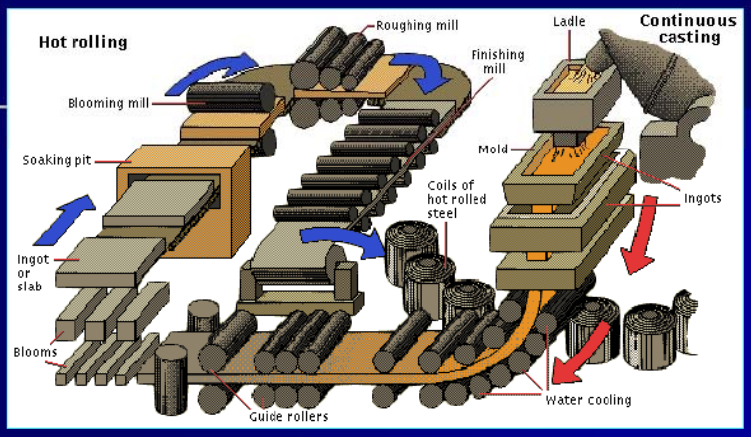
Metal powder is introduced between the rolls and compacted into a '***green strip***', which is subsequently sintered and subjected to further hot-working and/or cold working and annealing cycles.



Advantage :

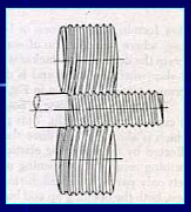
- Cut down the initial hot-ingot breakdown step (reduced capital investment).
- ***Economical*** - metal powder is cheaply produced during the extraction process.
- Minimise contamination in hot-rolling.
- Provide ***fine grain size*** with a minimum of preferred orientation.

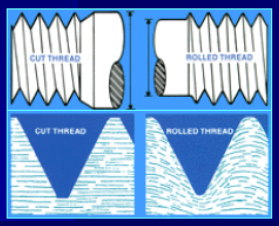
Continuous casting and hot rolling



- Metal is ***melted, cast and hot rolled*** continuously through a series of rolling mills within the same process.
- Usually for steel sheet production.

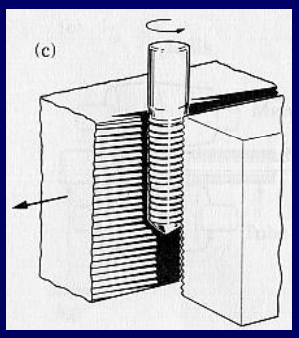
Thread rolling

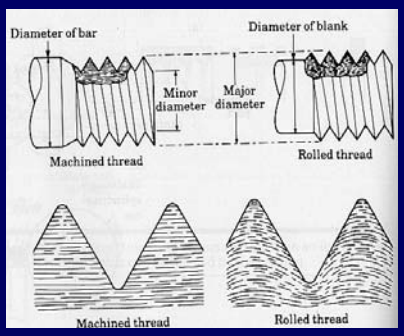




- ***Dies*** are pressed against the surface of cylindrical blank. As the blank rolls against the in-feeding die faces, the material is displaced to form the ***roots*** of the thread, and the displaced material flows ***radially outward*** to form the ***thread's crest***.
- A blank is fed between ***two grooved die plates*** to form the threads.
  - The thread is formed by the ***axial flow*** of material in the work piece. The grain structure of the material is not cut, but is ***distorted*** to follow the thread form.
  - Rolled threads are produced in a ***single pass*** at speeds far in excess of those used to cut threads.
  - The resultant thread is very much ***stronger*** than a cut thread. It has a greater resistance to mechanical stress and an increase in fatigue strength. Also the surface is burnished and ***work hardened***.

Thread and gear rolling





Typical products include screws, bolts and similar threased parts. Production rate depend on the diameter of the product. With small diameters the rates can be as high as 8 pieces per second and with large diameters (as much as 25 mm) about one per second. The threas rolling process generates threads without any metal loss and with greater strength because of cold work. The surface finish is very smooth and the process induces compressive stresses on the surfaces, which improve fatigue life.

Gear Rolling

- Similar to the screw thread.
- Typically for helical gears
- Shares the same advantages:
  - better material usage
  - smoother surface
  - stronger thread due to work hardening
  - better fatigue resistance due to compression

Problems and defects in rolled products

Defects from cast ingot before rolling

Defects other than cracks can result from defects introduced during the ingot stage of production.

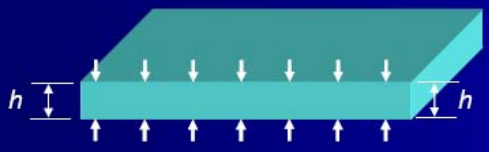
• ***Porosity, cavity, blow hole*** occurred in the cast ingot will be closed up during the rolling process.

• Longitudinal stringers of ***non-metallic inclusions*** or ***pearlite banding*** are related to melting and solidification practices. In severe cases, these defects can lead to laminations which drastically reduce the strength in the thickness direction.

Defects during rolling

There are two aspects to the problem of the shape of a sheet.

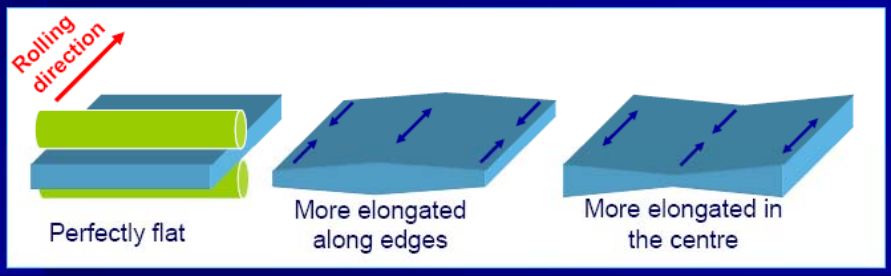
1) **Uniform thickness** over the width and thickness – can be precisely controlled with modern gage control system.



2) **Flatness** – difficult to measure accurately.

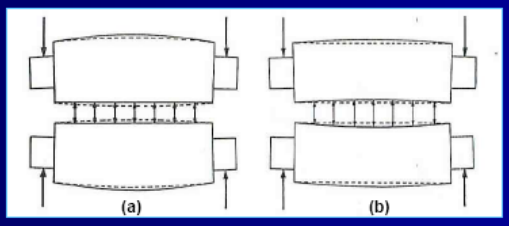
Flatness

- The **roll gap** must be perfectly parallel to produce sheets/plates with equal thickness at both ends.
- The rolling speed is very sensitive to **flatness**. A difference in elongation of one part in 10,000 between different locations in the sheet can cause waviness.



Solutions to flatness problems

• **Camber** and **crown** can be used to correct the roll deflection (at only one value of the roll force). Or use rolling mill equipped with hydraulic jacks to permit the elastic distortion of the rolls to correct deflection.

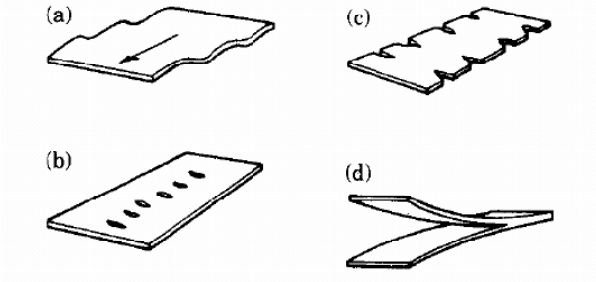


(a) The use of cambered rolls to compensate for roll bending.

(b) Uncambered rolls give variation of thickness.

Defects

- a) wavy edges
  - roll deflection
- b) zipper cracks
  - low ductility
- c) edge cracks
  - barreling
- d) alligatoring
  - piping, inhomogeniety



Effect of cold rolling on material properties

1. The tensile and yield strengths of material increase with increasing reductions
2. The ductility of material decreases
3. The thermal conductivity of material decreases
4. The density of material decreases
5. The stress corrosion resistance of material decreases
6. The residual stresses are induced in the material. They may be tensile or compressive in the surface layers depending upon the roll size.