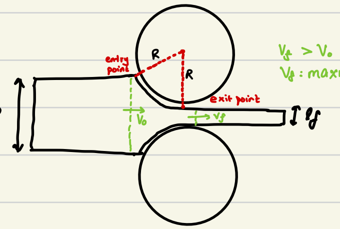
Chapter 13: Metal Rolling Processes and Equipment



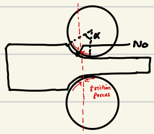
$V_f > V_0$

V_f : maximum velocity (at exit)

width remains same

Difference in heights $= l_0 - l_f$

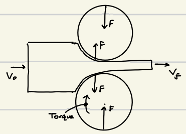
① No Slip Point



No slip point : • velocity of strip = velocity of roller
• to the left of this point, the roll moves faster than the strip and to the right of this point the strip moves faster than the roll.

② Maximum possible draft : $(l_0 - l_f)_{max} = \mu^2 R$ (μ : coeff of friction)

③ Roll Force, Torque and Power Requirements:



Force 'F' appears perpendicular to plane of strip, rather than at an angle because in practice, the arc of contact is very small compared with the roll radius, so we can assume that arc of contact is very small compared with the roll radius.

$$\boxed{\text{FORMULA: } F = L w Y_{avg} \quad \left\{ \begin{array}{l} L : \text{roll-strip contact length} \\ w : \text{width of the strip} \\ Y_{avg} : \text{average true stress} \end{array} \right\}}$$

← eqⁿ true for frictionless situation.
Actual Roll Force includes friction and is estimated as $F_{actual} = 1.2\, F_{calc.}$

Torque on the product

$T = F \cdot a$

Power required per roll : (assume that F acts in the middle of the arc)

$$P = \frac{2\pi F L N}{60{,}000} \text{ kW} \quad (a = L/2) \quad \{N : \text{RPM}\}$$

$$P = \frac{2\pi F L N}{33000} \text{ hp} \quad (F : \text{pounds},\ L : \text{feet})$$

Reducing Roll Force

→ **Reasons:** very high roll forces can cause significant deflection and flattening of the rolls which in turn can affect the roller operation. Additionally, the columns of the roll stand may deflect under high roll forces to such an extent that the roll gap can open up significantly. Hence, the rolls need to be set closer than originally calculated to compensate for this deflection and to obtain desired thickness.

→ **ways to reduce thickness :**

① Reducing friction at the roll-workpiece interface.
② Using smaller diameter rolls to reduce the contact area.
③ Taking smaller reductions per pass to reduce the contact area.
④ Rolling at elevated temperatures to lower strength of material.
⑤ Applying front and/or back tensions to the strip

⑤ Front or Back Tensions

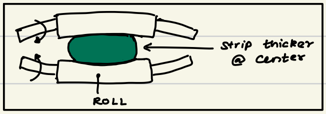
Application of longitudinal tension to the strip during rolling (as a result of which the compressive stresses required to plastically deform the material become smaller). Because they require high roll forces, tensions are particularly important in rolling HIGH STRENGTH Metels.

Tension Application
- → BACK TENSION : entry zone → applied by braking action to the reel that supplies the sheet into the roll gap by some suitable means.
- → FRONT TENSION : exit zone → applied by increasing the rotational speed of the take-up reel.
- → BOTH

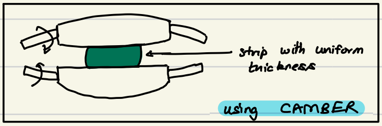
Steckel Rolling : Rolling carried out only by FRONT TENSION, with no power supplied to the rolls.

Geometric Considerations

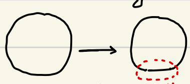
- Rolls undergo geometric changes during rolling. Roll forces tend to bend the rolls elastically during rolling. Higher the elastic modulus of the roll material, smaller the roll deflection.
- As a result of roll bending, rolled strip tends to be thicker at the center than at its edges. (crown)



- To avoid this problem of CROWN, we grind the rolls in such a way that their diameter at the center is slightly larger than their edges (CAMBER)

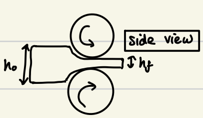


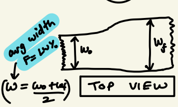
- To reduce the effects of deflection, rolls can be subjected to external bending by applying moments at their bearings.
- **THERMAL CAMBER** : because of the heat generated during plastic deformation during rolling, rolls become slightly barrel shaped. This can produce strips thinner at the center than at the edges.
- Consequently, total CAMBER can be adjusted by adjusting the location and the flow rate of the coolant along the length of the rolls during hot rolling.
- **Roll Flattening** →



Larger roll radius ⟹ Larger contact area for the same draft ⟹ larger roll forces

- **Spreading** : in workpieces with higher width to thickness ratios, the width of the strip remains constant during rolling but with smaller ratios, width increases significantly and this phenomena is known as spreading.





SPREADING
- → ① increases with decreasing width to thickness ratio entering strip.
- → ② increases with increasing friction
- → ③ increases with decreasing ratio of roll radius to strip thickness.
- ↳ prevented by using additional rolls (with vertical axis) in contact with the edges of the rolled product in the roll gap (edger mills), thus providing a physical constraint to spreading.

VIBRATION and CHATTER

→ have significant impact on product quality and productivity of metal working operations.

∴ Chatter : "self - excited vibrations" → can occur in rolling, extrusion, drawing, machining and grinding operations.

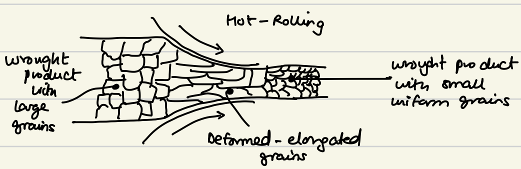
∴ Chatter leads to periodic variations in the thickness of the rolled sheet and in its surface finish, consequently leading to excessive scrap.

∴ Chatter occurs predominantly in Tandem Mills. It is very detrimental to productivity. Modern rolling mills could have operated at 50% higher speeds if not for chatter.

∴ Chatter results from interactions between the structural dynamics of the mill stand and the dynamics of the rolling operations. Roll-speed + Lubrication are very important parameters.

Chatter can be reduced by increasing the stands of the rolling mill, increasing the strip width, decreasing the reduction per pass (draft), increasing the roll radius, increasing the strip-roll friction and incorporating dampers in the roll-supports.

FLAT-ROLLING



Cast structure is typically dendritic and includes non uniform and coarse grains. This structure is usually brittle and may be porous. Hot rolling converts this cast structure to a wrought structure, with finer grains and enhanced ductility.

Temperature → 450°C : aluminums
→ 1250°C : alloy steels
→ 1650°C : refractory alloys

Product of first rolling operation → BLOOM → square cross section.
→ SLAB → rectangular cross section.
→ BILLET → smaller square cross section.

BLOOM : further processed by shape rolling into structural shapes such as I-beams and railroad rails.

SLABS : rolled into plates and sheets.

BILLETS: rolled into round rods and bars using shaped rolls.

HOT ROLLED round rods (wire roads) are used as starting materials for rod and wire-drawing operations.

- In hot rolling of blooms, billets or slabs, the surface of the material usually is conditioned prior to rolling them which is usually done using a torch aka SCARFING to remove heavy scale or by rough grinding to smoothen surfaces.

Prior to cold rolling, scales developed during hot rolling may be removed by PICKLING with acids (acid etching), by such mechanical means as blasting with water or by grinding to remove other defects as well.

COLD-ROLLING: carried out at room temperature and compared with hot rolling, produces sheets and strips with much better surface finish, better dimensional tolerances and enhanced mechanical properties due to lack of scales and strain hardening

PACK-ROLLING: 2 or more metal layers are rolled together to improve productivity.

example: Aluminium Foil

↳ pack rolled in 2 layers so only top and bottom outer layers have been in contact with the rolls. Note that one side of Al foil is matte while other side is shiny. Foil to Foil side has matte finish but foil to roll side is shiny and bright due to exposure to high contact stresses with the polished rolls during rolling.

Yield Point Elongation: a phenomenon that causes surface irregularities called stretcher strains or Lüder's Bands when Rolled mild steel is streched during sheet forming operations. To correct this, sheet metal is subjected to a final, light pass of 0.5 - 1.5% reduction

also known as "Temper Rolling"/Skin Pass

Flatness using Levelling Rolls

→ rolled sheet may not be sufficiently flat as it leaves the roll gap due to factors such as variations in the incoming material or in the processing parameters during rolling. To improve flatness, the rolled strip is sent through a series of levelling rolls.

Defects in Rolled Plates and Sheets

→ may be present as surface defects or internal structural defects of rolled plates and sheets compromising surface appearance and adversely affecting strength, formability and other manufacturing characteristics.

→ examples of defects: scales, rust, scratches, gouges, pits, cracks

① Wavy Edges: result of roll-bending. strip is thinner along the edges than the center, thus, the edges elongate more than the center. Consequently, the edges buckle because they are constrained by the central region from expanding freely in the longitudinal (rolling) direction.

② CRACKS : usually a result of poor material ductility at the rolling temperature.

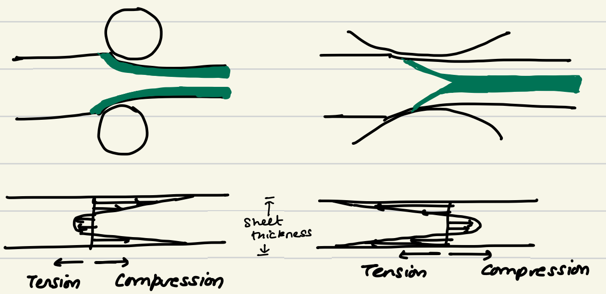
Note: Because the quality of edges of the sheet may effect sheet-metal forming operations, edge defects in rolled sheets are often removed by shearing and slitting operations.

③ Alligatoring: caused by non-uniform bulk deformation of the billet during rolling or by the presence of defects in the original cast material.

Other characteristics of Rolled Metals

① Residual Stresses

- because of non-uniform deformation of the material in the roll gap, residual stresses can develop in rolled plates and sheets, especially during cold rolling.



smaller diameter rolls | larger diameter rolls

small diameter rolls tend to deform the metal more at surface than bulk while converse is true for large diameter rolls. This is because of higher frictional constraint at the surfaces along the arc of contact. The diagram shows the residual stress distributions

② Dimensional Tolerances

- thickness tolerance for cold rolled sheets usually range from (0.1 – 0.35 mm) depending on the thickness.
- tolerances are much greater for hot rolled plates because of thermal effects.
- Flatness Tolerances → ± 15 mm: cold rolling
  → ± 55 mm: hot rolling

③ Surface Roughness

→ cold rolling produces a very fine surface finish and hence cold rolled products may not require additional finishing operations.

→ hot rolling and sand casting produce the same range of surface roughness.

④ Gage Numbers

→ used to identify sheet thickness

→ smaller number → thicker sheet

ROLLING MILLS

① Two-high Rolling Mills

- used for hot rolling in initial breakdown passes (primary roughing or cogging mills) on cast ingots or in continuos casting.

② Three-high Rolling Mills

- direction of material movement is reversed after each pass using elevator mechanisms and various manipulators. The plate being rolled is raised repeatedly to the upper roll gap, rolled, then lowered to the lower roll gap, rolled and so on.

③ Four-high Rolling Mills (Cluster Mills)

- Smaller diameter rolls lower rolling forces, power requirements and spreading.
- Smaller rolls can be replaced more easily and economically.
- However, small diameter rolls deflect more easily and have to be supported by large diameter rolls as is done in 4-high / Cluster mills.

④ Tandem-Rolling

- Strip is rolled continuously through a number of stands to thinner gages with each pass. Each stand consists of a set of rolls with its own housing and controls. A group of stands is called a train. Strip thickness and speed control is critical: computer controlled.

▶ Rolling Materials

→ materials must be strong and have resistance to wear.

↳ ex: cast iron, cast steel, forged steel, tungsten carbide is also used for small diameter rolls, such as the working roll in the cluster mill.

→ forged steel rolls (more costly) have higher stiffness, strength and toughness to cast iron rolls.

- Rolls made for cold rolling should not be used for hot rolling because they may crack from thermal cycling and spalling (cracking/flaking of surface layers).

▶ LUBRICANTS

- hot rolling of ferrous alloys is generally carried out w/o lubricants, although graphite may be used.
- water based solutions are used to cool the rolls and break up the scale on the rolled materials.
- Non-ferrous alloys are hot-rolled with a variety of compounded oils, emulsions and fatty acids.
- Cold rolling is carried out with water soluble oils or low viscosity lubricants, such as mineral oils/emulsions/paraffins/fatty oils.

Various Rolling Processes and Mills

I. Shape Rolling (Profile Rolling)

- used to design straight and long structural shapes such as I-beams, channels, rail road rails and solid bars formed at elevated temperatures

- **Cold Shape Rolling**: can be done with the starting materials in the shape of wire with various cross sections. Needs lots of expertise since cross section is considerably changed.

II. Roll-Forging (Cross Rolling)

- cross section of a round bar is shaped by passing it through a pair of rolls with profiled grooves.
- used to produce tapered shafts and leaf springs, table knives and hand tools.

III. Skew-Rolling

- used to make ball bearings.
- roughly spherical blanks formed continuously by the action of rotating rolls. The balls subsequently are ground and polished in special machinery.

IV Ring-Rolling

- thick ring is expanded into a large diameter thinner one. Thickness is reduced by bringing the rolls closer together as they rotate. Since volume of the ring material is constant, reduction in thickness leads to an increase in diameter.
- advantages: short production time, material savings, close dimensional tolerances and favourable grain flow in the product; thus enhancing its strength in the right direction.

V Thread Rolling

- cold forming process by which straight or tapered threads are formed on round rods or wire. Threads are formed on the rod/wire with each stroke of a pair of flat reciprocating dies.
- Advantages: generates threads with good strength due to cold rolling and without loss of any material (scrap). surface finish produced is very smooth and the process induces compressive residual stresses which improves fatigue life.
- Spurs and helical gears can be produced by similar processes.
- Internal Thread Rolling can be carried out with a fluteless forming tap. This operation is similar to external thread rolling and it produces internal threads with good strength.
- Lubrication is very important.

VI Rotary Tube Piercing (Mannesman Process)

- hot working operation for making long, thick walled seamless pipe and tubing.
- PRINCIPLE:

VII Tube Rolling