Rolling

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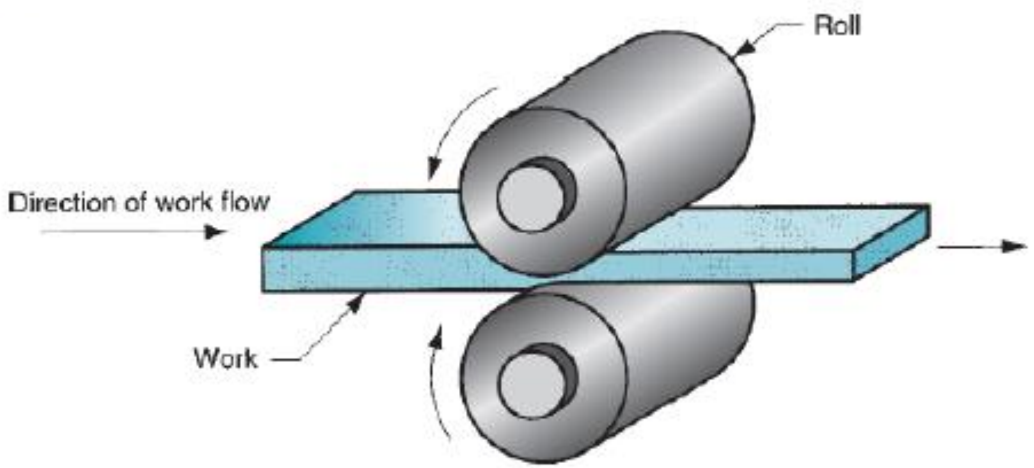
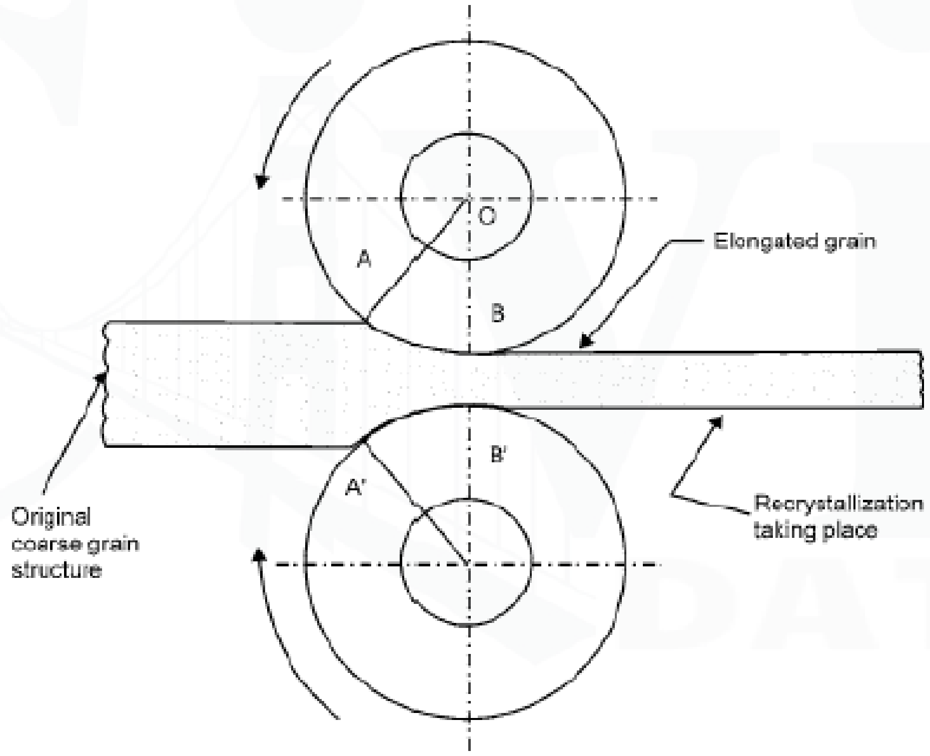
ROLLING

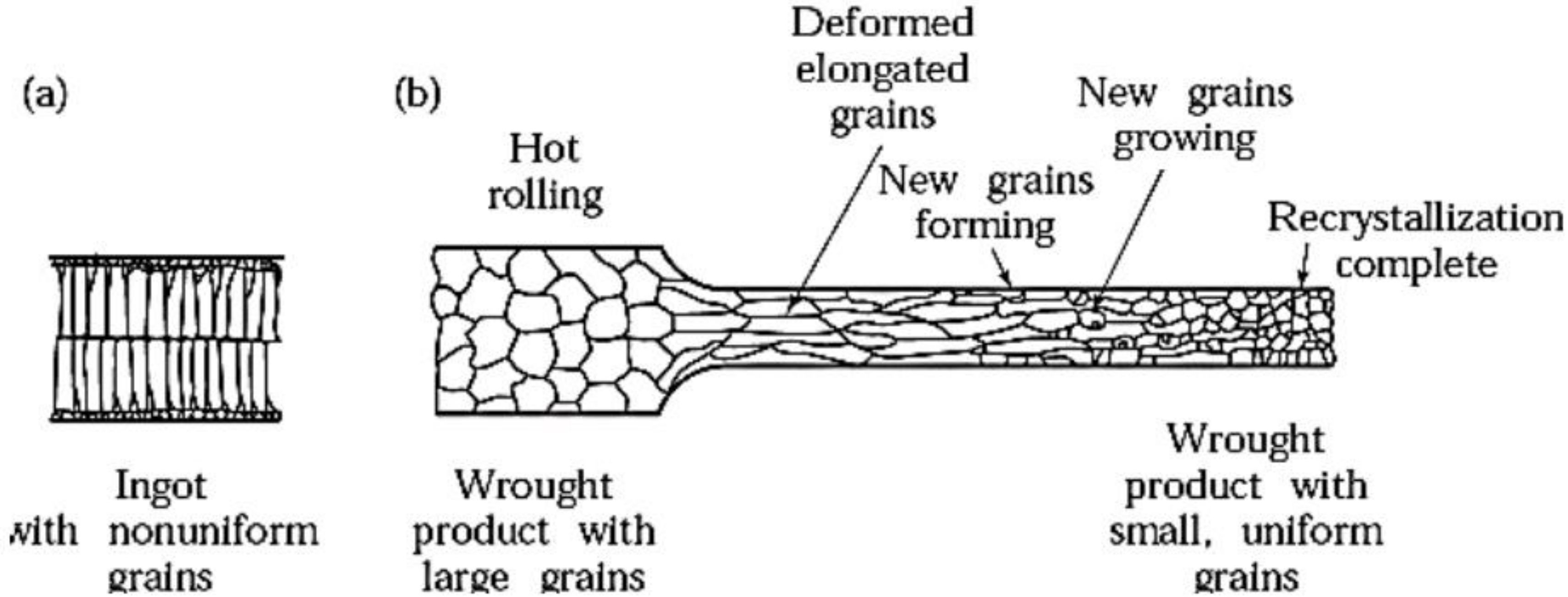




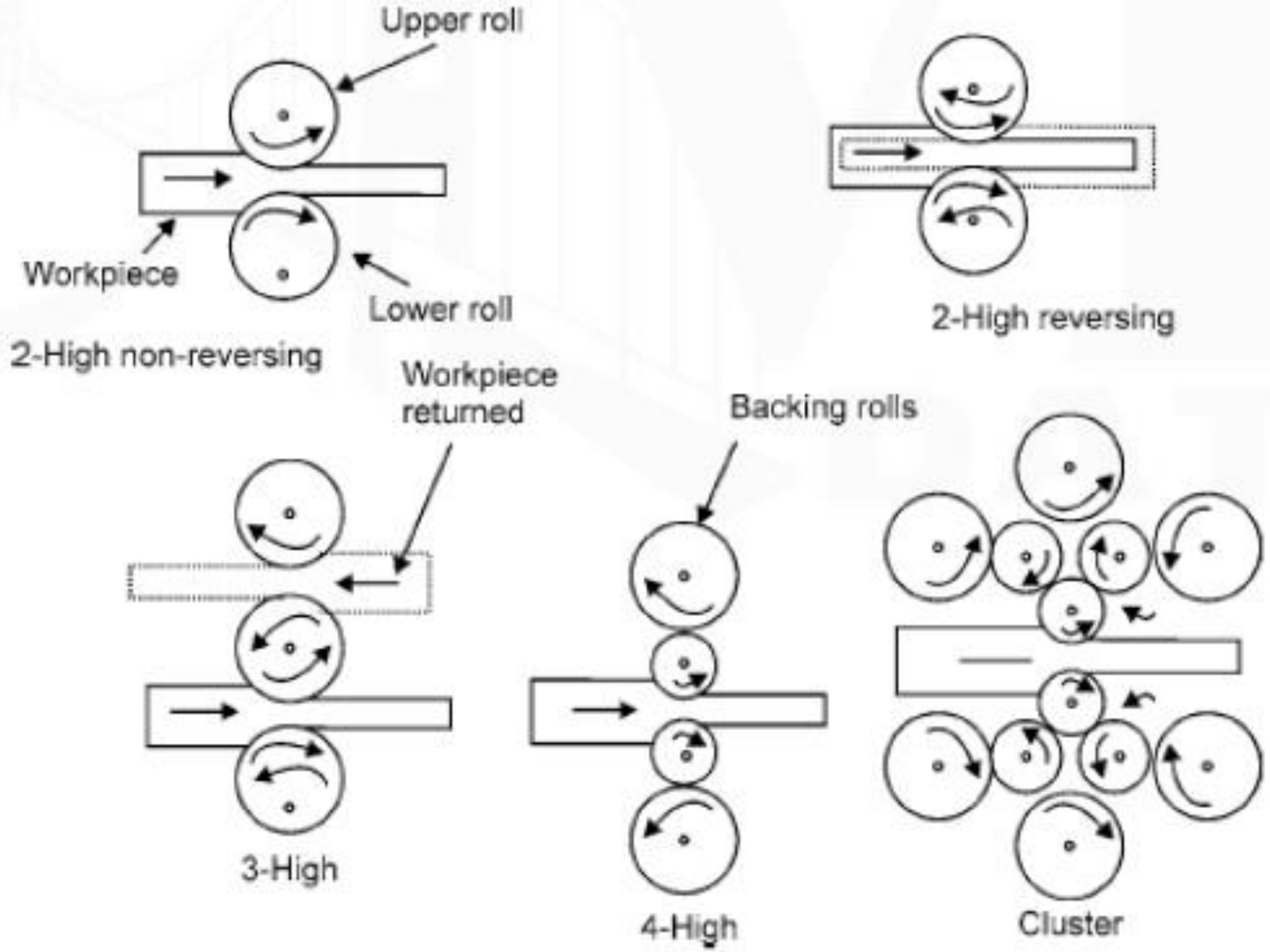
Rolling is the process of reducing the thickness or changing the cross section of a long workpiece by compressive forces applied through a set of rolls, as shown in figure.

It is the process of reducing the thickness or changing the cross-section of a long workpiece by compressive forces applied through a set of rolls. One effect of the hot working rolling operation is the grain refinement brought about by recrystallization, which is shown in Fig. Coarse grain structure is broken up and elongated by the rolling action. Because of the high temperature, recrystallization starts immediately and small grains begin to form. These grains grow rapidly until recrystallization is complete. Growth continues at high temperatures, if further work is not carried on, until the low temperature of the recrystalline range is reached.

Recrystallization in rolling



Rolling Mill



(1) **Two-high rolling mill:** It is basically of two types i.e., non-reversing and reversing rolling mill. The two high non-reversing rolling stand arrangements is the most common arrangement. In this the rolls always move in only one direction, while in a two-high reversing rolling stand the direction of roll rotation can be reversed. This type of stand is particularly useful in reducing the handling of the hot metal in between the rolling passes. About 30 passes are required to reduce a large ingot into a bloom. This type is used in blooming and slabbing mills.

(2) Three-high rolling mill: It is used for rolling of two continuous passes in a rolling sequence without reversing the drives. After all the metal has passed through the bottom roll set, the end of the metal is entered into the other set of the rolls for the next pass. For this purpose, a table-tilting arrangement is required to bring the metal to the level with the rolls. Such type of arrangement is used for making plates or sections.

(3) Four-high rolling mill: It is generally a two-high rolling mill, but with small sized rolls. The other two rolls are the backup rolls for providing the necessary rigidity to the small rolls. It is used for both hot and cold rolling of wide plates and sheets.

(4) Cluster rolling mill: It uses backup rolls to support the smaller work rolls. In this type of mill, the roll in contact with the work can be as small as 1/4 in. in diameter. Foil is always rolled on cluster mills since the small thickness requires small-diameter rolls.

Roll Passes

The final rolled products such as plates, flats, sheets, rounds and sections are obtained in a number of passes starting from billet or slabs. For rolling the flat product, plain cylindrical rolls are used but for sections, grooved rolls are used. The type of grooving done is decided by the final section desired.

The roll pass sequence can be broadly classified into three types:

1. Breakdown passes: These are used for reducing the cross-sectional area nearer to what is desired. These would be the first to be present in the sequence.
2. Roughing passes: In these passes also, the cross-section gets reduced, but along with it, the shape of the rolled material comes nearer to the final shape.
3. Finishing passes: These are the final passes which give the required shape of pass follows a leader pass.

Defects in Rolling

(1) **Surface defects** may result from inclusions and impurities in the material, scale, rust, dirt, roll marks and other causes related to the prior treatment and working of the material. In hot rolling blooms, billets and slabs, the surface is usually preconditioned by various means, such as torch to remove scale.

(2) **Structural defects** are defects that distort or affect the integrity of the rolled product.

(3) **Wavy edges** are caused by bending of the rolls; the edges of the strip are thinner than the centre. Because the edges elongate more than the centre and are restrained from expanding freely, they buckle.

(4) **Zipper cracks** are usually caused by low ductility and barreling.

(5) **Edge cracks** are occurs in plates and slabs because of either limited ductility of metal or uneven deformation especially at the edges.

(6) **Alligatoring** is a complex phenomenon that results from inhomogeneous deformation of the material during rolling or from defects in the original cast ingot, such as piping. The workpiece splits along a horizontal plane on exit from the rolls.

Applications of Rolling

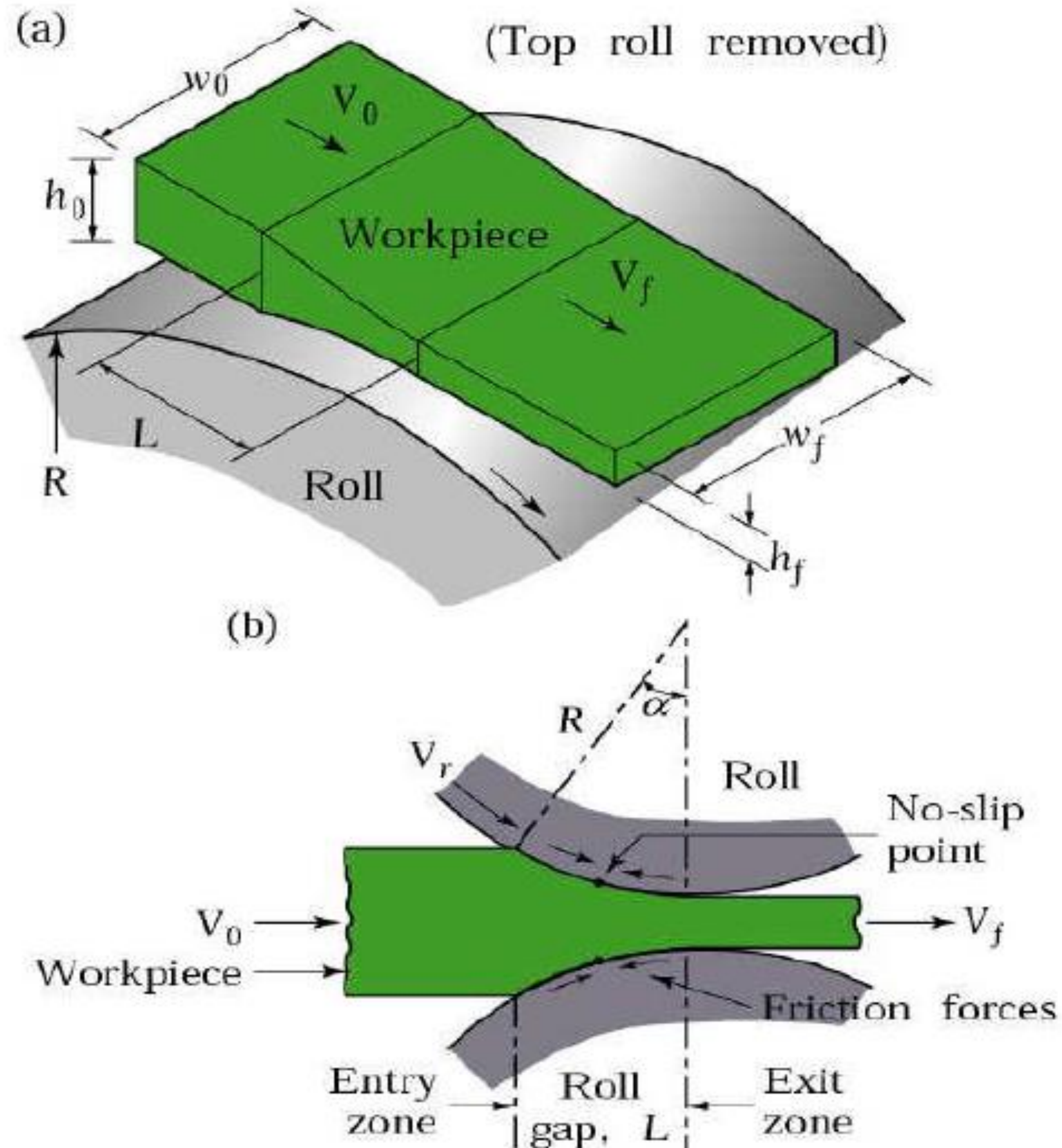
Rolling is used to produce components having constant cross-section throughout its length. The whole range of rolled products can be divided into the following types:

(a) **Structural shapes or sections:** This includes sections like round, square, hexagonal bars, channels, H and I beams and special sections like rail section.

(b) **Plates and sheets:** These are produced of varying thickness.

(c) **Special purpose rolled products:** These include rings, balls, wheels and ribbed tubes

Analysis of Rolling



Flat rolling is illustrated in Figures. It involves the rolling of slabs, strips, sheets, and plates workparts of rectangular cross section in which the width is greater than the thickness. In flat rolling, the work is squeezed between two rolls so that its thickness is reduced by an amount called the **draft**:

$$d = h_\circ - h_f = 2R\,(1-\cos\alpha)$$

Where d = draft, mm (in); $h_\circ$ = starting thickness, mm (in); and h_f = final thickness, mm (in).R = roll radius in mm and (α) = bite angle in degree. Draft is sometimes expressed as a fraction of the starting stock thickness, called the **reduction**

$$r = \frac{d}{h_\circ}$$

Where r = reduction. When a series of rolling operations are used, reduction is taken as the sum of the drafts divided by the original thickness. In addition to thickness reduction, rolling usually increases work width. This is called spreading, and it tends to be most pronounced with low width-to-thickness ratios and low coefficients of friction, so the volume of metal exiting the rolls equals the volume entering

$$h_\circ w_\circ L_\circ = h_f w_f L_f$$

Where w_o and w_f are the before and after work widths, mm (in); and L_o and L_f are the before and after work lengths, mm (in). Similarly, before and after volume rates of material flow must be the same, so the before and after velocities can be related:

$$h_\circ w_\circ v_\circ = h_f w_f v_f$$

Where v_o and v_f are the entering and exiting velocities of the work.

The surface speed of the rolls is V_r the velocity of the strip increases from its entry value of V_O as it moves through the roll gap; the velocity of the strip is highest at the exit from the roll gap and is denoted as V_f. The metal accelerates in the roll gap in the same manner as an incompressible fluid flowing through a converging channel.

To keep constant the volume rate of the material, the velocity of the strip must increase as it moves through the roll gap

$$V_f = V_0\left(\frac{h_0}{h_f}\right)$$

NEUTRAL POINT:
point in the arc of contact where the roll velocity and the strip velocity are the same

$$\text{Forward slip} = \frac{V_f - V_r}{V_r}$$

Because the surface speed of the rigid roll is constant, there is relative sliding between the roll and the strip along the arc of contact in the roll gap, **L**. At one point along the contact length **(called the neutral point or no-slip point) the velocity of the strip is the same as that of the roll**. To the left of this point, the roll moves faster than the strip; to the right of this point, the strip moves faster than the roll. Consequently, the frictional forces-which oppose motion between two sliding bodies-act on the strip as shown above. On either side of this point, slipping and friction occur between roll and work. The amount of slip between the rolls and the work can be measured by means of the forward slip, a term used in rolling that is defined:

$$S = \frac{V_f - V_r}{V_r}$$

Where *s* = forward slip; $\mathbf{v}_f$ = final (exiting) work velocity, m/s (ft/sec); and $\mathbf{v}_r$ = roll speed, m/s (ft/sec).

The rolls pull the material into the roll gap through a net frictional force on the material. Thus, the net frictional force must be to the right in Fig. This also means that the frictional force to the left of the neutral point must be higher than the friction force to the right. Although friction is necessary for rolling materials (just as it is in driving a car on a road), energy is dissipated in overcoming friction. Thus, increasing friction also increases rolling forces and power requirements. Thus, a compromise is made in practice: Low and controlled friction is induced in rolling through the use of effective lubricants. **The maximum possible draft** is defined as in equation below; it can be shown that this quantity is a function of the roll radius, R, and the coefficient of friction, μ, between the strip and the roll by the following relationship:

$$d_{max} = \mu^2 R$$

Thus, as expected, the higher the friction and the larger the roll radius, the greater the maximum possible draft becomes. Note that this situation is similar to the use of large tires (high R) and rough treads (high, μ.) on farm tractors and off-road earthmoving equipment, thus permitting the vehicles to travel over rough terrain without skidding.

The true strain experienced by the work in rolling is based on before and after stock thicknesses. In equation form,

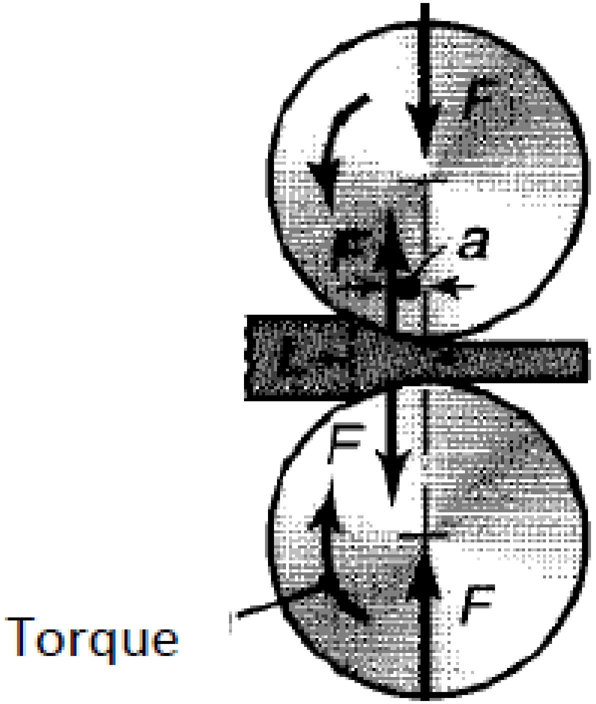
$$\varepsilon = \ln \frac{h_\circ}{h_f}$$

The true strain can be used to determine the average flow stress Y_f applied to the work material in flat rolling.

$$\bar{Y}_f = \frac{K\varepsilon^n}{1+n}$$

The minimum number of passes= $h_\circ - h_f / d_{max}$

Roll force, torque and power requirements



Note that this force appears in the figure as perpendicular to the plane of the strip, rather than at an angle. This is because, in practice, the arc of contact is very small compared with the roll radius, so we can assume that the roll force is perpendicular to the strip without causing significant error in calculations. The roll force in flat rolling can be estimated from the formula

$$F = \bar{Y}_f \; w \, L$$

Where $\overline{Y_f}$ = average flow stress, MPa (lb/in^2); and the product (wL) is the roll-work contact area, mm^2 (in^2). Contact length can be approximated by

$$L = \sqrt[2]{R(h_o - h_f)}$$

The torque in rolling can be estimated by assuming that the roll force is centered on the work as it passes between the rolls, and that it acts with a moment arm of one-half the contact length L. Thus, torque for each roll is

$$T = 0.5FL$$

The power required per roll can be estimated by assuming that (F) acts in the middle of the arc of contact; thus, a = L/2. Therefore, the total power (for two rolls), in S.I. units, is

$$\text{Power (in Kw)} = \frac{2\pi FLN}{60000}$$

Problem

A 300-mm-wide strip 25-mm thick is fed through a rolling mill with two powered rolls each of radius = 250 mm. The work thickness is to be reduced to 22 mm in one pass at a roll speed of 50 rev/min. The work material has a flow curve defined by K = 275 MPa and n = 0.15, and the coefficient of friction between the rolls and the work is assumed to be 0.12. Determine if the friction is sufficient to permit the rolling operation to be accomplished. If so, calculate the roll force, torque, and horsepower.

The draft attempted in this rolling operation is

$$d = 25 - 22 = 3mm$$

From equation we can find the maximum draft

$$d_{max} = (0.12)^2(250) = 3.6mm$$

Since the maximum allowable draft exceeds the attempted reduction, the rolling operation is feasible. To compute rolling force, we need the contact length L and the average flow stress Yf . The contact length is given by Eq.

$$L= \sqrt[2]{R(h_\circ - h_f)}$$

$$L= \sqrt[2]{250(25-22)} = 27.4 \text{ mm}$$

Y_f is determined from the true strain:

$$\varepsilon = \ln\frac{h_\circ}{h_f}$$

$$\varepsilon = \ln\frac{25}{22} = 0.128$$

$$\bar{Y_f} = \frac{275X0.128^{0.15}}{1+0.15} = 175.7 \text{ MPa}$$

Rolling force is determined from Eq.

$$F = 175.7(300)\,(27.4) = 1.\,444.\,254\ \text{N}$$

Torque required to drive each roll is given by Eq.

$$T = 0.5(1.\,444.254)\,(27.\,4)\,(10^{-3}) = 19.\,786\ \text{N-m}$$

And the power is obtained from Eq.

$$\text{Power (in Kw)} = \frac{2\pi X 1.444.786 X 0.274 X 50}{60000} = 207.284\ \text{Kw}$$

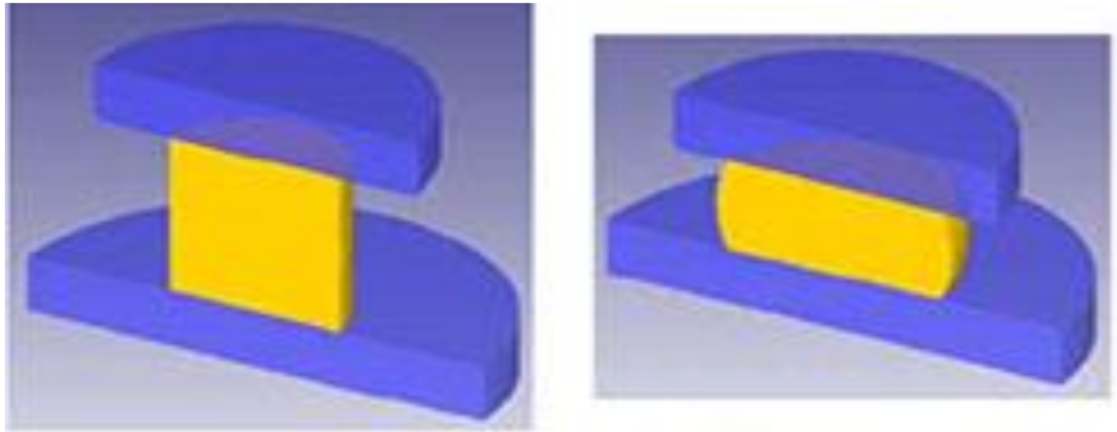
(We note that one horsepower =745.7 W):$\longrightarrow$ Power in hp $= \frac{207284}{745.7} = 277.97 = 278$ hp

Ring Rolling

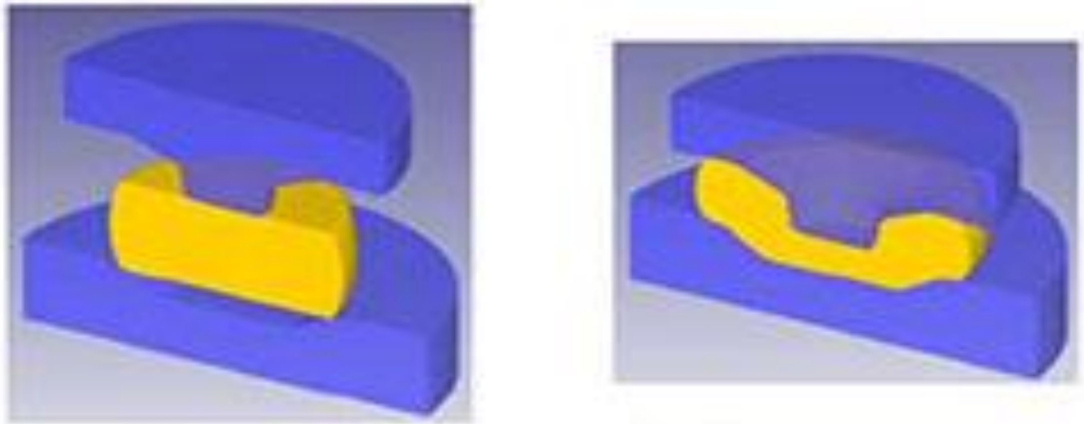
The ring rolling process can be performed with the material at high temperature (hot) or initially at ambient temperature (cold). Ring rolling is an advanced technique to manufacture seamless rings with flexible cross-sectional shape, improved grain structure, and minimal scrap.

The process and equipment are similar in principle to rolling mills used for plate production. Indeed in both processes the metal is rolled between two rolls which move toward each other to form a continuously reducing gap. In ring rolling, the rolls are of different diameters and geometries.

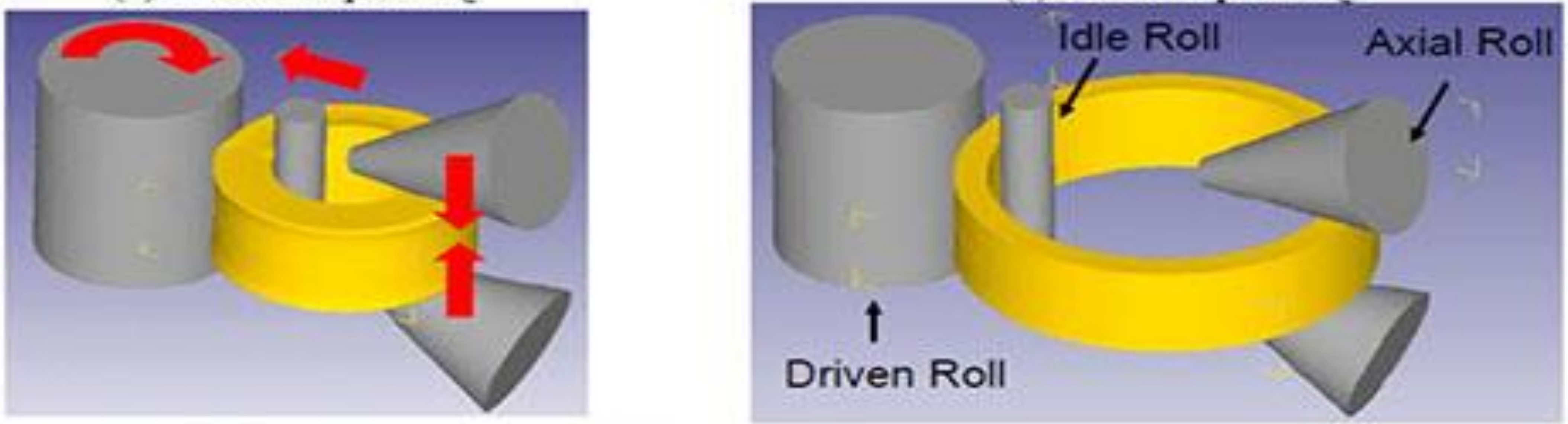
The ring rolling process is basically used in the production of railway wheels, anti-friction bearing races and different ring shaped work pieces for automotive and aerospace applications. The advantages of the ring rolling process include short production time, uniform quality, close tolerances and considerable saving in material cost.



(a) Preform upsetting



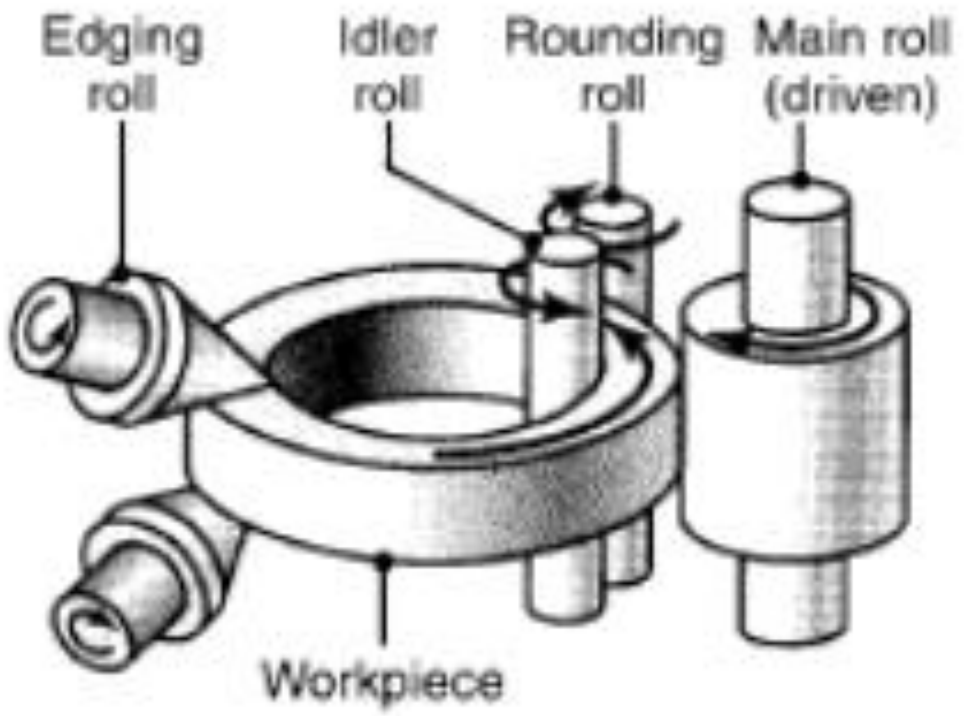
(b) Preform piercing



(c) Ring Rolling

As shown in figure, it begins with a forged bar that has been upset (a) and pierced (b) to obtain a hollow circular preform. The preform is placed over the idle roll that is forced toward the driven roll (c). At the same time, the axial rolls apply pressure in a direction parallel to the ring axis. So the idle roll reduces the width while the axial rolls reduce the height of the ring cross section.

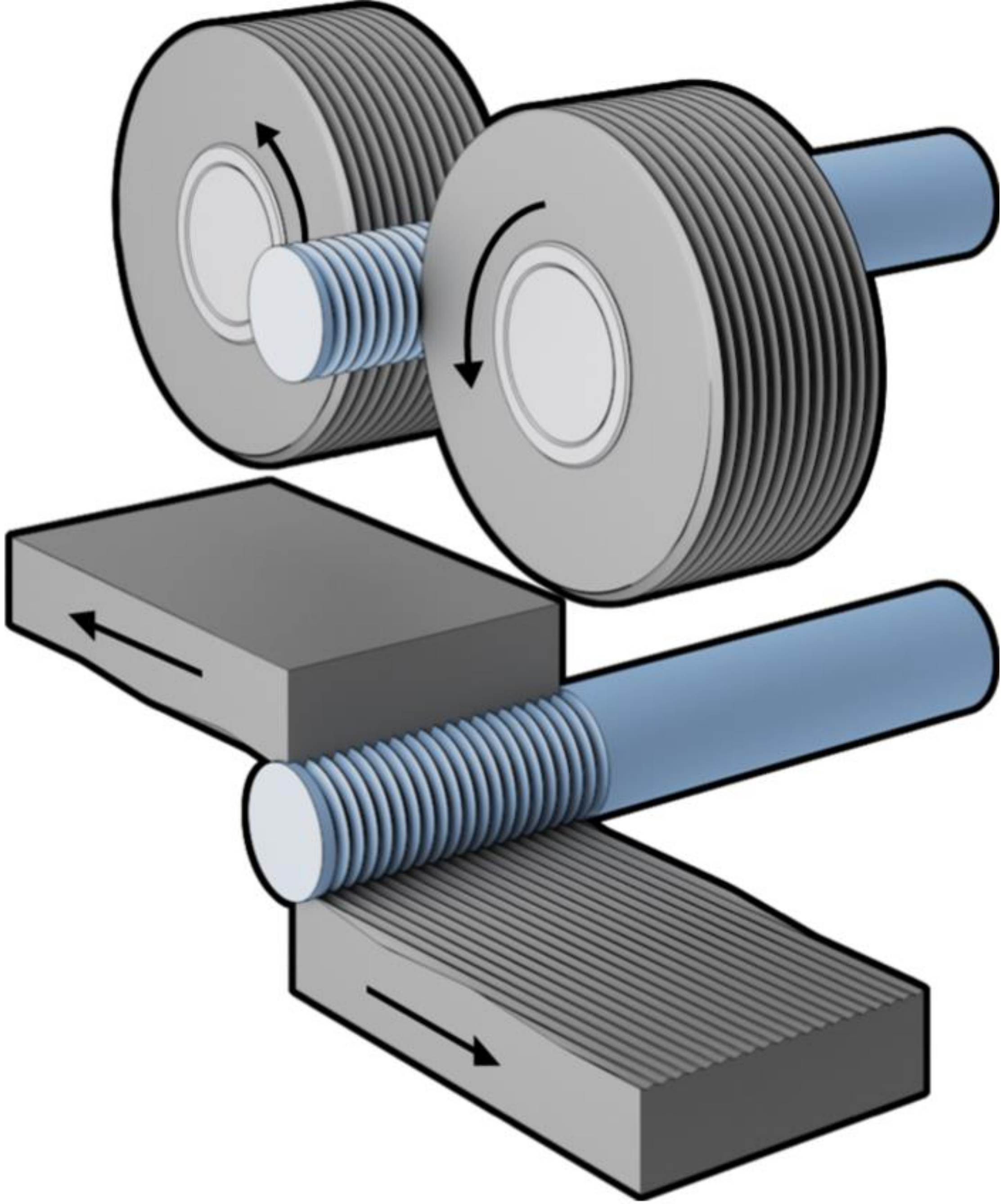
The coupled idle and axial rolls movement imparts the desired shape to the cross section and increase the ring diameter. The work piece starting section could have a rectangular or complex shape.



Ring Rolling

Thread Rolling

- Thread rolling is a cold forming process by which straight or tapered threads are formed on round rods or wire. The threads are formed on the rod or wire with each stroke of a pair of flat reciprocating dies. In another method, threads are formed with rotary dies. The thread rolling process has the advantages of generating threads with good strength (due to cold working) and without any loss of material (scrap). The finish produced is very smooth and the process induces compressive residual stresses on the workpiece surfaces, thus improving fatigue life.



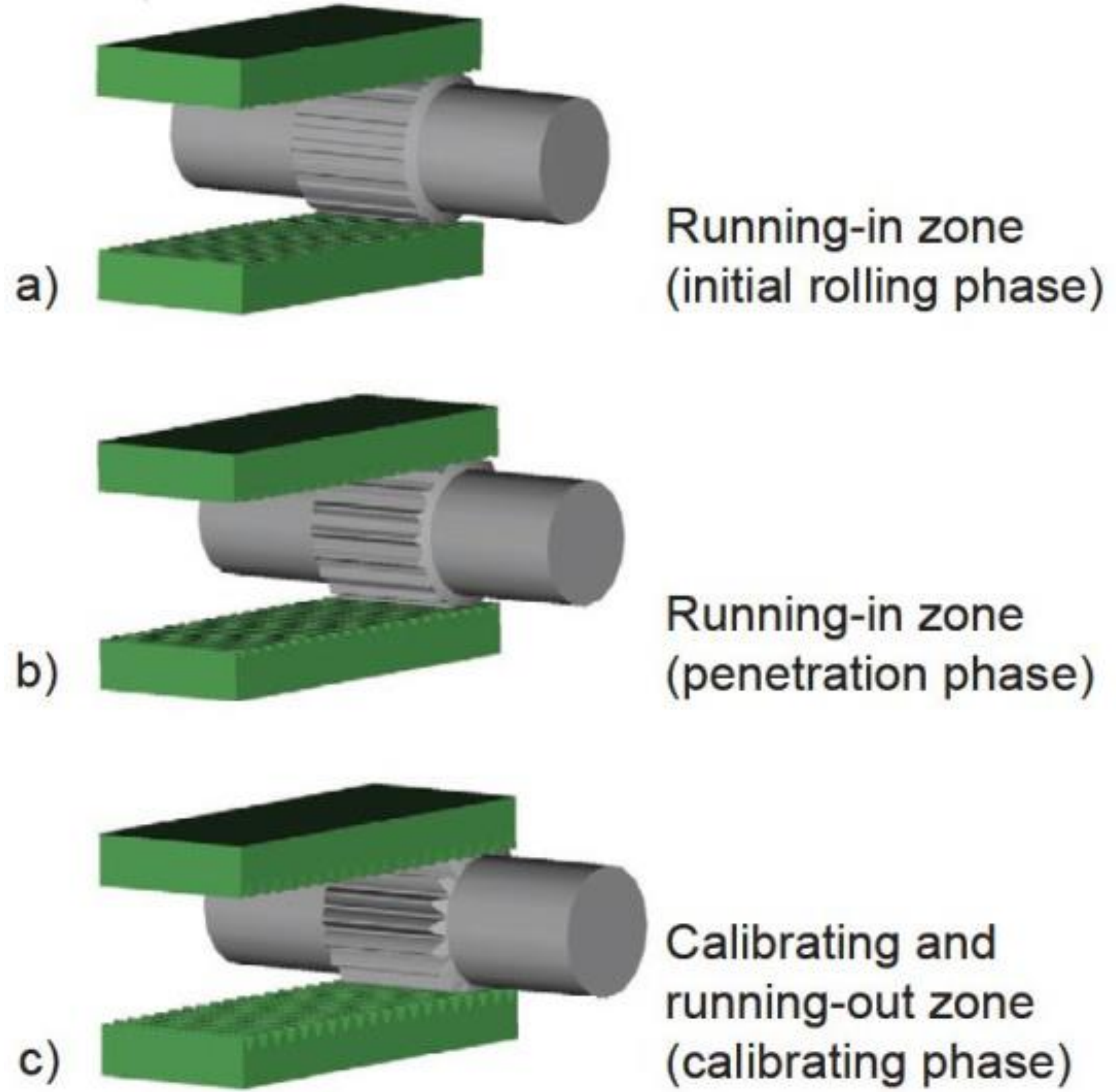
Thread rolling

Gear Rolling

The interest in manufacturing of gear wheels by gear rolling instead of conventional cutting methods like hobbing has increased in recent years. Gear rolling is not very well known, because of the complexity and need for more experiments and analysis to fully understand the nature of the process. There are not so many scientific publications directly looking at using this process as a gear production process.

Gear rolling can be performed in two different ways. The first way is to use flat tools (racks) as the forming tools. This is called the flat rolling method. The second way of gear rolling is to use circular toothed gears as tools. This is called the round rolling method.

In flat rolling, the tools have linear movement. The work-piece is in contact with both tools. The forming takes place in one course of movement of the tools against each other. The deformation is caused by the press load applied from the tools into the work-piece at the same time as the linear movement. The steps of the flat rolling are illustrated in Figure.



Flat rolling process steps

The flat rolling process includes three main steps to form a gear wheel from a cylindrical blank into a full teethed gear. The gear rolling is performed in three subsequent phases as below:

The initial step is to engage the work-piece and tools by applying a very small initial penetration from both sides. This first step ensures the contact between the tools and work-piece. This contact generation is necessary in order to force the material to be deformed in the next steps. The first step is known as the initial rolling phase in the literature as shown in Figure a.

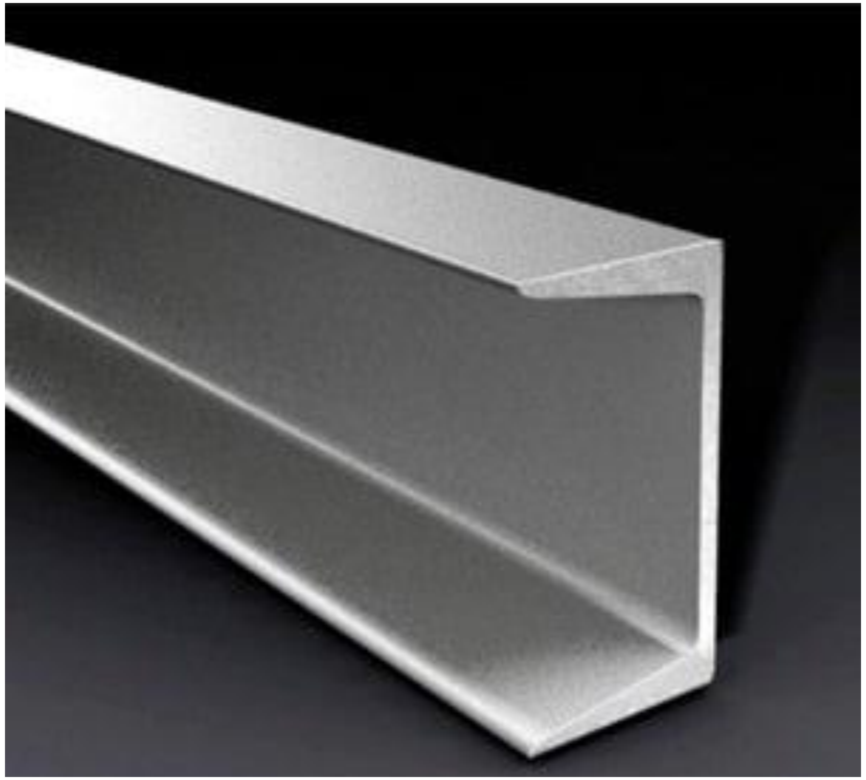
In the second step due to the linear movement of the tools in opposite direction and their gradual penetration into the work-piece large deformations occurs in the work-piece and it changes into a fully toothed wheel. This part is identified as the penetration phase in the literature as shown in Figure b.

The third phase of the flat rolling process is to calibrate the formed gear wheel. The calibration occurs when the tools moves just in linear direction and there is no additional penetration into the work-piece. This phase results in equal deformation of all teeth of the work-piece to finally get the right shape of the gear profile. This is called the calibration phase in the literature. The calibration phase is shown in Figure c.

Various Rolled Sections

1. Rolled Angle Sections

2. Rolled Channel Sections

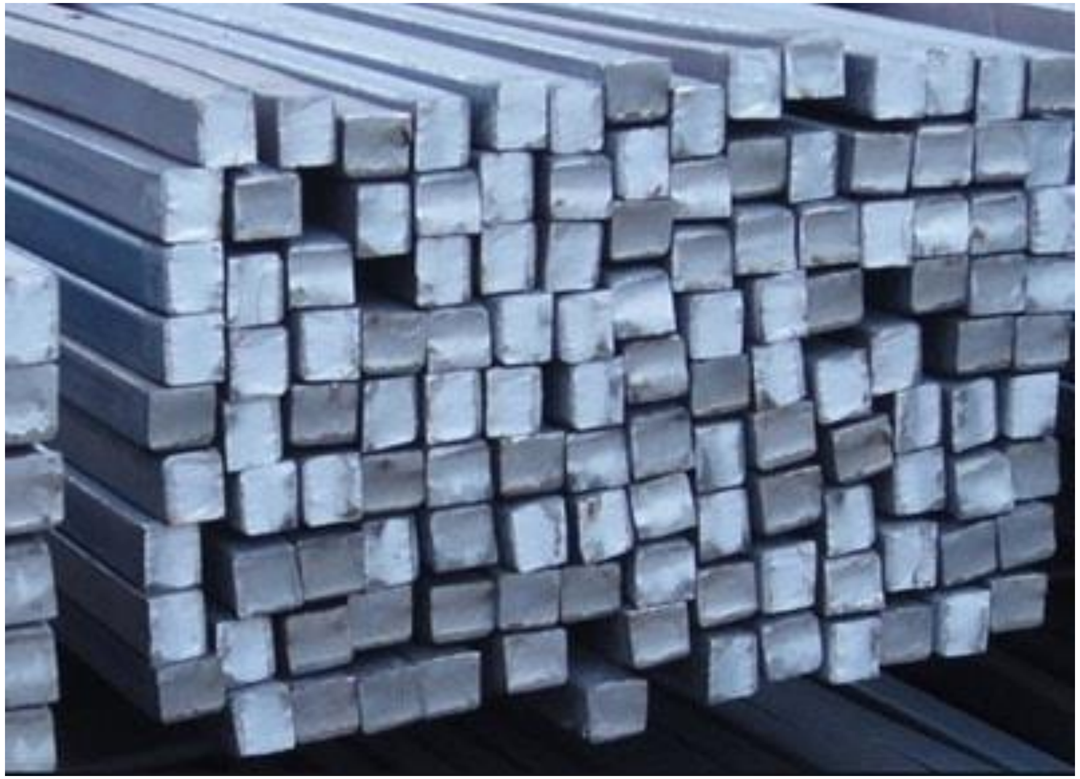


3. Rolled T- Sections

4. Rolled I - Sections

5. Rolled Round Bars

6. Rolled Square Bars



7. Rolled Flat Bars

8. Rolled Thermo-Mechanically Treated (TMT) Bars

DEFECTS OF ROLLING:

Following are the types of defects in rolling:

- Surface rolling defects
- Internal structural rolling defects

Surface Defects:

Surface defects can occur during the rolling process due to a number of factors such as uneven deformation, cracks, scratches, etc. The following are some common surface defects in rolling process:

- Scale Pits – They are cavities or depressions that appear on the material surface.

- Edge Cracks – They appear on the edges on metal stock due to excessive deformation.

- Scratches – They are caused due to abrasive particles or other debris on the surface.

Internal Structural Defects:

The following are some common Internal Structural Defects in rolling process:

WAVY EDGES CRACK:

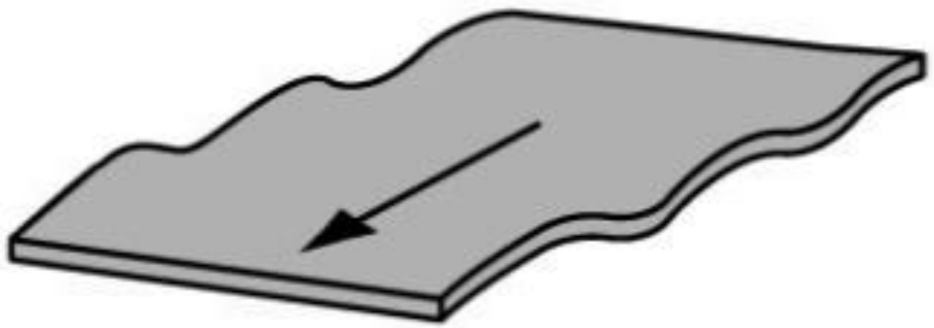
The result is thicker as the middle portion of the rolling part is bent or deflected by the compressive load. There are some different cases. Those are as follows.

•For the imperfection of the roll gaps, variation occurs on the rolling sheets.

•If the thickness varies and along with that volume and width are constant then the center is shortened than the edges. But the body is continuous.

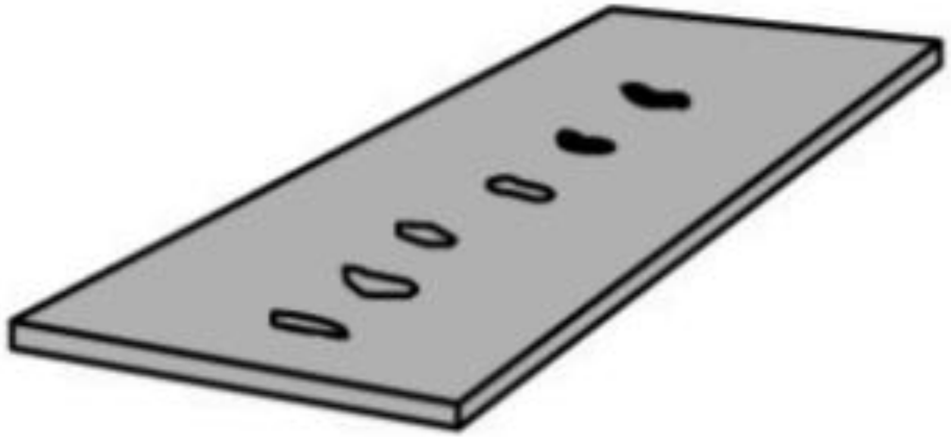
•The edges portions are in the compression and the center portion is the tension.

•The result of the edge is wavy.



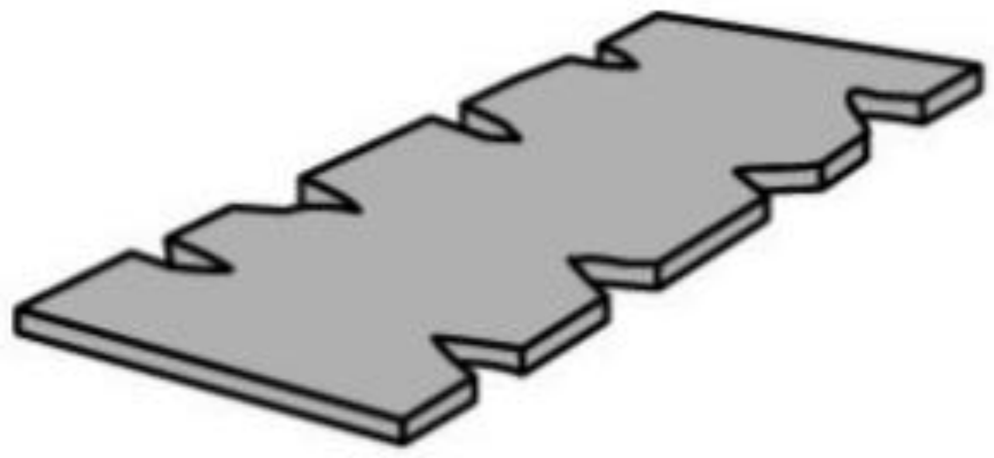
ZIPPER CRACKS IN CENTRE OF STRIP:

Zipper Crack is a type of Wavy Crack. If there is an uneven stress distribution on the strip, then the crack occurs in the centerline of the strip. It is called Zipper Cracks in the Center of the Strip. This crack looks like a zip so it is called Zipper Cracks.



EDGE CRACK:

Edge cracks occur when the hot rolls are cooled. It happens as excessive quenching effects on the strip. Excess water is used to cool the edges. The use of excess water might give result into unflatten strips. The edges of the metal gets rounded off as the friction force prevents the corners and increases the length of the center portion.



ALLIGATOR CRACK:

Alligator Crack is a type of cracking where the metal has any inclusions or weakness of metallurgy. As this crack separates the layers and increases the slab openings, it looks like the mouth of an alligator. Hence this crack is known as Alligator Crack.