Basics of Mechanical Engineering-2

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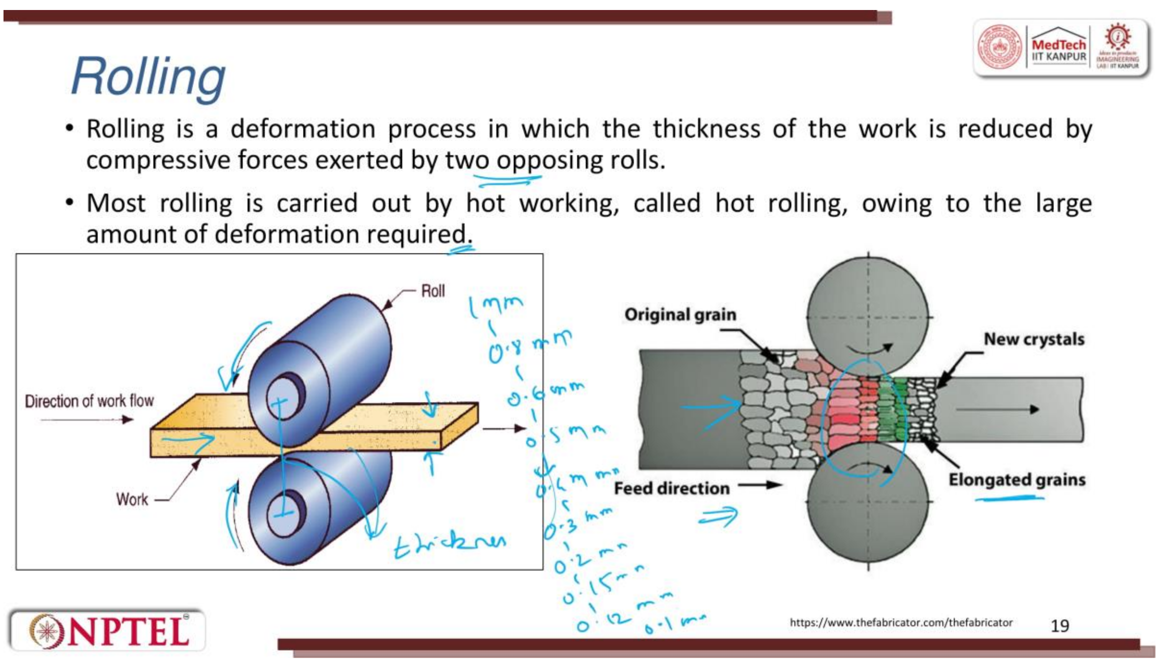
Week 05

Lecture 17

Basics of Forming (Part 2 of 5)

Welcome to the next section of the course.



Rolling is a deformation process in which the thickness of the workpiece is reduced by compressive forces exerted by two opposite rollers. So, one is rolling in this direction, and the other one will be rolling in the opposite direction. If both rolls move in the same direction, the input will not happen.

It is something like making sugarcane juice. You have two rollers. The sugarcane is fed inside, and when it is fed inside, you see the thickness reduces and the juice comes out.

So next time, what we do is take it out and then refeed it. Or what you can do is reverse the rollers.

Whatever thickness reduction occurs, you can pull it back and then try to reduce the thickness further. The thickness or the gap between the rolls is reduced. So, then what happens is the next squeezing occurs. Like this, you do it multiple times to get the best out of the sugarcane. The same thing can also be done multiple times.

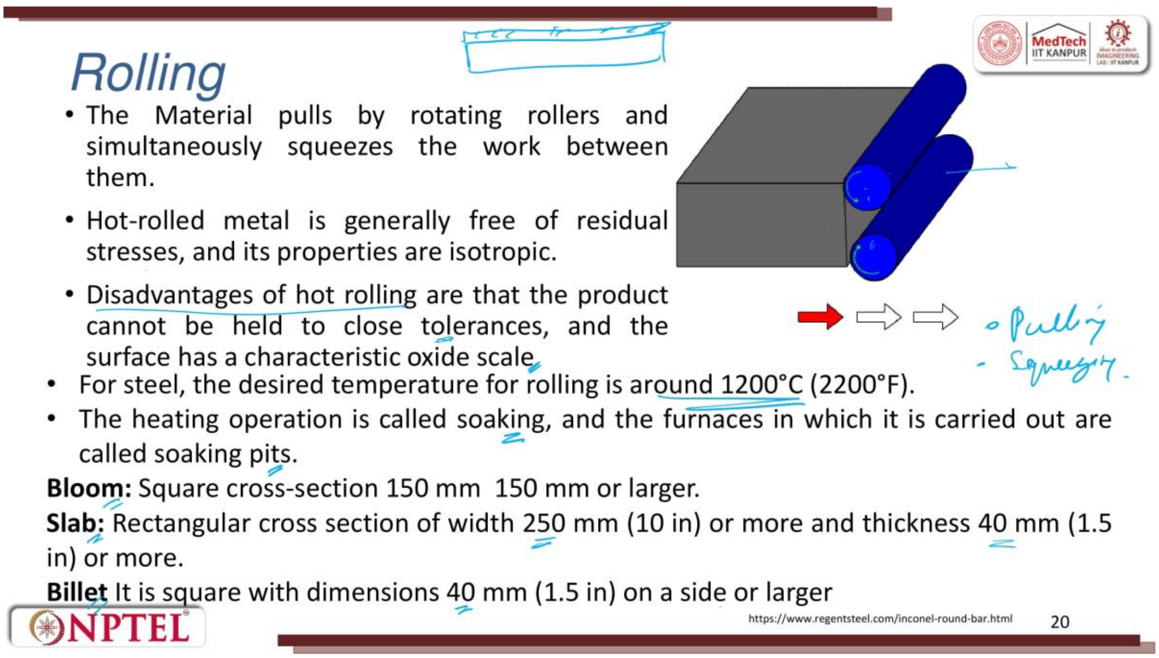
So, in each operation, you try to reduce it by a certain delta x. So, you cannot go from 1 millimeter to 0.1 millimeter in one shot. Because then it undergoes a strain hardening rate. And then, material feeding will also not happen properly. So, what we do is we go step by step.

First, we roll from 1 millimeter to 0.8 millimeter, then from 0.8 to 0.6 millimeter, then 0.6 to 0.5 millimeter. Then to 0.4, then to 0.4, then we go up to 0.3, then we go up to 0.2. Then we go up to 0.15, then we go up to 0.12, then finally we go up to 0.1. So, all these measurements are in millimeters. We go through multiple steps, right?

So, multiple steps mean each time the metal is out, we try to reduce the thickness, then feed it back in. So, you can do it like that, or what you can do is have a series of rollers placed one after the other along the length direction. And the reduction can be done that way; that is also possible. If you want a continuous process, then we put all the rollers in series, and it drags the material through. So, if you have only two rollers, then you have to do it one after the other.

Most rolling is carried out by hot rolling, called hot working, or by hot working, called hot rolling. Owing to the large amount of deformation required. If the deformation is very large and the forces are not sufficient, then we always heat the workpiece. So, this is the original grain which is there when you try to push it inside. So, the feeding direction is this; the rollers are moving in the opposite direction so that they bite and drag the material outward.

So, here if you see the original grains, the grains are getting elongated, and then new grains are formed when it comes out of the roller zone. So, this is the deformation zone; when it comes out, you get elongated grains—these are elongated grains—and new crystals are also forming.



Rolling, the material pulls by rotating rollers and simultaneously squeezes the workpiece between them. So, pulling—so here it has two things: one is pulling, another is squeezing. Hot-rolled metal is generally free of residual stress and has isotropic properties.

The disadvantage of hot rolling, as we have already seen, is that you cannot achieve very close tolerances, and there can be a possibility of oxide formation. So, why are we talking so much about it? Because these oxides, which are forming, are brittle in nature. So, they will form, and these oxides will be formed on the top. The oxides are brittle in nature.

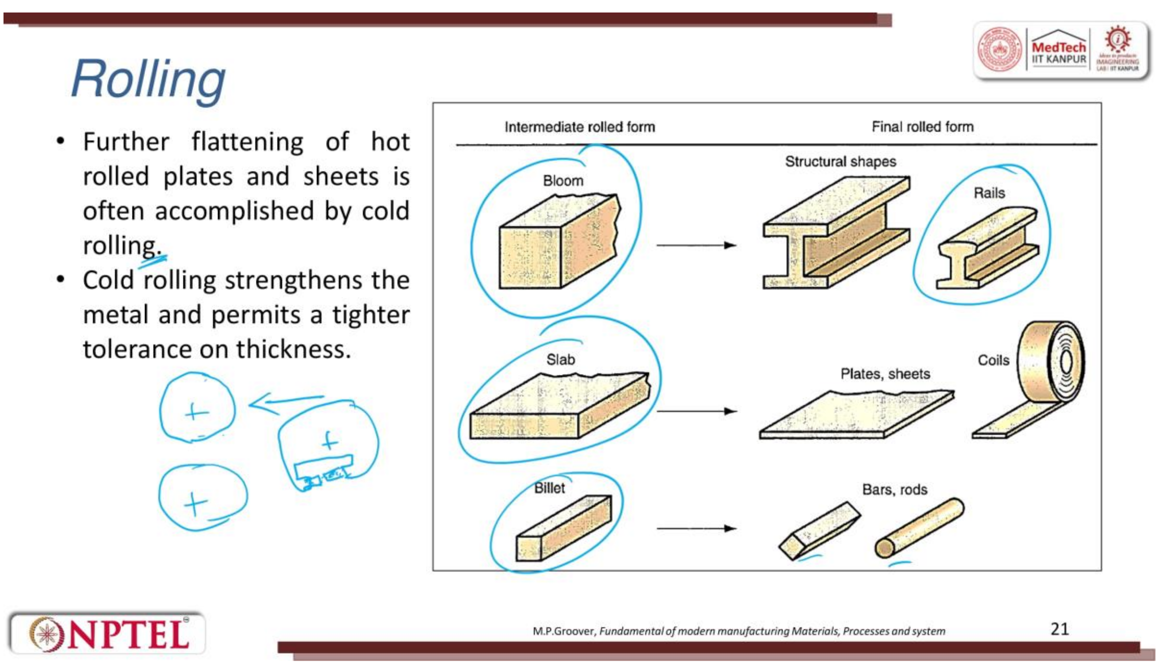
In the next time when you try to roll this, it will try to easily crack and this can scratch the roller as well as the workpiece. So, oxidation scales should be avoided. So, which becomes very common when we start working on hot rolling. For steels, desired temperature for rolling is around about 1200 degree Celsius. The heating operation is called a soaking.

We saw this in the previous chapter when we started looking into heat treatment, soaking and the furnace in which it is carried out is called as a soaking pit. Blooms, slabs and billets are different types of work pieces which are there. A bloom is nothing but a square cross section area of 150 millimeter cross 150 millimeter or larger. Slabs are rectangular cross section with a width of 250 millimeter or more and the thickness is 40 millimeter reduced. Earlier was 150 bloom, slab was 40 thickness wise I am saying and the width is expanded.

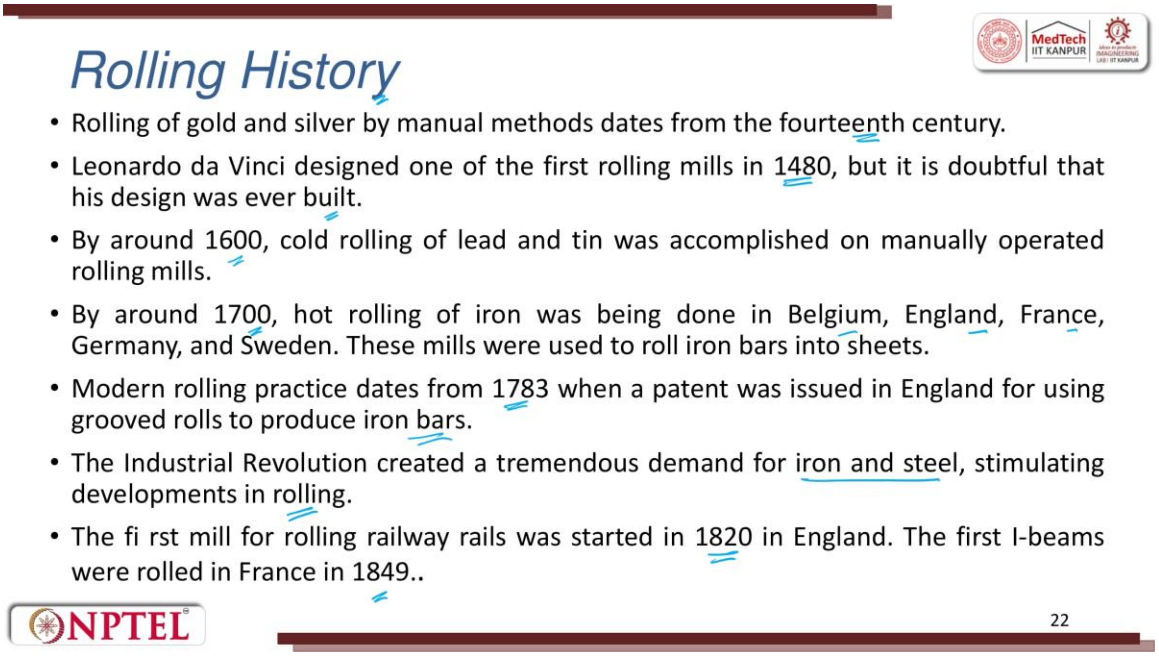
Now, when we talk about billet, it is a square of 40 mm on the sides or larger. So, the bloom is large, billet is small, slab is much small. So, that is what we are trying to say. So this is a bloom, this is a slab and this is a billet. From this, by a rolling operation, you can try to produce I channels.

We can try to produce railway tracks. So, how do you do that? So, if you try to do the cross-section area, this is the roller. When you look from the side, this is how the roller looks. So here, when we look from the front, what will happen is you will see they will have something like this—the roller.

So, this will try to bring this structure. The roller cross-section is changed so that you can get the required output. In slabs, it is straightforward. So, rails are made from blooms by a rolling process. Then, slabs can make coils, plain sheets, and all these things out of it. Billets are bars, and rods can be made for operation.



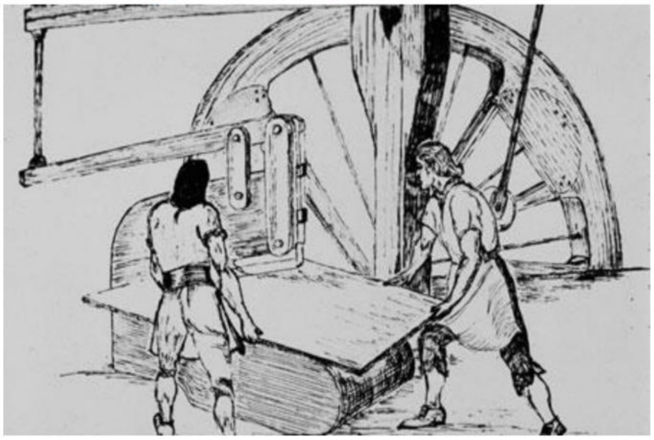
Further flattening of hot-rolled plates and sheets is often done by a cold-rolling process. Major changes in shape are done by hot rolling, and then further you can do it by cold rolling. So, cold rolling strengthens the metal and permits tighter thickness tolerances. So, hot rolling did not happen now; it has a history.

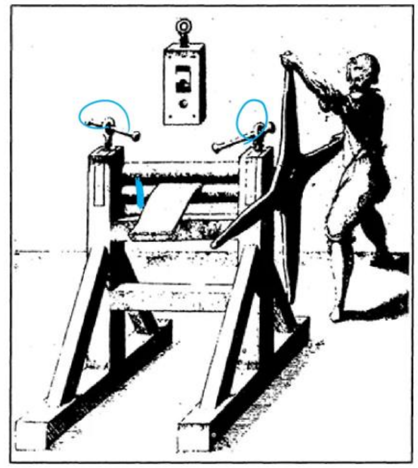


The rolling of hot gold and silver by manual methods dates from the 14th century. Leonardo da Vinci designed one of the first rolling mills in 1480, but it is doubtful that his design was ever built. Around 1600, the cold rolling of lead and tin was accomplished by manual operation of rolling mills. By 1700, hot rolling of iron was being done in Belgium, England, France, Germany, and Sweden. In Europe, it typically happened.

These mills were used to roll iron bars into sheets. Modern rolling practice began in 1783 when a patent was issued in England for using grooved rollers to produce iron rods or bars. The Industrial Revolution created a tremendous demand for iron and steel, simultaneously advancing the development of rolling processes. The first mill for rolling railway rails was established in 1820 in England. The first I-beam was rolled in 1849 in France. So, you see, casting has a very long history. It started from BC and then continued into AD. But rolling started, with evidence only in the AD era.

Rolling History





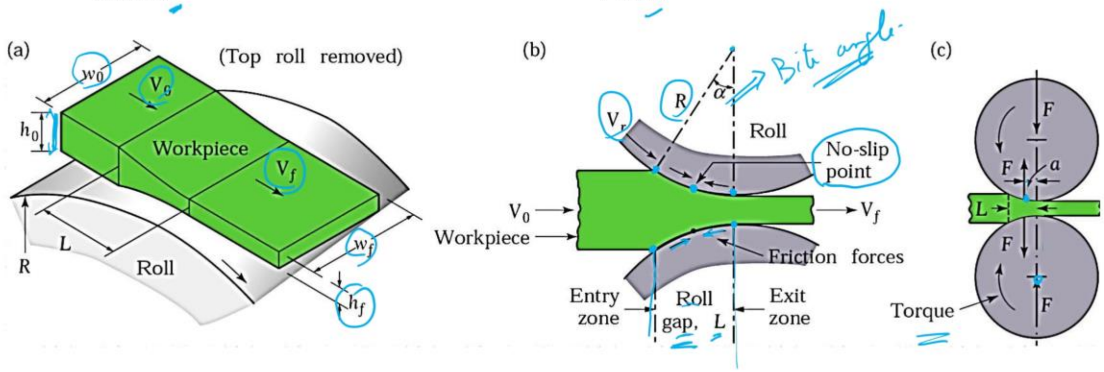
https://steelmuseum.org/206_Mill_Exhibit_2018/early_history.cfm
https://www.perlego.com/book/1579280/cold-rolling-of-steel-pdf

So, this was the initial roller that existed, and this is the slight advancement we have. So, you had a flywheel. This flywheel is rotated to create to give a huge impact. So, that is done. So, then rollers were also done. Even today when we wanted a sheet bending operation. We have these two arms which can reduce or increase the spacing here. And then we try to apply load manually and then get the output done.

Flat Rolling

It involves the rolling of:

- Slab
- Sheets
- Strips
- Plates



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When we talk about flat rolling, it involves the rolling of slab and sheet. So, this is a roll. This is the input material height. This is the width.

V0 is the velocity with which it is pushed inside. vf is the velocity with which it comes outside. H0 is transformed into Hf. v0 is transformed into wf. So, moment there is a reduction in the thickness, there will be an expansion in the width.

So, input v0 and vf will not be the same. So, when we try to look at further details, this is the roll we have, which has a radius of r. The velocity with which the roll rotates is called vr, right. And there is an angle which we have marked here. This is called the bite angle. Okay, bite which chews and pulls it inside, the bite angle.

So, you can see here there is an entry zone, and there is an exit zone, right. So, here you can see there are tensile and compressive loads which are getting applied at this point. The distance from the entry to the exit zone is called the rolling gap, L. And from the start to the end, from the entry zone to the exit zone, in between you have a point which is called the no-slip point. We have a point which is called the no-slip point.

This is very important. So, entry zone, exit zone, no-slip zone, no-slip point, and then you will have a gap, the rolling gap of L which is there. So, now when the roller has to be rotated, there has to be torque which is given to the roller, which is attached to a motor. So, this gives the torque F. This is the length L, which we have said, the roll gap L, and you can see here this is the α.

So this is the neutral point. So you can see F compressive acting here and entering inside; you will have a small tensile which rejects here. So at this point, you will have a no-slip point. So in rolling, we can make slabs, sheets, strips, and plates.

Rolling Analysis

- In flat rolling, the work is squeezed between two rolls so that its thickness is reduced by an amount called the draft.

$$d = t_0 - t_f$$

Where, d=draft (mm)

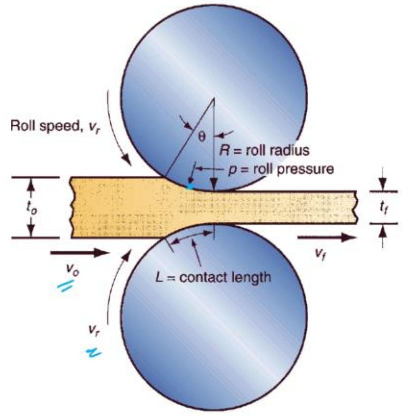
t_0=starting thickness (mm)

t_f=final thickness (mm)

- Draft is may be expressed as a fraction of the starting stock thickness, called the reduction(r)

$$r = \frac{d}{t_0}$$

- Increase in the width of work in rolling is termed as spreading(w).



Rolling Analysis

- In rolling ,conservation of matter is preserved, so the volume of metal exiting the rolls equals the volume entering:

$$t_0 w_0 L_0 = t_f w_f L_f$$

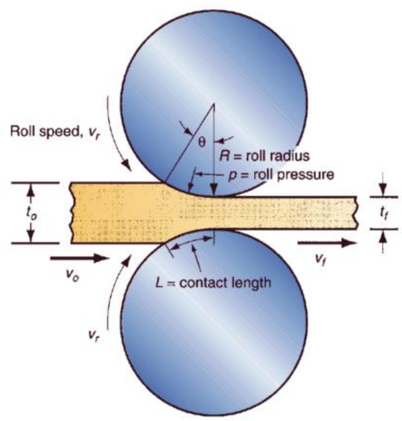
Where,

w_0 , L_0 are starting width and length,

w_f , L_f final width and length respectively.

- Also in rolling process before and after volume rates of material flow must be the same , if v_0 and v_f are the entering and exiting velocities of the work(in m/s), then:

$$t_0 w_0 v_0 = t_f w_f v_f$$

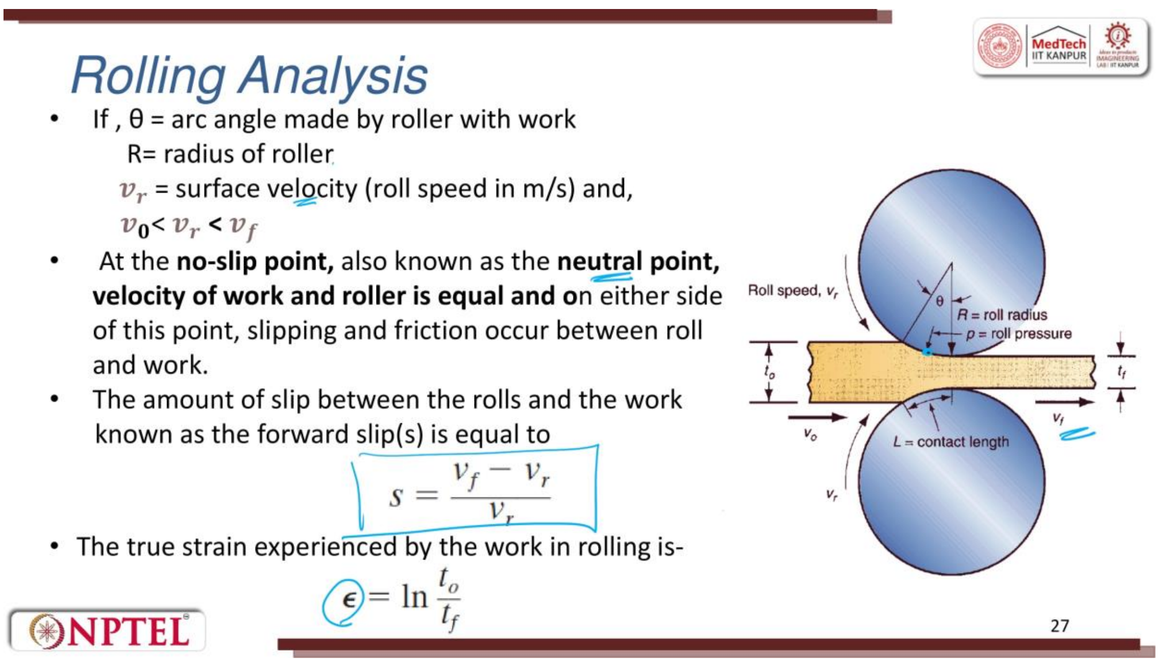


So, a little bit of analysis if we do. So, in flat rolling, the work is squeezed between two rollers so that the thickness is reduced, and the amount of reduction is called the draft. Draft d = t original - t final. So, t0 is the starting thickness; tf is the final thickness. The draft may be expressed as a fraction of the starting stock thickness. So it can be in terms of a reduction R, which is nothing but d/t0.

You can have it as a reduction R. The increase in width of the roller by spreading is called w. We have seen everything here: theta, the rolling radius is r, the bite at this point is called the neutral point. And here, the roller pressure with which it is entering inside is called P. And then you have a contact length L. The velocity of the rolls is vl; the velocity with which the component goes inside is v0, and t0, tf, vf.

So in rolling the conservation of matter is preserved. So that means to say the input equal to output. So volume consistency happens. So the volume of the metal exiting the roller equals the volume entering in. t0 w0 L0 =tf wf Lf.

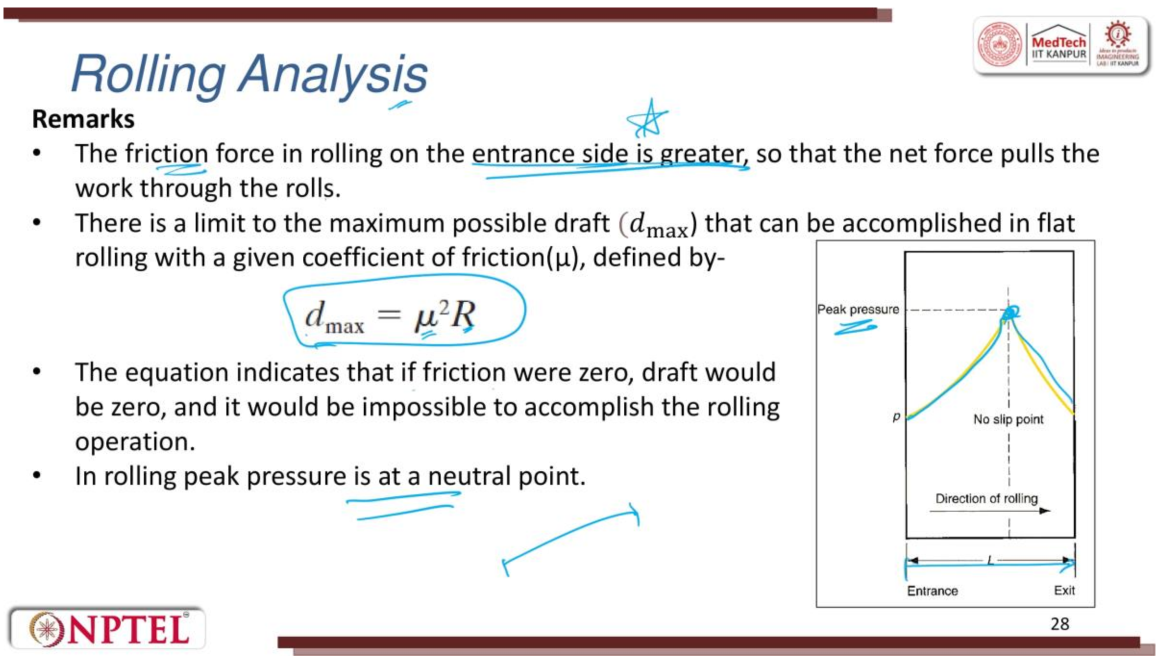
The length will increase, width will increase, the thickness will reduce. Okay. Also in rolling process before and after the volume rates of material flow must be the same. So v0 = vf. So t0 w0 x v0 = tf wf x vf.



So, θ = arc angle made by the roller with workpiece, r is the radius of the roller, vr is the surface velocity, v0 will be lesser than vr which will be lesser than vf.

At the no slip point is known as the neutral point, the velocity of the work and the roller is equal on either side of this point. The slipping and friction occurs between the roller and the workpiece. See the amount of slip between the roller and the workpiece can be evaluated by the forward slip.

S = vf is the output, vr is the roller velocity. The true strain expressed by the work rolling is $\epsilon = \ln \frac{t_o}{t_f}$

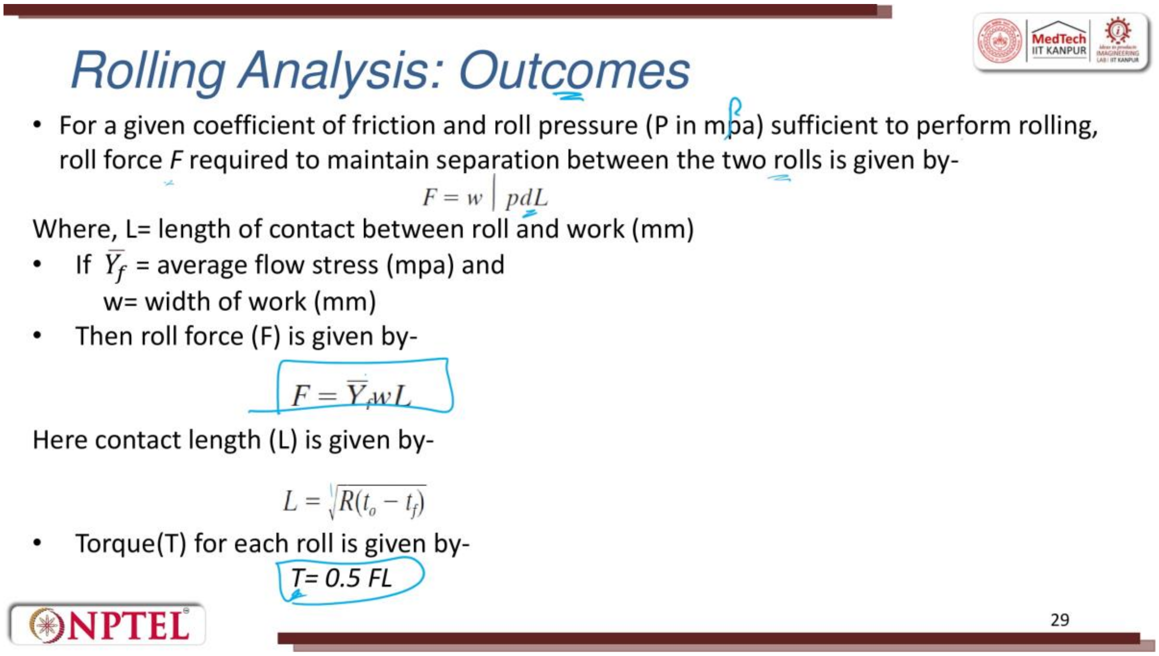


So, when we talk about the rolling analysis, the friction force in rolling on the entrance side is always greater; on the entrance side, it is greater. So, the net force pulls the work through the roller. So, the friction force at the entrance side is greater—an important point. So, what happens is that it can be pulled; there is a limit to the maximum reduction. You can have

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

Where μ^2, is the coefficient of friction, and r is the roller radius. So, the equation indicates that if the friction were zero, the draft would be zero. It would be impossible to accomplish the rolling operation. So, if the friction force is zero—if I put lubricant, bringing it to zero—then dmax will just slip, and nothing will happen. So, the rolling peak pressure is always at the neutral point.

This is also very important. At the no-slip point, the peak pressure—the rolling pressure—will be very high. This is the L. What is L? Start to L. This is the rolling pressure. A gap—whatever we saw that. This is gap L.



So, what are the outcomes? If, for a given coefficient of friction, and rolling pressure, sufficient to perform rolling, force F is required to maintain the separation between the two rollers. So,

$$F = w \int pdL$$

So, the rolling force can be calculated as

$$F = \overline{Y}_f wL$$

So here,

$$L = \sqrt{R(t_o - t_f)}$$

It is a simple calculation. You can try to find out what the torque force required for a roller will be, given that it can try to deform.

Rolling Analysis: Outcomes

- The power required to drive each roll is the product of torque and angular velocity($2\pi N$).
- Thus, the power for each roll is -

$$2\pi NT$$

- As a rolling mill consists of two powered rolls,

  Then-

$$P = 2\pi NFL$$

Where N is speed (rpm)of roll.

So, the power required—since we know the torque—from there, we calculate the power. So, the power required to drive each roller is the product of torque and the angular velocity, 2 pi N. So, the power will be equal for each roller to 2 pi NT, as the roller mill has two powered ones. So, the power is equal to 2 pi NT FL. So, N is the rolling speed.

With this what we can do is we can try to figure out what power you should apply for a rolling operation to try to deform from this thickness to this thickness. As I told you earlier, the reduction cannot happen in one shot. So, what we do is we try to have these rollers multiples. So, when these rollers are kept one or the place where they are kept or the machine is called as a rolling mill. Various rolling mill configurations are showed for various applications.

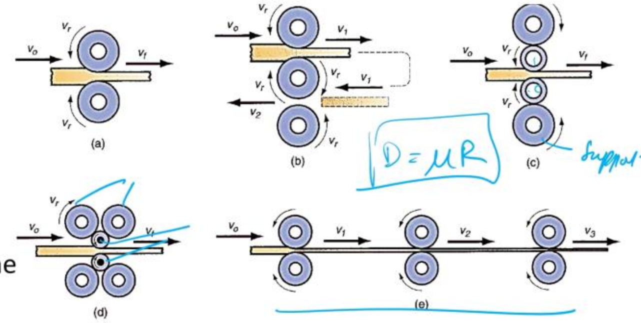
So, what we do is in order to see the friction the draft is equal to mu into R naught. So, there is a limitation reduction of this thing R naught right this is the roller radius. So, that is why we also try to reduce the roller radius so that you get a draft reduction.

Rolling Mills

- Various rolling mill configurations are used to deal with various applications and technical problems in the rolling process.
- Various configurations of rolling mills:

(a) 2-high
(b) 3-high
(c) 4-high
(d) Cluster mill, and
(e) Tandem mill.

- increasing the roll mills, increases the total force on the forming sheets.

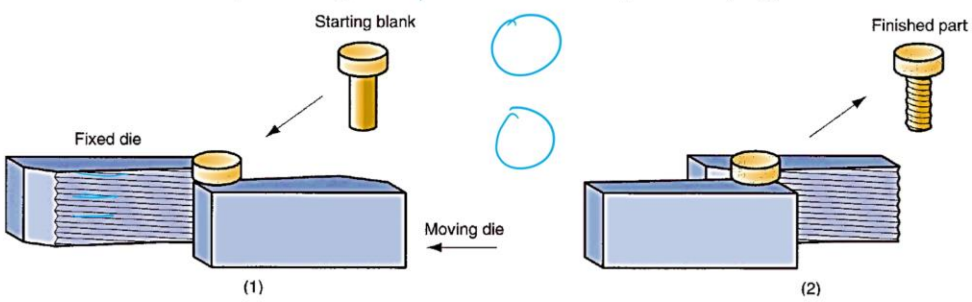


- Owing to the high roll forces, these smaller rolls would deflect elastically between their end bearings as the work passes through. The larger backing rolls were used to support.

So, the rolling mills can be 2 mill, 3 mill, flow 4 mill or cluster of mills. Or tandem, this is called as tandem mills. Increasing the rolling mill increases the total force read on the forming sheet. Owing to the high rolling force, these small rollers would deflect. So, we have supporting rollers on the back. That is what these rollers are called as supporting rollers. Same way here, supporting, these are supporting rollers.

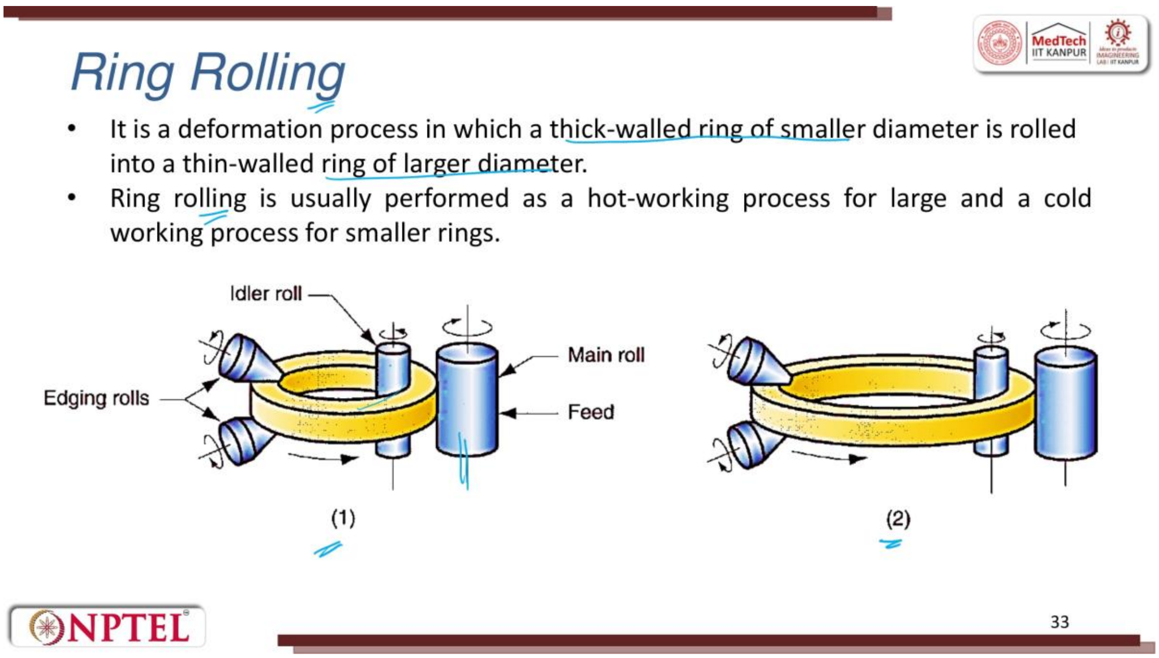
Thread Rolling

- It is used to form threads on cylindrical parts by rolling them between two dies.
- It is used for mass-producing external threaded components (e.g., bolts and screws.



The rolling, we can also make threads. So in the die, if you have this threads made, so your screw is kept there. It is just rolled. So rolling need not be always cylindrical. You can also make flat.

If the geometry is given, you roll it one shot, you get the output. So you get the finished one. So, it is used to form threads or on cylindrical shafts by rolling between the two dies. It is also used for mass production of external threads. This is thread rolling. So, modification of the roller you can try to get the output.



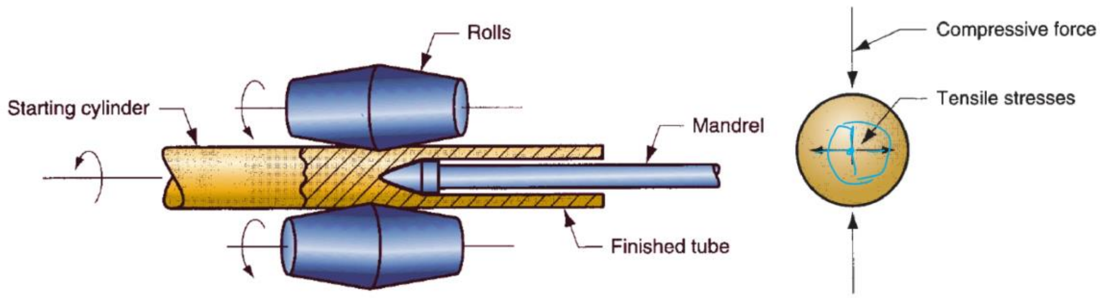
There is a variation which is called as ring rolling. If I have to produce rings of a large diameter, we start with a smaller one and we keep expanding. So, here what we do is we have two edging rollers, then we have one ideal roller, one roller which is attached. So, this is attached to the feed.

So, here what happens is these two rollers, the edging roller, will try to squeeze and reduce the thickness. So, when it reduces the thickness, the ring expands. So, when the ring expands, it has to maintain the geometry. So, we use an ideal roller and a main roller. So, you can see here how the ring expands.

High-strength rings, which are used for aerospace applications, are made by ring rolling. It is a deformation process in which a thick-walled ring of a smaller diameter is rolled into a thin-walled ring of a larger diameter. Ring rolling is a very interesting process; it has a lot of applications. In boilers, the rings are also made using a ring rolling process.

Ring Piercing

- Roll piercing is a specialized hot-working process for making seamless thick-walled tubes.
- It utilizes two opposing rolls, and hence it is grouped with the rolling processes. The process is based on the principle that when a solid cylindrical part is compressed on its circumference.



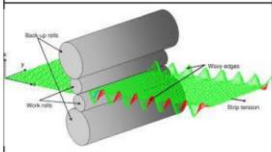
There is also a ring piercing process. See, if you wanted to use rollers, pierce it, and form a tube. This is the starting material. You have a mandrel which pierces it. This piercing will try to bring in a tensile load, and this will try to have a compressive force on the top. So here, there will be a crack that is formed, and you will try to have a hollow shape.

So, the rolling piercing is a specialized hot working process for making seamless thick-walled tubes. Seamless tubes are tubes where there is no seam. If you take an ordinary sheet and roll it, you will have something like this, right? So, then finally, what you do is you try to weld it. So, these are all seamed tubes.

So, seamless tubes are made by a rolling process. So, two rollers are there in opposite directions, hence it is grouped into the rolling process. The process is based on the principle that when you try to squeeze it, there is compression. So, at the center, there will be tension. So, you push a mandrel, and it tries to form a pipe.

You can also have other applications; corrugation can also be done. But rolling is also not straightforward; it produces a lot of defects.

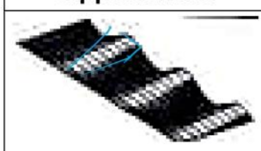
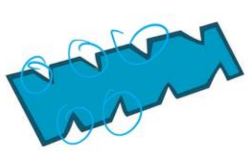
Rolling Defect

Appearances	Type of Defect	Causes	Corrective Action
	**Center Buckle** The fibers at the center are longer than its edges.	If the cold and hot roll mills have too much crown, the mill will roll out the	
	**Wavy Edges** Fibers at the edge are longer than the center	Result from concave roll bending and elastic deformation.	Hydraulic jack are used, which control the elastic deformation of rolls according to requirement.

So, in appearance, it will be like this. So, this one is called center bulging. So, if the cold or hot roll mill has too many crowns, the mill will roll out and have a central buckle.

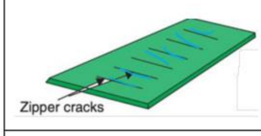
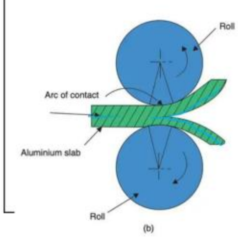
This is a waviness which is created because of residual stresses that are present. The fibers at the edge are longer than the center ones. So, it tries to create the waviness. So, these are some of the defects which come out of the rolling process. So, in the appearance, you will have this.

Rolling Defect

Appearances	Type of Defect	Causes	Corrective Action
	**Bed Leveling** The length of fibers are increase from one edges to another		
	**Edge Crack** Various crack and metal cutted- pieces at the edge of the metal sheets.	Secondary tensile stresses induced at the work piece surface by inhomogeneous defect.	Roller levelling or stretch leaving under tension using edge rolls

These are bed leveling and these are edge cracking. Because there is not sufficient material, there will be tensile and compressive forces. So, you will get this edge cracking. So, the length of the fibers is increased from one edge to the other. So, it is almost like a taper also; you see it is a taper bed leveling, and then edge cracking is this. So, these are the defects, these are the causes, and these are the corrections which are made.

Rolling Defect

Appearances	Type of Defect	Causes	Corrective Action
	**Zipper Crack** Small uniform crack in the middle of the metal	Occur due to high tensile stress	Cambering of can prevent such defect.
	**Alligator Crack** Separation of the layer giving rise to opening of the slab which looks like an alligator mouth in opening position	Secondary tensile stresses induced at the work piece surface by inhomogeneous defect.	Roller levelling or stretch leaving under tension using edge rolls.

NPTEL

https://www.sciencedirect.com/science/article/pii/S0020768315001596

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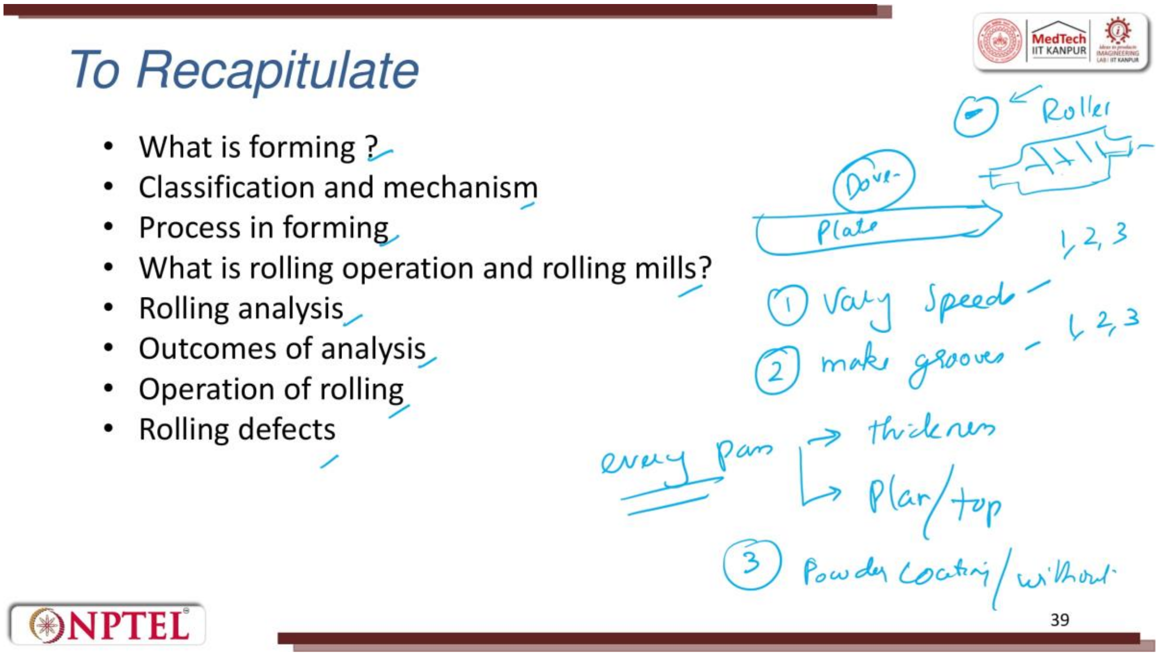
You can also have zipper cracks; these are cracks which are seen all along the line, and you can also have something like an alligator crack. So, the contact is there, and once it rolls and comes out, it forms a crack like this. So, these are all due to improper stress-strain application or the process parameters, the velocity, roll pressure, everything. So, if we start optimizing this, we can try to reduce it.

So, the camber on the can prevents the defects. So, these are central splitting. This is alligator crack, and this is central splitting, which can happen.



To recap, my friends, in this lecture, we saw what forming is. Then classifications and mechanism, the process in forming.

What is the rolling operation and rolling mills, rolling analysis? We saw outcome analysis, operations of rolling, and rolling defects, okay. So, this will try to give you a very good idea about the rolling process in metal forming. I am going to give you a simple job which is to be done. Please try to take dough and then try to take a roller.

So, if I put the side view of a roller, it will be something like this. So, this is a flat plate; this is the dough. Now, you take the roller; this is a roller. Now, the roller, you will try to vary the speeds of rolling faster, right? So, vary the roll speeds by three levels, one whatever it is in your level you can do.

Next, you will try to make some grooves on it, make grooves on it. And then you try to roll at 1, 2, 3 speeds. After every pass, try to measure the thickness by using your smart mobile phone. On the side area, you can try to take the thickness. And also try to take a photo in the plan view or from the top.

You will see several different shapes getting formed. So these shapes are nothing but defects, and once you do this exercise, you will have a perfect understanding of what the process parameters are and how they affect the raw material. And you should also try to have one last example. That when we try to do this dough, first you give a powder coating on the flat plate, and next you do something without a powder coating.

Powder coating is given, one with powder coating and then without. You see the surface and what happens. When you do this exercise at home, you will completely understand and appreciate the rolling process.

References

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These are the references which we have used.

Thank you so much.