Fundamentals of Material Processing (Part- II)

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Lecture - 20
Effect of Friction in Rolling

Welcome back. This will be the last lecture for this module which is metal working, and in this we were discussing about friction. We have looked at all the various aspects of friction particularly the deleterious effects.

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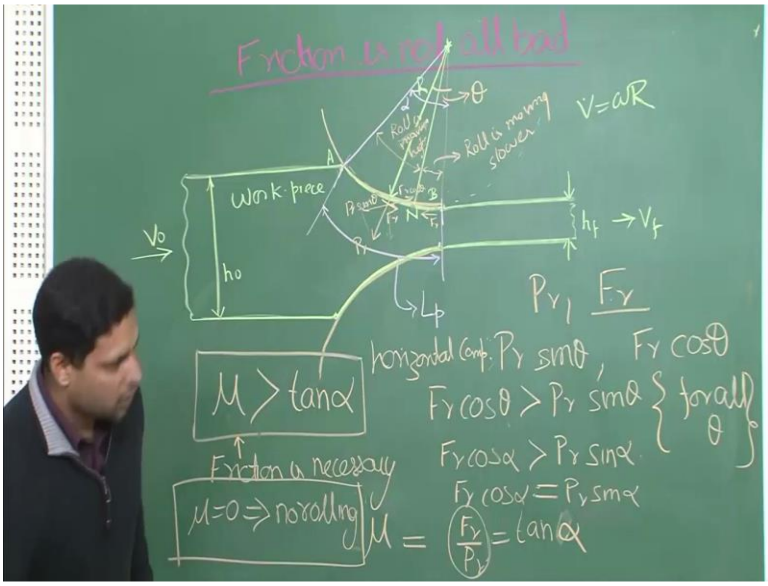

Now, what we are going to look at is that friction is not all bad; there is a role of friction. And you will see that if friction did not exist you would not be able to do rolling which is one of the most ubiquitous process used in metal industry. And we will begin like I said with example of rolling. So, let me draw a schematic of rolling. Let us say these are the two rolls, and this is our material which is being deformed, so it is gradually getting reduced. This is the point of entry, and it moves on this point which is the exit point. So, this is our work piece which has a height let us h naught, it is moving at a velocity v naught. After rolling it heights become h f height final and it has a velocity v f.

This is the point at which entering the roll and these are the points where it is exiting the load roll. So, I will give these two particular points as level, so this one is A this one is B. And this is the roll I have not drawn it completely, but somewhere over here you will have the center of the roll. Now look at the roll and the fact that the material is moving. What is the velocity of the roll at the surface? It will if the angular velocity is omega then the linear velocity will be equal to omega R let say this is the radius R. So, v is equal to omega R is the constant velocity of the roll across this length.

But, if the metal piece moving with the constant velocity; at this particular point if you look it will be moving it with a velocity v naught. At this point if you look it will be moving with a velocity v f. And which one will be larger, this has a larger area and this has a smaller area, and if we take into account the constancy of volume we can write this relation b h naught v naught is equal to b; b is that dimension in the third dimension b h f v f. From here we can see that v f is equal to h naught by h f times v naught. So, this ratio is greater than 1 it means v f will be greater than v naught.

So this velocity is larger, this velocity is smaller. And, if you look at the different points or even at different points we can have b h v I, where h will be the cons instantaneous height, v will be instantaneous velocity, and b will be the third dimension. So, at each and every point you have a height you have a velocity, and the velocity will keep increasing with the gradual decrease in the height. So, velocity at this point is v naught, but it is continuously increasing as it goes on to this point h f. It means that the velocity of the work piece is not same as velocity of the roll, at least for most of the point. There may be one point and there is actually just one point where velocity is equal, and that point is called as a neutral point N.

So before this if you look the roll is moving slower to work piece, sorry roll is moving at a higher speed; because, over here the velocity is gradually increasing and at some particular point it will gain the same velocity as the velocity of the roll. Beyond this point let say this is the connected line up to this point roll is moving slower. Now, again let us go back and look at this; so there is some pressure or load Pr that is acting onto this particular point. So there is a Pr, and simultaneously there will be a frictional force. What will be the direction of that frictional force? The frictional force would be acting in this particular case because here the roll is moving at a higher speed, so it is trying to pull the material to the outside. So, the friction is acting in this direction. And what will happen to this friction force after the neutral point? It will start to act in the reverse direction.

So, the friction force here is acting in this direction, the friction force is acting over here in this direction, and the inversion point is our neutral point. And this is our Pr which is. So, let me define Pr is our rolling load, and if you take the vertical component of this which will be called P vertical component of Pr, what will that be. So, you have a Pr which is pressure Pr that load Pr that is acting in this direction, so it will have some contribution also in this direction. And what will that actually be trying to do, it will be trying what it will trying to do is actually not only pushing or deforming the material, but it is also pushing away the two rolls. So, it is also called as separating force.

So, this is the geometry for rolling. Now over here let us try to understand; how will the pressure vary across the contact length. What is the contact length? So let me come back here again this is the point at which it starts to get in touch and it is this point where the material exits. So, this total length is called contact length or L p. And there is a geometrical way or relation to calculate L p in terms or R and the angle alpha.

So, if this is what will be alpha here, alpha is the total angle subtended onto this contact length. In terms of the radius R of the roll and contact length alpha you can calculate L p. And what we are trying to do is, trying to find out how is the normal pressure acting along this contact length. You remember when we talked about friction we saw that in that disc the normal pressure was not uniform. It also so happens to be the case over here.

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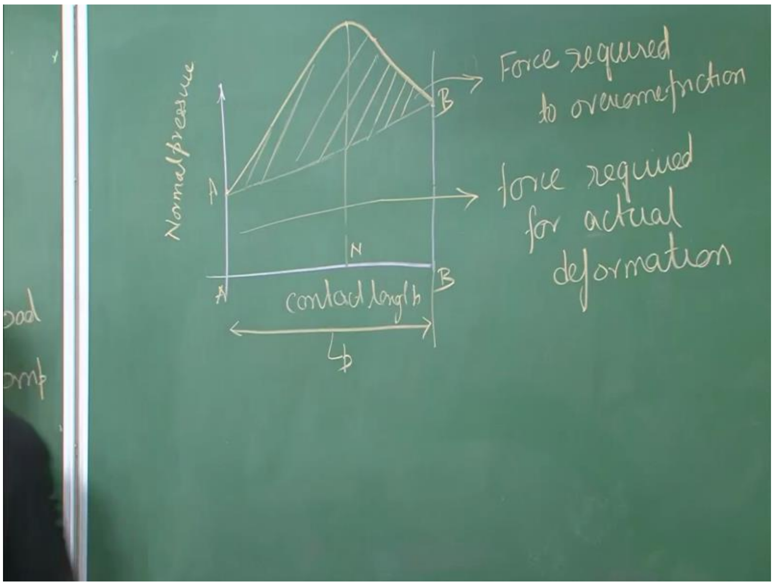

If you look at, let say this is point A this is point B, and this normal pressure, and this is your contact length across the contact length. So, this is again point A to point B and the total length will be L p. This is how the variation exists. At some point there is a maxima, and can you guess what will be that point where it is maxima; yes it will be your neutral point. So, this is your neutral point the point at which the velocity of the work piece equals to the velocity of the rolling die.

Now, if you look at this plot and if you connect these two lines there are two different components to it. This let us hatch it, then this hatched region is the pressure of force required to overcome friction. So, it seems that at this point it would look like the friction is still acting in a negative way, we have to act we have to provide some force to overcome friction. But very soon we will get to the point where you will see that if friction did not exist rolling will not have would have happened. And it is this region I will not hatch; it is this region where force required for actual deformation. So, this is the force that is actually doing the deformation and this is the force that is actually being required just because their friction exists.

So far it like I said it looks like friction is not really helping us it is working against it, but let us look again. What will be force or what will be the condition for us to ensure that the work piece actually moves in the forward direction. For that we will have to calculate. So, here I will keep this geometry and we have two forces acting over here Pr and Fr; the friction forces. Both of them will have component in the x direction. What are the components in the x direction, there if you look at the and if we call this as theta then the horizontal component of this is Pr sin theta and the horizontal component for friction is Fr cos theta.

Now, if we want the material to move in the positive direction we must have Fr cos theta greater than Pr sin theta. You see Pr’s which directions of Pr were acting for this particular configuration that I have shown this horizontal component of; these are the horizontal components. So, this is Pr sin theta and this is Fr cos theta. We want that the material should move in that direction right, because rolling is should ensure that the material comes out in that direction which means Fr cos theta must be greater than Pr sin theta. And this should be true for all theta. Theta varies between 0 to alpha. So, if this happens to be true for alpha where cos theta would be smallest then we can be sure that each and every point Fr cos theta is greater than Pr sin theta.

So, we can write it as Fr cos alpha should be greater than Pr sin alpha and in the limiting condition and this becomes equal to sin or we have Fr by Pr equal to tan theta. But what is Fr by Pr? Fr by Pr is nothing but what we had defined earlier as mu. So, this is mu equal to tan theta or if we use the again the inequality what it is saying is that mu should be; sorry this is now alpha here, so mu should be greater than tan alpha. And what is this condition necessary for? This is the condition necessary to ensure that the work piece actually moves in the positive direction.

Otherwise, what if the mu the friction is less than this value tan alpha then the work piece will not move forward and hence no rolling will take place. So, for rolling to take place mu should be greater than tan alpha, and that is this is where I was saying that friction is not only useful but it is important or you can say necessary. If this were not true or if friction was not existing then or when you say let say mu is equal to 0 then it will always be less than tan alpha and hence the m material or rolling will not take place. And therefore, you may not have heard of any process like rolling. So, mu equal to 0 implies no rolling.

Again, let me emphasize that friction is not always deleterious in some cases particularly in this case it is even necessary, not only useful but it is necessary. Now, let us move to even another important relation related since we are talking about rolling, so let us talk about still another important relation.

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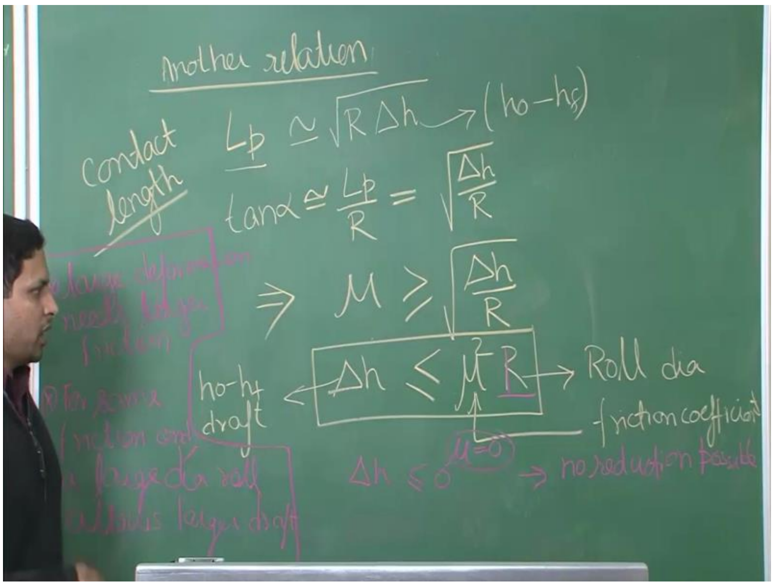

If you look at the L p which is the contact length you can see that L p is actually equal to square root r delta h; where delta h is h naught minus hr. So, this is one way to write the relation for the contact length. Now over here, if you go back to the diagram over here we can say that tan alpha is also related to L p approximately. Let us come back to this figure this is our alpha, if we are calling this as tan alpha then approximately tan alpha is equal to L p by R.

So, let us use this relation over here tan alpha equal to L p by r, and therefore we have tan alpha equal to under root delta h by r. And since, mu should be greater than tan alpha we can say mu should be greater than equal to under root delta h by R. Or again simplifying or putting or readjusting the terms we see that delta h would be less than mu square R. So, where R is the roll diameter mu is the friction coefficient, and delta h is h naught minus h f which is also called as draft, which says that the maximum of the draft of the delta h the maximum reduction that you can get is related to these two terms mu square R.

Now, let say again here this one again proves what we have already seen in the previous example. Let say you put mu equal to 0, what will happen to this, this will become delta h should be less than equal to 0; that is you cannot get any reduction. So, this is delta h is describing nothing but the maximum reduction that you can get. And here it is saying that when you have mu equal to 0 then the maximum reduction is 0. So, you cannot basically get any reduction.

Another thing that we can deduce from this relation is that if you need larger deformation, for example let say your rolling die diameter is fixed that is R is fixed and you want to increase delta h, what is the best way to increase that delta h? You increase mu. So, large deformation needs larger friction, this is again something that we are able to deduce from this relation. Only when you increase R you will be able to get, sorry only when you increase mu square you will be able to increase delta h for a given rolling die.

Now, mu mostly depends upon the rolling material die material and the work piece. So, let say that your rolling die material is fixed and the material that you want to deform is fixed, so mu gets fixed. But you still want to get very large delta h. Another way is to increase the radius of your roll; even if you are using the same material for the rolling die, but by using a larger diameter for the same thing you can improve or increase the delta h value.

So, for same friction condition a large dia roll allows larger draft or deformation, so you can you will be able to get larger delta h value either by increasing in simple terms all we are saying is that if you want to increase delta h you either increase mu and if you cannot increase mu you will have to increase R. And if your mu is 0, which is the condition of friction less condition then you will get no rolling. So, these are some of the important take away messages from our rolling that we have considered so far.

So now that we have looked at rolling in so much detail there are few more aspects about rolling that we can consider here and continue discussing on this. Although it these are not directly related to friction; and that is defects in rolling. What are the kinds of defects; now we that we have discussed so much on rolling.

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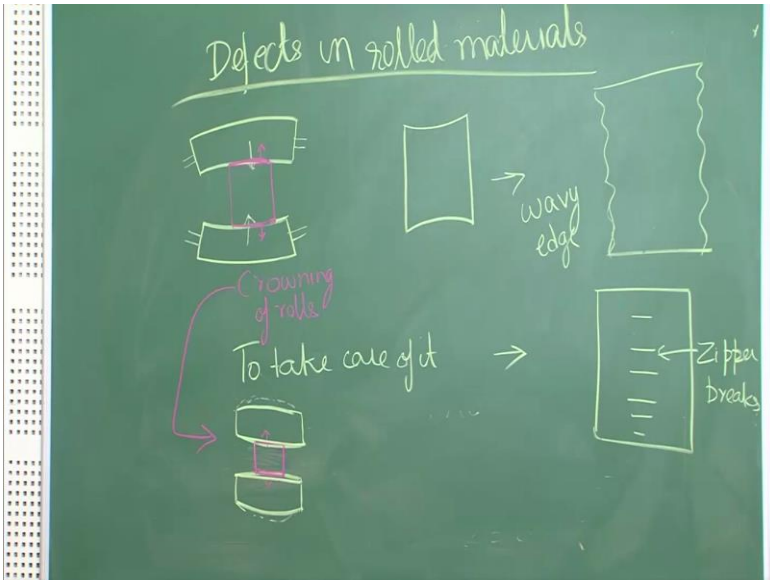

Defects in rolled materials; now whenever you do rolling you must have seen that the rolls onto which you do the deformation they themselves get a little bit deformed. So, let say this is the front view of a rolling mill and you have put a work piece over here. So what is happening over here? The rolls are applying a pressure onto the work piece, but at the same time the work piece is also applying a pressure onto the rolls. And because of that you would see a deformation taking place over here. This is called Crowning of the rolls.

And if you have something like this, what it would mean is that your deformation for the work piece would also be non uniform. So, over here you are getting larger deformation under extreme ends and on the inside you are getting lesser deformation. So in effect the final product should have looked like something like this. However, if you have very large pieces what you may see is something actually like this. So, this is called Wavy edge. Why is this happening? Like I said, on the extreme ends larger deformation is taking place. So, this part is elongated more than the central region, and this extra elongation is sometimes accommodated by this wavy nature. So, this becomes wavy in the center you have still very flat region, but on the edges this becomes wavy.

Another outcome that is possible is something like this. So, let say the material does not wavy but still there is more long elongation over here on the edges and less elongation over here. So, this would try to accommodate that by breaking up in somewhere in between; and this is called Zipper breaks. So, these are some of the problems that naturally occurred if you use a simple plain roll. And the way to take care of it; what do you think can we do to take care of it, we see that the rolls become deformed like this. So, in order to ensure that the final product of the after deformation it remains straight as you would have wanted why not start with a roll which is a little bit dumble in shape. So, the rolls to begin with are dumble in shape, and actually this is what is termed crowning of rolls. So, you have crowned the rolls, there is curvature to it there you have given additional material in the center.

And now let say I will put a work piece over here, this work piece will tend to deform this and to be more accurate let the work piece should be thicker, so let me draw it a little bit thicker work piece. And to take care of this additional load being applied from the work piece this becomes flat. It has actually deformed, but because the original shape has a curvature in the middle, so after deformation it becomes flat in the centre. And the other hand, the other side will become even more curvature have will have even more curvature. So, when you do this the work piece that will come out will be flat because the rolls are near the contact are flat they do not have any curvature. So, the work piece will come out flat and it will have no more wavy edges or zipper breaks.

So, this is one kind of defect that you can expect when you are doing rolling. There is still another, there are few more kind of defects that are possible when you are rolling. So, let us look at the other one.

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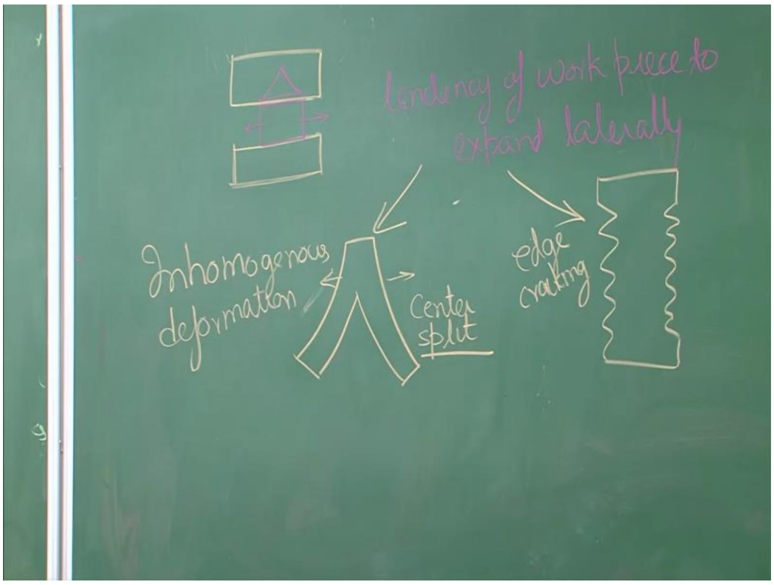

Again, let say you have a roll like this and you have put a work piece over here. Now our ideal theory is that the work piece should elongate only in this direction. However, there is always a tendency for the work piece to elongate also along lateral directions.

Now, this tendency to expand laterally would also depend on the pressure that is acting onto the material. But is the pressure that the acting onto the material uniform across? We know from our friction understanding that it is not really uniform; there may be a pressure distribution like this. So, in the center of the material piece there will be more normal pressure on the extreme ends there will be lesser pressure acting on it.

And therefore, this part will try to elongate or try to extend laterally more than the others. And hence, what you may see are conditions like this. So, this is edge crating. And it happens because of the tendency of the material to expand laterally, and moreover this tendency is higher in the center and it gradually becomes lower and lower it towards the edges.

Other kind of defect that this can lead to is what is called as center split. So, this part is trying to extend this direction, this part is trying to extend in this direction, and you end up with actually splitting the material from the center. And hence it is called Centre Split. So, origin of both of these is because the pressure is acting and the material has a tendency to expand laterally. And this particular kind of defect can also occur when do you have inhomogeneous deformation. Meaning let say, the sheets were not exactly flat in some regions they are thicker than the other region. In those cases also you can see this kind of defects.

And there is still another kind of defect that happens only because of inhomogeneous deformation, and this will look like something like this.

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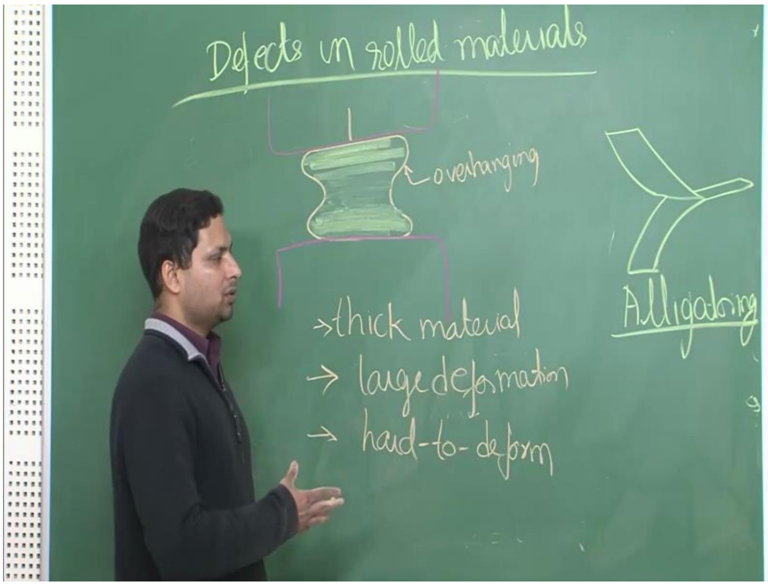

So, let say you have take a very hard material and try to deform it. What you would see is that there may be some kind of barreling on the edges, so the material is being deformed or the rolls are over here. So, the rolls are over here and this is the material and what you what has happened is some kind of barreling effect or over hanging sides.

There is not deformation talking place over here, no deformation taking place over here and less deformation taking place in the center, along the direction of the deformation. In this particular region you; have if I were to draw, so the intensity of these green shading says where the more deformation lies. So, there are more deformation over here and here and much small or very little deformation comparatively in the centre. And this can happen under what circumstances, when you have very thick material that you are trying to deform. So, your starting material is very thick or when you are trying to give very large deformation in one go or you are trying to deform a material which is hard to deform which has very high hardness.

So, if you do this for more than one past of rolling you may end up getting something like this. So, it gets split from the center, its different from the split over there it is getting, so if you if I look at a sample which has which is being rolled like this then in this particular condition it was getting split from over here; so it would split of one part will go this way, one part is going this way and here are my rolls. But in this particular case it is getting split over here like this, so one part is getting over here and another part is getting on the lower side, and here are our main where the rolls are. So, this is called Alligatoring.

So, these are some of the different kinds of defects that can occur when we are doing rolling, and as you can see that all of them are interrelated. So, rolling some of these defects that we have seen happens because there is load being applied, and the load is also being back applied on to the rolls. And sometimes it happens because there is uneven pressure being applied which happens due to presence of friction, and at other times it happens because of home inhomogeneous deformation of materials. And we get something from center split to h cracking to alligatoring.

So, now we have covered all the important; there are various other aspects but we have covered all the fundamental aspects of metal processing. We started with the simple stress strain, plastic deformation; then we looked into the mechanics, the two important ones; the lower bound and the upper bound if you have these two you know there is a win what is the window to calculate forces and loads for the deformation.

And then we looked at the role of friction; first we looked that only the deleterious effects, the two different kinds of definition of the friction one is the coulombic and the other interface friction factor. And then we looked at the positive aspect of the friction which was in rolling. So, we saw that if there were no friction at all in rolling you would actually get no deformation or no rolling at all. And then in continuing our discussion on rolling we also looked at the various kinds of defects that can from during rolling. And we looked at three different classes of these defects.

So, I hope you enjoyed this course, and in the next module Professor Anshu Gaur would be talking about Thin Film Deposition.

Thank you.