**Fundamentals of Manufacturing Processes**
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**Lecture – 26**
**Metal working processes: Rolling**

Hello, I welcome you all in this presentation related with the subject fundamentals of the manufacturing processes and we are talking about the metal working based processes. So, the first process which is very extensively used in very versatile very high productivity process which is deformation based process that is rolling.

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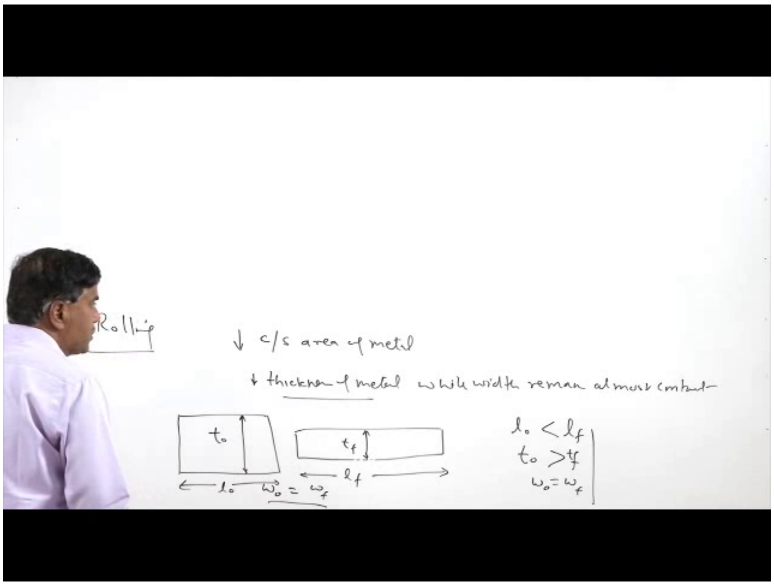


So, this processes basically used for the reducing the cross sectional area of the metal a stock. So, this cross sectional area is used by decreasing the thickness of the metal. So, while width remains almost constant. So, if like say if we see this is the plate before the rolling then after the rolling its thickness is reduced significantly like t naught and t f like this t naught and t f. So, t naught is the initial plate and t f is the final plate thickness which is achieved after the rolling.

So, whenever this is carried out there is no change w almost remains constant. So, v naught and v f in both the cases it remains constant, but there is a significant increase in length. So, these three components will you forming the volume of the metal. So, l naught is the initial length and l f which will be significantly greater than the l naught.

So, whenever rolling is carried out what we will see l naught is less than the l f and t naught is significantly greater than the t f. So, thickness is reduced and length is increased while width almost remains constant, w naught and w f. So, this is what is achieved through the rolling.

How it is achieved through the rolling that is what we will try to see. Whenever the rolling is carried out it helps to reduce the cross section throughout its length. The variation in cross section is not possible in case of the rolling and whatever is the length of the product being made through the rolling it has uniform cross section.

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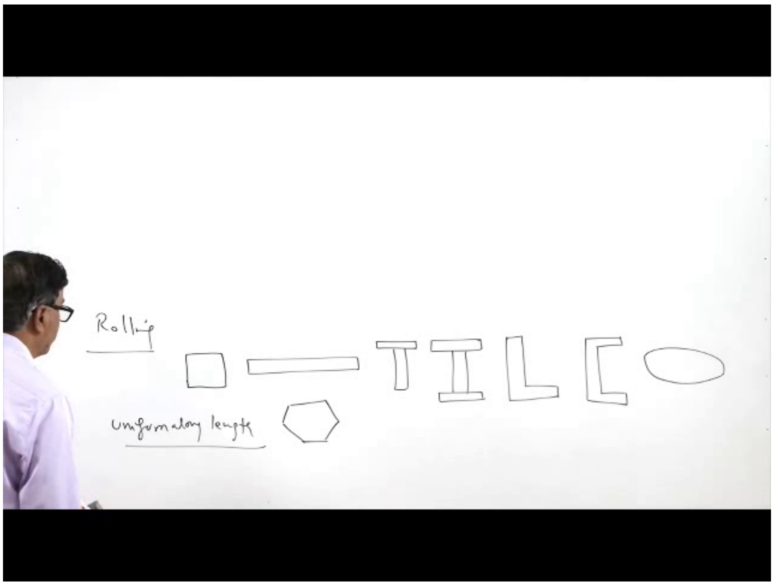


So, if we consider the case the variety of the shapes which can be produced by the rolling and these are these may be inform of like say a square section in form of the plates, in form of the T section, like this in form of I section, L section, C sections. So, such kind of numerous simple shapes oval shape section can be produced easily using the rolling based processes. And likewise there are so many other shapes like a hexagonal shape. So, all these cross sections these are the various cross sections of the plate which can be cross sections of the members or stocks which can be obtained while these sections will be uniform along the length.

So, the variation in cross section is not possible in the products, which is achieved through the rolling. So, how it is achieved through the rolling, but is what will try to analyze.

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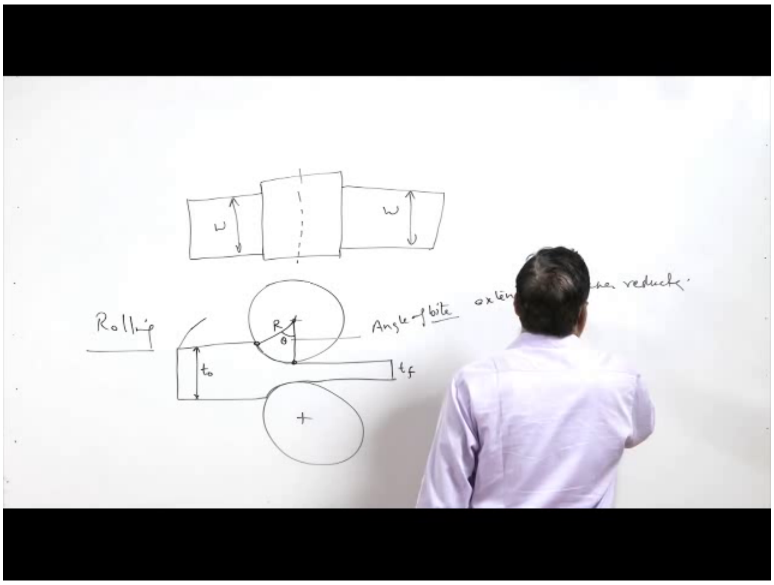


For this purpose basically the rollers are used, we can see the rollers in this way. So, these are the two rollers and this is the plate which is being passed through the rollers. And here it will be reducing the cross sectional area gradually and then it will be passing out this manner.

So, here this will be the final thickness and this is the initial thickness t naught and t f is the final thickness. Since if we take any particular length unit length and width since whatever reduction is obtained that reduction happens in case of the thickness only while the width of the plate which will be along this, along the if we can see the same thing in the top view also where in we can have the rollers in this manner and say the plate entering in the roller like this and then coming out the same width like this. So, this is the axes of the roller. So, width of the plate before rolling and width of the plate after the rolling both are same, but there is a significant reduction in the a thickness. So, width is same thickness is getting reduced, so considering the constancy of the volume. So, what will be having here for unit length we will be getting the much greater length of the metal.

So, the length will be more thickness will be less and widths are same which is achieved. So, if we consider this is the center of the roller center of the roller and this is the radius R of the roller and this is where the plate is coming out of the rollers. So, entry is taking place at this point and exist is taking place at this point. So, this is the entry point and this is the exit point and angle formed between these two points is called theta and which is basically the angle of bite.

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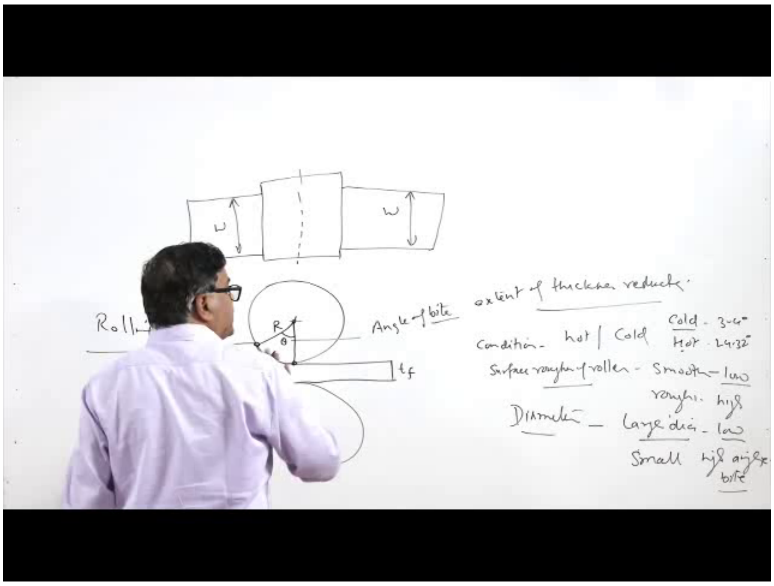


It determines the extent of thickness reduction which will be taking place. So, greater the extent of the reduction in thickness greater will be the draft which will be achieved during the rolling. So, this angle of the bite also depends upon the condition in which the rolling is being carried out means it is hot or it is cold or the surface roughness of the rollers, rollers so for a smoother surface or for rough surface. So, for a smooth surface low angle of the bite is used while for the rough surface high angle of the bite is used the diameter of the rollers large diameter of the large dia rollers, used for the low angle of the bite while the small dia roller result in the high angle of bite.

So, hot and cold rolling angle of the bite for cold its very low like 3 to 4 degree bite for the hot it is very high may be like 24 to 32 degree also. So, since the angle of bite it determines the extent of reduction which in turn is influenced by the diameter of the rollers surface roughness of the rollers and the condition or the temperature of the metal in which rolling is being carried out.

So, with the regard to that if we see these are the factors which will be governing the angle of the bite which can be used which eventually be determining the extent of the reduction during the rolling.

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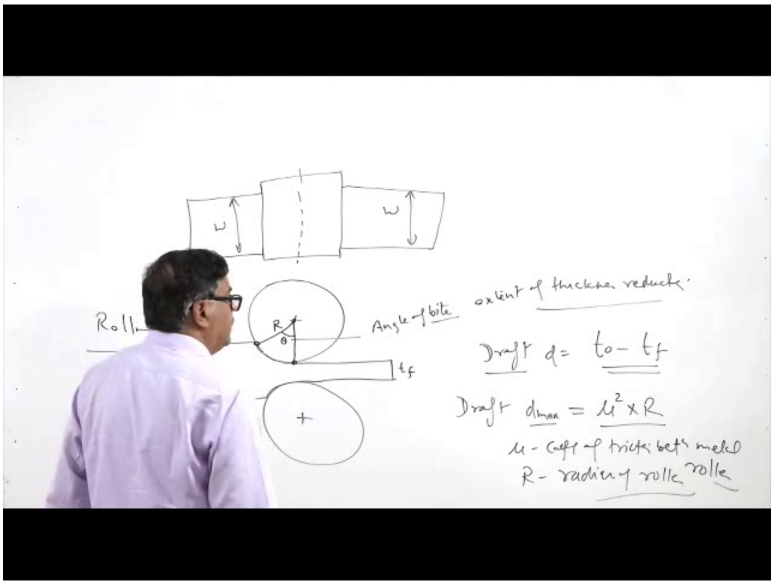


So, this is what is a defined as a draft, draft d is basically the difference in the initial plate thickness to the final plate thickness. So, the maximum draft which can be achieved maximum draft d max which can be achieved is found function of the mu square into R where in mu is the coefficient of the friction, coefficient of friction between the metal and the rollers.

So, if the surface roughness is more if the surface roughness is more the draft more draft is possible and if the roller diameter is more than the more draft is possible. So, the friction coefficient between the metal and the roller surface and R is the radius of the roller which is being used for the rolling purpose. So, this will help us to determine the what x what is the maximum extent of the draft which can be achieved during the rolling. We know that at the high temperature at high temperature the coefficient of the friction increases which helps in increasing the draft.

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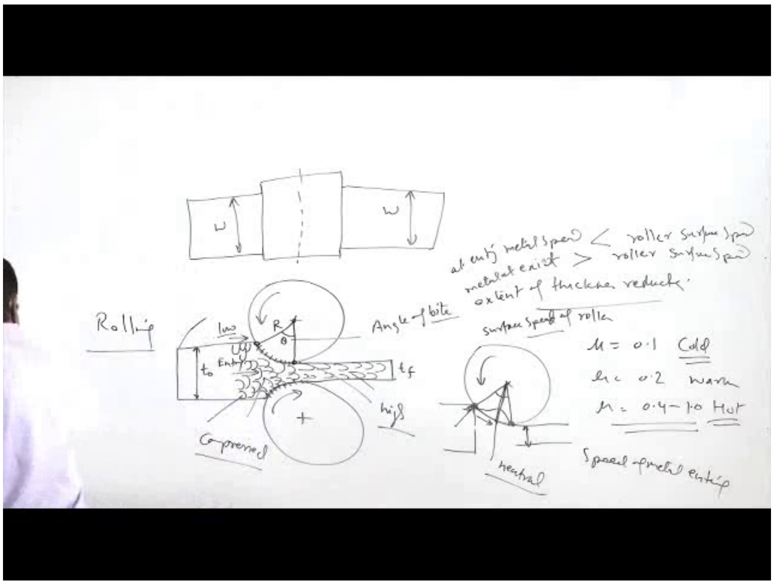


So, if we see with regard to that the coefficient of friction mu is found 0.1 for cold working, mu is in the range of the point is 0.2 for warm working and mu is 0.4 to 0.4 to 1.0 for hot working conditions because at the high temperature the metal gets softened and it forms more grip between the matting surfaces which in turn increases the friction coefficient.

So, basically during the rolling when the rollers are rotating, so the friction between the roller and the plate surface actually tends to pull it in between the rollers. So, when the metal enters in the rollers this is where entry of the metal takes between the rollers. So, here it is compressed and compression leads to the reduction in the thickness of the metal by deforming it plastically. So, here the metal may have the (Refer Time: 13:34) grain, but when it is deformed plastically after passing through the roller here it will be elongating gradually.

So, after the deformation its gets elongated significantly like this. So, the elongation after the deformation and equest grain before deformation is found. So, this is the case when the two rollers are being used. So, when the material is deformed by the rolling we will see that the metal entry the speed of the metal to be at the time of entry a between the rollers is very low and the speed of the metal between the rollers when at the time when it comes out is high. So, at the exit the speed is high while when it enters the speed is low. So, if we see this configuration here it exists and here it enters this is the angle of the bite and this is the center. So, speed is low here and is speed is high because here the volume of the metal for a given volume of the metal this is the thickness and when it comes out the thickness is significantly less. So, in unit time it comes out with the grater line. So, the speed of the metal in the beginning becomes low and it keeps on increasing until it exists. So, it comes out of the rollers.

So, what happens when the metal enters between the rollers? So, initially what we see that the metal pressure builds up in the metal and then it will keep on in increasing and then again it will keep on decreasing. So, maximum pressure is founds somewhere at the neutral plane here.

So, what is this neutral plane? So, what we see that the roller is rotating at the certain a speed. So, there is surface is speed of the speed of roller and there is some speed of, the is speed of the metal which is entering, entering. So, in the beginning the metal enters speed of the metal entering is low while the speed of the roller is high at the entry point. So, at entry the metal speed is less and roller surface speed is high this while at the end the reverse happens the metal at exit metal speed at exit is higher than the roller surface speed.

So, there the two things one when the metal enters the speed of the metal with respect to the roller surface is less when the metal comes out the speed of the metal with respect to the roller surface is high in between somewhere the speed of the metal which is entering between the rollers and the speed of the roller surface both are same. So, that plane where it happens that is called neutral plane. At the neutral plane the speed of the roller surface and the speed of the metal both becomes equal.

So, if we see with regard to this with the way by which pressure builds up during the rolling between the rollers on to the metal and how can we calculate the forces acting on to the rollers torque being consumed the torque acting on and power being consumed that is what can be calculated using some fundamental equations.

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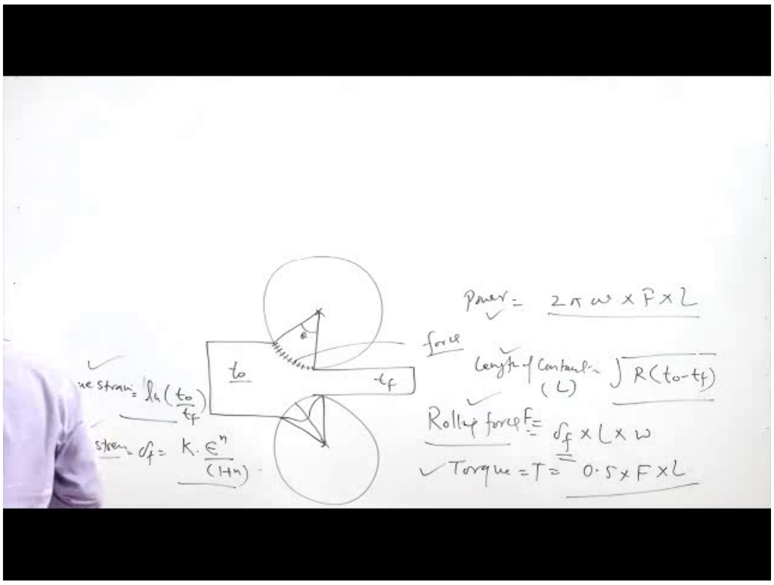


So, we have the rollers center of the rollers the plate metal entering and then it is coming out this is the angle of bite this is the angle of bite this side. So, in both the sides will see the pressure gradually build up and then it reaches to the maximum level and then it is start decreasing. So, the variation in the pressure build up is seem like this where it is maximum somewhere at the neutral plane and then it is starts decreasing at that time when metal comes out of the rollers it is a the pressure is released and pressure is a reduced and this is the angle of the bite.

So, in this process of the reduction in the thickness the initial plate thickness and the final plate thickness this is used for calculating the true strain on a count of the rolling, is calculated using the simple equation the log of t naught divided by t f. So, this is the simple equation for calculating the true is strain. And then average flow is stress acting flow stress of the metal and under which the metal will be deforming can be calculated using the (Refer Time: 20:14) sigma f is the flow a stress which can be calculated using the k strength coefficient strain race to the power n divided by 1 plus n - n is the strain exponent and. So, the k is the strength coefficient.

So, this is how it the average flow is stress can be calculated and if we have to determine the contact length that is means the this length of the contact between the rollers and the metal which will be governing the force to be applied for the given flow stress. So, this the length of contact can be obtained using the simple equation R is the roller radius multiplied by t naught minus t f square root of this one can be used for calculating the contact length then the roller force of the force acting on to the rollers or the rolling force can be obtained from the product of the flow stress multiplied by the contact length multiplied by the width of the plate.

So, L is the contact length and W is the width of the plate which is being rolled and sigma f is the flow stress and the torque can be calculated t can be calculated using the equation 0.5 times of the rolling force F into the contact length and the power for the rolling can be obtained using the simple equation of the two pi omega into the rolling force multiplied by L the contact length.

So, these are the equations which can be used for determining the true strain average flow a stress and the power required for the rolling the contact length, the role force, rolling force the rolling force and the torque which will be acting on to the rollers. So, this is how the rolling process can be analyzed with regard to the stress strain power and the torque which will be acting on to the rollers.

Now, will see this kind of this analysis applicable for the true roller system, but for achieving the higher draft value the other rolling arrangements are also used.

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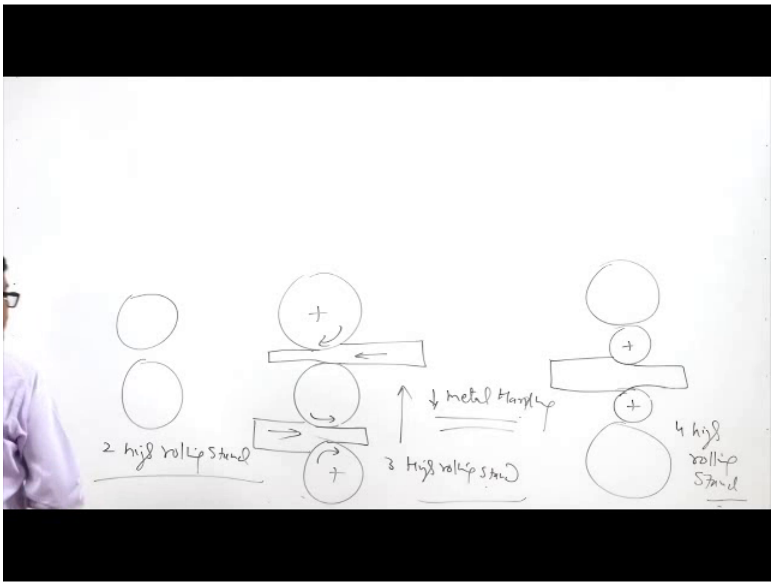


So, when the two rollers like this R used it is called two high rolling stand when the 3 rollers are used like this in this case it is called three high rolling stand in this case first of all the metal is passed through this one stand and once it is completely passed then using the metal transfer arrangement, but we will handling device it will simply lifted up and then it is passed through the another rolling means set up of the rolls for further reduction in the thickness like this.

So, there first it will passed in one direction then it will be passed in the opposite direction. So, this will the kind of the direction of the rotation for three high rolling stand this actually reduces the material handling which is needed for the rolling then there is a 4 high rolling is stand it is in this case we use the small rollers for having the higher angle of the wide since they small rollers cannot be very rigid and strong. So, in order to provide the suitable the backup the large diameter rollers are used as a backup and the high angle of the bite is achieved through these small diameter rollers like this. So, this is the arrangement for four high rolling stand.

Now, we also use one more arrangement which is commonly used for high draft values that is called cluster arrangement and in the case of the cluster arrangement again the small diameter rollers are used like this.

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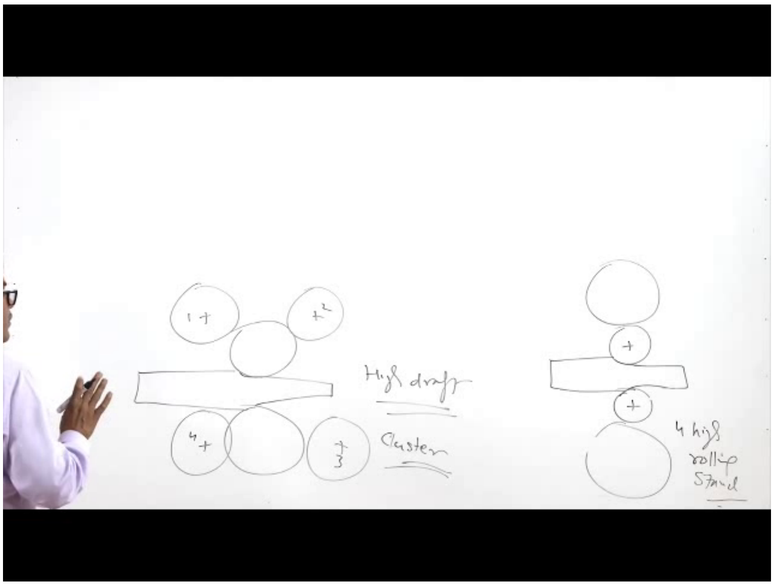


And then these rollers are supported with the help of the 4 other rollers from 4 sides. So, 1 2; 1 2 3 4 these are the 4 support rollers and these are the main 4 working, 2 working rollers which are smaller in size. So, this kind of arrangement is called cluster a rolling machine and it is used for the high draft using the low a small diameter the rollers.

The advantage of the small diameter rollers that it reduces the rolling, rolls separating force or the rolling force which will be acting on to the rollers we know that when the roll the force is act on to the rollers then rollers stands to bend in a particular way and that leads to the non uniform thickness of the plate which is being rolled.

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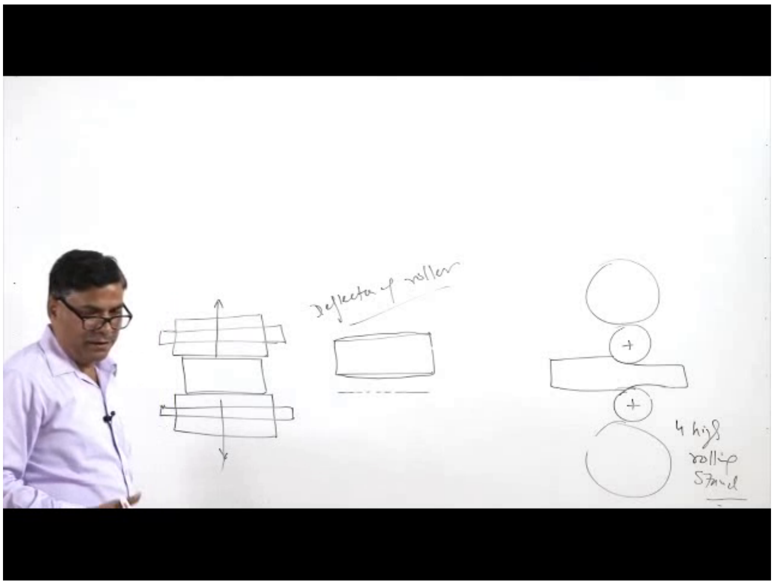

So, normally it is expected that the rollers like this these are the rollers and between these rollers if the plates and they will be having the like say support at the ends and the plates will be passed through these rollers this.

So, because of the rolls separating force at the center the roll stands to bend outward and because of this outward bending of the rolls the thickness of the plate at the center increases like this while at the ends it reduces. So, this leads to the non uniform thickness across the width of the plate. So, in order to avoid this kind of and this is primarily due to the deflection of the rollers due to the rolls separating force. So, what is done basically the diameter of the rollers is not made cylindrical means the diameter of the rollers is not made uniform, but it is slightly made of the larger diameter at the center. So, that the bending effect or the deflection effect of the rollers can be negated.

So, instead of having the simple uniform diameter rollers the diameter of the roller is slightly increased at the center like this so that even after the bending the diameter. So, when it bends it simply gets straighten like this and we get the uniform thickness of the rolled plates after the rolling. So, the bending and the deflection of the rollers which leads to the greater thickness at the center and lesser thickness at the corners this effect can be negated or countered by making the rollers of the larger diameter at the center and the smaller a diameter at the corners.

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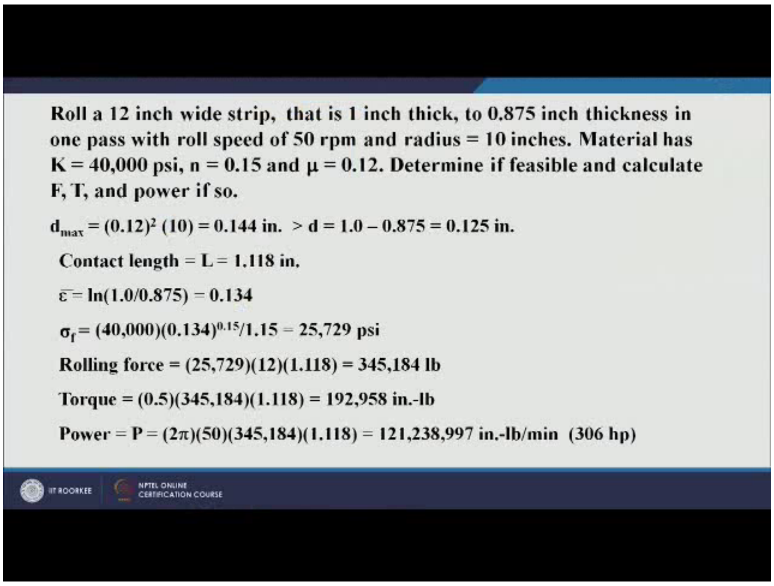


Now, we will see one typical example related with the rolling strain stress torque and the power consumption analysis. So, if we see here in this example the roll rolling of the twelve inch width plate of 1 inch thickness is carried out to the thickness of 0.75 inch. So, means there is a thickness reduction from 1 inch to the 0.875 inch in one pass. Using the roller speed of the 50 rpm and the radius of the roller is 10 inches if the materials strength coefficient K is 40000 psi and strain hardening exponent is the strain hardening exponent n is 0.15 and the friction coefficient is 0.12, then we have to identify whether it will be feasible to achieve this much thickness or not or which is normally achieved through the maximum draft value which is achievable and that we can achieve through the mu square into R.

So, mu in our case is 0.12. So, since the formula for determining the maximum draft is mu square into R. So, this is what gives us 0.14 inch. So, what it suggest that in our case 0.14 inch this is the maximum draft which can be achieved, but in which is much larger than what is to be achieved in our case, in this case are the reduction which is to be achieved is from 1 to 0.875. So, the reduction is just up to 0.125 which is to be achieved while the maximum achieve will reduction in thickness is 0.144, this kind of the case is already feasible I means it is very much do able.

Now, we can determine the contact length the formula for contact length is already I have written, the contact length can be obtained from the square root of R t naught minus t f.

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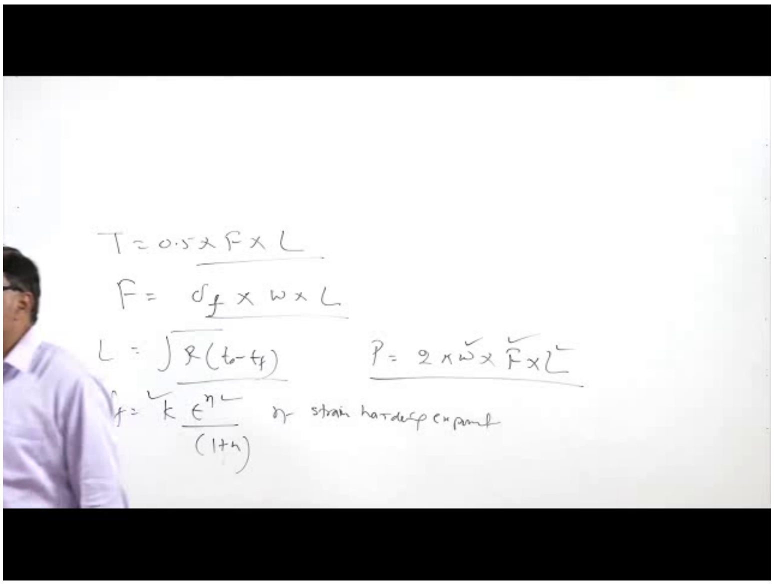

So, in this case t f is the 0.875 and t naught is the 1 inch and the R is the 10 inch radius. So, these three can be used for calculating the contact length which comes out to be 1.118 inch and the strain which is occurring due to the rolling on account of the reduction in thickness from 1 inch to 0.875 inch the strain can be calculated using the simple equation log of t naught divided by t f. So, t naught is here of 1 inch and t f is the 0.875 inch which leads to the strain of 0.134, now we can calculate the flow stress, the flow stress can be calculating using the simple equation where in the flow stress the sigma f or can be calculating like k into the strain and raised to the power n divided by 1 plus n. So, n is the strain hardening, hardening exponent.

So, all these values are given in our examples. So, here this can be used a strain hardening exponent is here 40,000 psi, n is 0.15 and the strain which has been calculate is 0.134 and the n is 0.15. So, this gives us 25,729 psi that is the flow stress. Now using this we can calculate the rolling force, rolling force is rolling force f is obtained from the sigma f into the width and the length of the contact. So, all these are there the flow stress 25,729 12 inches the width of the strip and length of the contact is 1.18 inch. So, this gives us the rolling force of 345,184 pound and the torque can be calculated using the formula the torque T can be calculated 0.5 multiplied by F the rolling force multiplied by the contact length.

So, in our equation here 0.5 multiplied by the rolling force is 345,184 multiplied by 1.118 that is the contact length. So, this gives us 192,958 inch pound and the power consumption for, power consumption for the rolling for reducing the thickness from 1 inch to 0.857 inch can be calculated using the simple equation has I have mentioned in the power consumption is from the 2 pi mega into the force into the contact length. So, this is the rolling force, L is the contact length, omega is the rotational speed. So, using the these three terms the power consumption can be calculating using 2 pi 50 is the rotational speed omega and the 245,184 is the rolling force and the contact length is 1.18 this gives us one 121,238,997 inch pound per minute which is corresponding to 304 hp is a power required.

So, now, I will summarize this presentation. In this presentation I have talked about the rolling process which is primarily used for reducing the cross section and the reduction in cross section is primarily used by reducing thickness and increasing the length, while the rolling produces the components of the uniform cross section along the length. Additionally, we have also talked about the kind of stress strain, torque and the power consumption calculations for the rolling process.

Thank you for your attention.