Production Technology: Theory and Practice
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Lecture - 09
Discussion Session

Hello and welcome back to the discussion sessions of the production technology theory and practice course. Let me remind you that during the last session, we have gone through the discussion on the two models clarifying the mechanics of metal cutting. Both models are of the thin zone model meaning that the assumption is that the deformation takes place in a thin zone.

I would like to remind you that this thin zone is an assumption because the deformation occurs in a zone. Now, as the cutting velocity and the temperature increase, this zone becomes thinner, I mean zone where the plastic deformation occurs. So, if we are saying that the zone is assumed to be a plane, that means we are talking about machining at much higher speed; even then the zone cannot be very thin. So, it is just an assumption.

The first model we discussed is the Merchant and Ernst model where there are 8 assumptions such as the model is valid for orthogonal machining overall. So, this is a 2-dimensional case and the principle that has been adopted in that model of Merchants and Ernst is the minimum power consumption during the machining process. For that what we have done is that final equation of the power we have derived through the F_c and V_c and that was in terms of a ratio of numerator and denominator.

And then we said that for the power to be minimum the denominator has to be maximum and therefore, the first derivative of the denominator has to be 0. So, we have taken the first derivative of the denominator, made it equal to 0 and that is known as the first equation of Merchant and Ernst, That came from the Merchant's circle diagram where it is again based on the fact that the material is rigid and perfectly plastic.

And it is moving at a constant velocity over the rake face of the tool. Therefore, the resultant of the forces acting on the chip from the tool side and from the work piece side, are the equal opposite and collinear. Second model that we have discussed is the Lee and Schaffer model that is also a thin zone model. However, here the principle is different. The principle is based on the slip line field theory. Here, what they are saying is that there should be a stress field within the chip.

This is for transmitting the forces from the shear plane to the tool site. In that stress field, the entire material is plastically deformed up to the yield stress and then the slip line field theory has been adopted to say that there is a free surface. Beyond the free surface there is no forces acting and the shear plane where the maximum plastic deformation occurs, makes an angle of 45^0 with the free surface.

Then within the triangular zone that is within the chip, which is the stress free in the sense that is already maximally stressed, there we have taken perpendicular and parallel to the shear plane. Lee and Schaeffer have derived the final equation from the coefficient of friction along this chip tool contact length and the Mohr circle diagram.

Stresses at these planes have been carried over to the Mohr circle at the periphery of the circle that is for the 2-dimensional case and then it was a simple derivation, deriving the relationships of the angle. That is the shear plane angle ϕ, friction angle λ and the rake angle α We have discussed how the relationship has been derived by Lee and Schaeffer.

This relationship of those three angles is very close to the derivation which has been made by the Merchant and Ernst. Although different principles have been adopted in deriving these equations and for looking into the mechanics of metal cutting in these 2 models.

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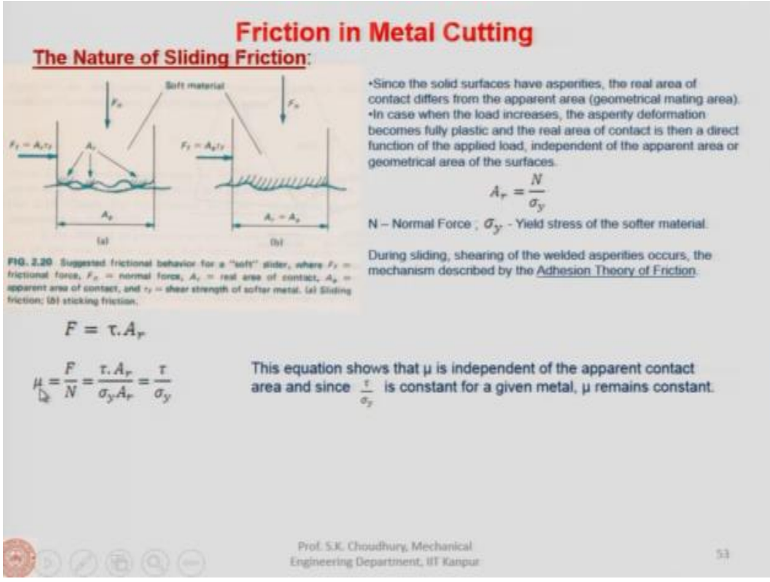

Next, we are going to discuss friction in metal cutting. Let us talk about first the nature of the sliding friction. What is sliding friction? That means, when 2 surfaces slide on each other, with respect to each other. When they are sliding, the normal force acting at the interface is not very high or let us say not as high as in case of the metal cutting.

Since the solid surfaces have asperities, asperities are the undulations as shown, the real area of contact differs from the apparent area of contact. The real area of contact will be on the asperities when the 2 surfaces meet. Both these surfaces have asperities. These 2 are different surfaces. Apparent area is the geometrical area which is the actual area.

Now, in case when the load increases, the asperity deformation becomes initially elastic and then fully plastic and the real area of contact is then a direct function of the applied load independent of the apparent or the geometrical area of the surfaces. Next, the 2 surfaces are resting on the asperities and there is a force applied to the contact surface here.

In that case, these asperities will be deformed initially and they will be deformed elastically and then gradually as the force increases further this deformation becomes plastic and then the real area of contact then, that is on the asperities, is a direct function of the applied load; applied load is let us say N which is the normal load, that will be independent on the apparent area of or geometrical area of contact.

When the force is very high, then the real area of contact may be almost equal to the apparent area of contact. This is the equation that we get here. You can see that this is independent of the geometrical area. On the geometrical area it does not depend, it is only the real area of contact. N is the normal force here and σ_y is the yield stress of the softer material, i.e. out of these, whichever is the softer material, this is the yield stress of the softer material.

Now, during sliding with respect to each other, shearing of the welded asperities occurs. These asperities, since they are welded because the force is becoming more, will be sheared and the mechanism is described by the adhesion theory of friction, which says the following. F, that is the friction force, is equal to τA_r .

Now, the coefficient of friction μ is given by $\left(\frac{F}{N}\right)$ and the friction force is shear stress, τ multiplied by the real area of contact, A_r .

Therefore, the area on which it is resting, is the real area of contact and geometrical area or apparent area is the entire area irrespective of these asperities. Now, if we say that that $F = \tau . A_r$ and $N = \sigma_y A_r$. in that case we get $\mu = \frac{\tau}{\sigma_y}$ τ is the shear stress and σ_y is the normal stress or this is the yield stress of the softer material.

Now, this equation shows that the coefficient of friction is independent of the apparent area of contact and since this remains sufficiently constant because these are the material properties, you select a material for which the shear stress and the yield stress values will be constant. Therefore, μ remains sufficiently constant.

μ remains constant means the F is proportional to N.

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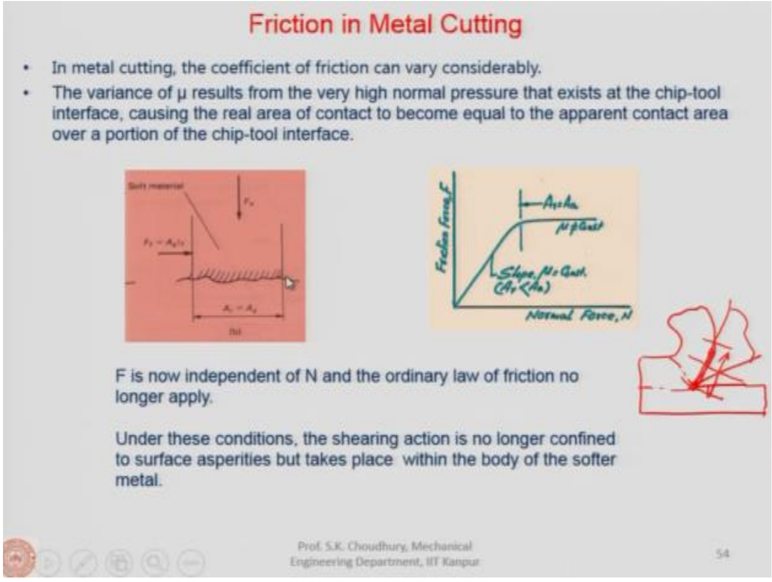

Now, in metal cutting the coefficient of friction can vary considerably. Here is that μ remains constant this is for the sliding friction where the force is not very high. In metal cutting, the coefficient of friction however, does not remain constant as in case of the sliding friction, the variance of μ results from the very high normal pressure that exists at the chip-tool interface.

So, if we see the cutting process, this is the chip being formed, this is the work piece and this is the tool. Now, as this process goes on, at the tool tip the normal pressure is very high. Now, this very high normal pressure that exists causes the real area of contact to become equal to the apparent area of contact over a portion of the chip tool interface, meaning that if the chip-tool interface length is this, the normal pressure is maximum here.

But it decreases as you go up along the contact length of the tool and the chip. Therefore, up till a certain distance, this apparent area of contact and the real area of contact become almost same, but beyond certain value of the length this does not happen. Now, the real area of contact is almost equal to the apparent area of contact

So, F is now independent of the normal force and the ordinary law of friction then no longer applis which is $\mu = \frac{F}{N}$ which is $\frac{\tau}{\sigma_y}$ and this does not remain any more applicable because in this case the normal force is very high and the real area of contact is almost equal to the apparent area of contact. Under these conditions, the shearing action is no longer confined to surface asperities.

Now, suppose in this case as it slides, the shearing of the welded asperities happens. But, theshearing happens within the softer material.

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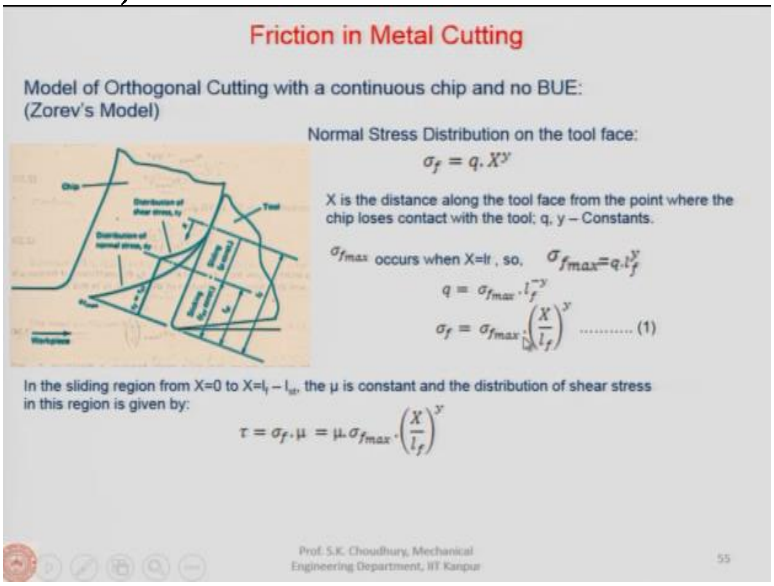

Model of orthogonal cutting with a continuous chip and no built-up edge formation is offered by professor Zorev, a Russian scientist, and he is defining the average coefficient of friction between the chip and the tool along the chip tool contact length. This is important because it is no more the sliding friction since the normal pressure is very high at the tool tip.

At the vicinity of the tool tip, up to some length, very high normal pressure continues to remain and therefore, the apparent area of contact is almost equal to the geometrical area. So, $\left(\frac{F}{N}\right)$ does not remain constant. Therefore, *F* is now independent of *N*. but in case of sliding friction μ = constant and *F* is proportional to *N*.

But here *F* is now independent of *N* and therefore, the ordinary law of friction no longer remains valid. The Zorev's model determines the average normal stress distribution on the tool face. Let us see this diagram. This is the tool and this is the work piece, here is the chip flowing along the rake face of the tool and let us say that at this point the chip loses contact with the tool. From here to here, here it is designated as a l_f this is the chip-tool contact length that is the length at which the chip contacts with the rake face of the tool.

Now, here the 2 curves are drawn one is the normal stress and this curve is for the shear stress. Now, let us say that this is the point up to which the normal pressure remains very high. Beyond this point, that means above this point, the normal pressure does not remain very high, not as high as let us say in this region. And here the sliding friction rules still remain valid because along this length the normal pressure is not very high.

This zone where the normal pressure remains very high it is called the sticking zone. And where the normal pressure is not so high is called the sliding zone. As we have already discussed in the sliding zone, the μ remains constant, i.e. $\left(\frac{F}{N}\right)$ is constant like case of the sliding friction, but in the sticking zone, this is no more valid because the normal pressure is very high and $\left(\frac{F}{N}\right)$ is not constant and therefore, F is not proportional to N, μ is not constant.

These are the 2 zones, one is the sticking zone and the other is the sliding zone, this is the tool. This is the distribution of the shear stress. And this is the distribution of the normal stress. This is up to the point where the chip loses contact with the rake face of the tool. So, as you can see from this curve that the normal stress is maximum at this point.

And as it goes along the chip tool contact length, normal pressure goes down, along this length. The shear stress remains nonlinear. We will show why it is that and how we can get the equation, but here in this zone is the sticking zone, the shear stress remains maximum, and the shear stress is constant everywhere.

This is maximum, let us say this is equal to τ_{st}, which is the shear stress in the sticking zone. Now, this length is the l_f that is the chip-tool contact length, and this length is the l_{st} that is from the tool tip up to the end of the sticking zone. This point, let us say from this point, if you go towards the tool tip, the X value increases. Let us say X value is 0 here and as we go along this chip-tool contact length, if we come to this point, the X value will be l_f. If you are here, it will be $\left(l_f - l_{st}\right)$ and so on.

So, the normal stress distribution on the tool face given by Zorev is $\sigma_f = qX^y$, q and y are constants and X is the value representing the distance along the tip tool face here from the point where the chip loses contact with the tool. So, as I said that X is 0 here and as you are coming towards this tool tip the X value increases; X value is maximum where $X = l_f$.

$\sigma_{f\,max}$ occurs when $X = l_f$. Now, the $\sigma_{f\,max}$ therefore, can be found out as $\sigma_{f\,max} = ql_f^{\,y}$. In this equation in place of X we are putting the value of l_f. This is the maximum because we said that the maximum normal stress occurs here. Now, q from here we can find out equal to $q = \sigma_{f\,max} l_f^{\,-y}$.

Therefore, sigma f from here we can estimate as $\sigma_f = \sigma_{f\,max}\left(\frac{X}{l_f}\right)^y$ In the sliding region from $X = 0$ up to $X = (l_f - l_{st})$, μ is constant and the distribution of shear stress in this region is given as shown in the slide.

The equation of this curve will be $\sigma_f \mu$ that is, normal stress multiplied by the μ which will be the shear stress. σ_f we already found out as $\sigma_{f\,max}\left(\frac{X}{l_f}\right)^y$. It is just μ multiplied by the value of the σ_f which you have put here in terms of the $\sigma_{f\,max}$.

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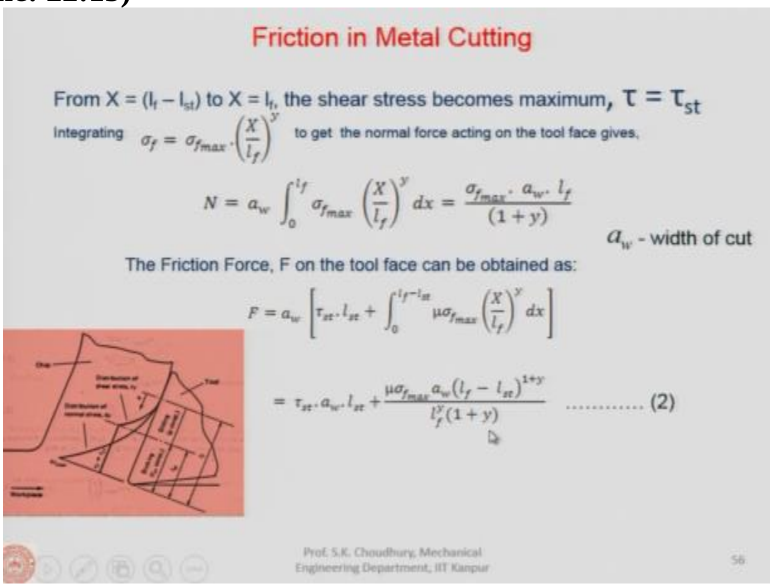

inlet us discuss in another region from $X = \left(l_f - l_{st} \right) to\ X = l_f$. In this region τ or the shear stress becomes maximum which is τ_{st}. We have shown earlier that $\sigma_f = \sigma_{f\max} \left(\frac{X}{l_f} \right)^y$.

Now,the normal force we can get if we integrate the area below this multiplied by the width of cut in the following way $N = a_w \int_0^{l_f} \sigma_{f\max} \left(\frac{X}{l_f} \right)^y dx$, where a_w is the width of cut.

This will result in a value of normal force as $N = \frac{\sigma_{f\max} a_w l_f}{(1+y)}$ f

This is the normal force that we are getting by integrating the area on the σ_f. Now, to get the friction force similarly, we can consider the area under the curve of shear stress. Therefore, the friction force, F can be found out as, $F = a_w \tau_{st}\ l_{st} + a_w \int_0^{l_f - l_{st}} \mu \sigma_{f\max} \left(\frac{X}{l_f} \right)^y dx$ which will result in a value of the friction force as $F = a_w \tau_{st}\ l_{st} + \frac{\mu \sigma_{f\max} a_w \left(l_f - l_{st} \right)^{1+y}}{l_f{}^y (1+y)}$

Here, up to a length of $\left(l_f - l_{st} \right)$ we have to integrate the τ. So, this is a normal stress into the μ. This will be the shear stress. Then we are coupling them together and summing them to get the friction force, that is, we are integrating the area under the entire curve of this τ from 0 to $\left(l_f - l_{st} \right)$ and from $\left(l_f - l_{st} \right)$ up to the tool tip.

Now, we have the *F* and *N*, friction force and the normal force, then we can find out the μ which is the coefficient of friction between the chip and the tool and that coefficient of friction will be along the chip-tool contact length. Now, we have to see if we get this *F* and if we try to divide *F* by *N* , this will be very difficult to operate in the sense that this has to be simplified.

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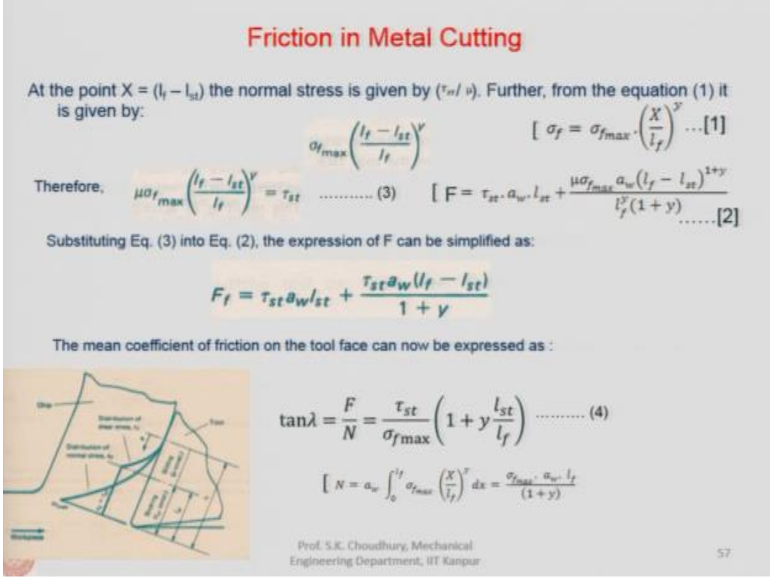

This can be simplified in the following way that at the point $X = \left(l_f - l_{st}\right)$ if you see that there are 2 shear stresses. We have the shear stress as a non-linear curve here and at the same time we have the shear stresses here which is constant, τ_{st}. So, at that point $X = \left(l_f - l_{st}\right)$ the normal stress is given by $\frac{\tau_{st}}{\mu}$.

Now, we have the equation that we have derived as $\sigma_f = \sigma_{f\max}\left(\frac{X}{l_f}\right)^y$, if we now take this equation, and put the value of X as $\left(l_f - l_{st}\right)$, here in the in the place of X , then the simplified version of the friction force, F will be as shown in the slide.

This has been done by substituting the value of τ_{st} as $\sigma_f \mu$ which is equal to $\mu\sigma_{f\max}\left(\frac{l_f - l_{st}}{l_f}\right)^y$.

So, in the simplified version of F, the μ is gone as you can see. We try to avoid the μ and the $\sigma_{f\max}$ which has been done here. Now, we can take the ratio of the *F* and *N* to get the tan of the friction angle and the mean coefficient of friction on the tool face can then be expressed as $\tan\lambda = \frac{F}{N} = \frac{\tau_{st}}{\sigma_{f\max}}\left(1 + y\frac{l_{st}}{l_f}\right)$ and $\sigma_{fav} = \frac{N}{a_w l_f} = \left(\frac{\sigma_{f\max}}{1+y}\right)$ this we are calling as the mean friction of coefficient.

Because we have taken the sliding friction and the sticking friction zone. Therefore, whatever will be the estimated value of μ now, it will be a mean value.

So, that is the value of $\tan\lambda$ which is the ratio of *F* and *N*.

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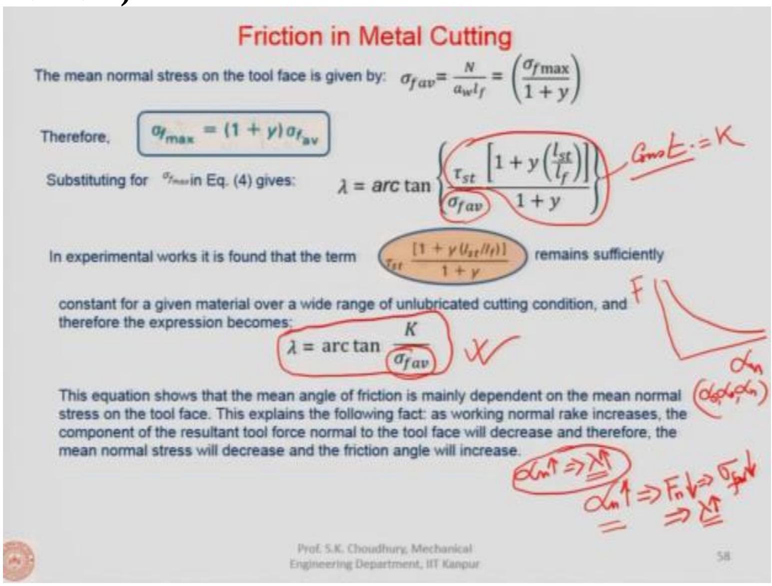

Now, the mean normal stress on the tool face is given by the normal forceN acting on that tool face divided by the area and the area is the width and the length. This is shown in the slide as $\sigma_{fav} = \frac{N}{a_w l_f} = \left(\frac{\sigma_{f\max}}{1+y}\right)$.

now, if we substitute $\sigma_{f\max}$ then we will be getting that the value of λ as $\lambda = \text{arc}\tan\left(\frac{K}{\sigma_{fav}}\right)$ where $K = \frac{\tau_{st}\left[1 + y\left(\frac{l_{st}}{l_f}\right)\right]}{1+y}$. Experimentally it has been seen that the value of K which is

$\frac{\tau_{st}\left[1+y\left(\frac{l_{st}}{l_f}\right)\right]}{1+y}$ remains sufficiently constant in practice for a given material, over a wide range of unlubricated cutting condition.

Because you understand that when we are having the lubricated cutting condition then of course the μ comes into picture and it changes the condition. It may not remain so much of constant as we say for the unlubricated condition.

And this equation shows that the mean angle of friction is mainly dependent on the mean normal stress on the tool face. σ_{fav} is nothing but the mean normal stress on the tool face. This explains the fact that as the working normal rake α_n increases, the component of the resultant tool force normal to the tool face will decrease.

In this contextlet me give you this reference that the relationship between cutting force, *F* and the rake angle α is in decreasing order, as the alpha decreases the F increases.

So, as the normal rake increases, the component of the resultant tool force normal to the tool face, F_N will decrease and therefore, the mean normal stress will decrease and the friction angle will increase.

This you can explain only by this equation otherwise it is very difficult to explain this fact that as the normal rake angle increases, the friction angle will increase. This is the contribution of Dr. Zorev's model that through his model and through the curves of distribution of the shear stress and the normal stress, he has shown what is the mean coefficient of friction in the chip-tool contact length.

In the chip tool contact length, the μ does not remain constant and he has distributed that in 2 sections - one is the sticking zone one is the sliding zone. And in these 2 zones in one of these zones, I will just summarise that as we have shown that in the sliding zone the μ remains constant and in the sticking zone the μ does not remain constant.

Within that he has shown that μ has to be some average value. And finally, he has shown that this is the relationship between the σ_{fav} and the friction angle and as you know that friction angle is related to μ because $\frac{F}{N}$ is μ and this is the friction angle this is $\tan^{-1}\left(\frac{F}{N}\right)$.. This is the gist of Zorev's model through which he is finding out the mean coefficient of friction between the chip and the tool during the metal cutting.

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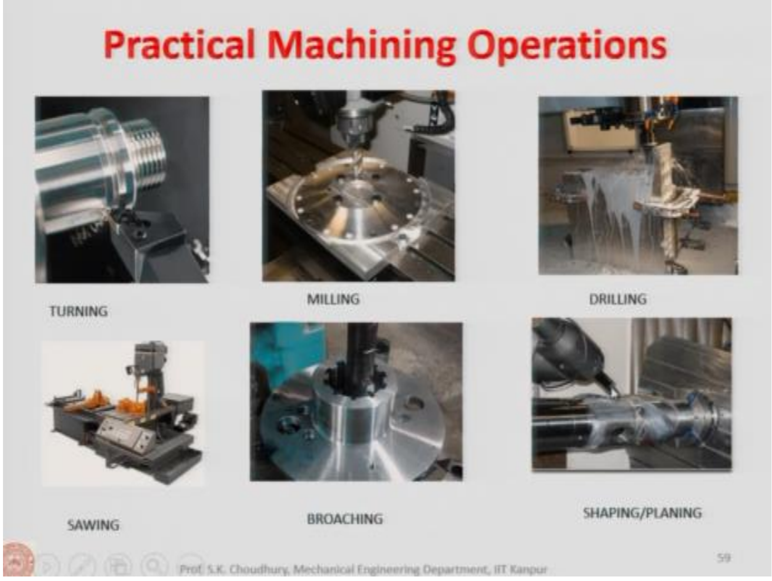

Now, let us discuss the practical machining operations. Here pictorial views of some of the processes are shown which you will also see in the lab. First one is the turning where you can see that this is the tool and here is the work piece. Next is the milling process, particularly the vertical milling is shown. Next is the drilling, this is the drilling machine and the hole is being drilled here as you can see that this is the work piece.

This is the sawing process where we have the saw and the material is being cut. Next is broaching which is an operation that is not very popularly used because this is an expensive operation, particularly the broach, which is the tool for the broaching operation. This broach is very expensive but with the broaching you can produce very fine surface.

Broaching can also be used for making the internal slots which is otherwise very difficult to get and here you can see that the internal slots along the axis of the work piece are being made.

Slots are also made by shaping or planning. We will discuss later the principle of shaping and planning, how the flat surfaces, inclined surfaces and the groovesare fabricated.

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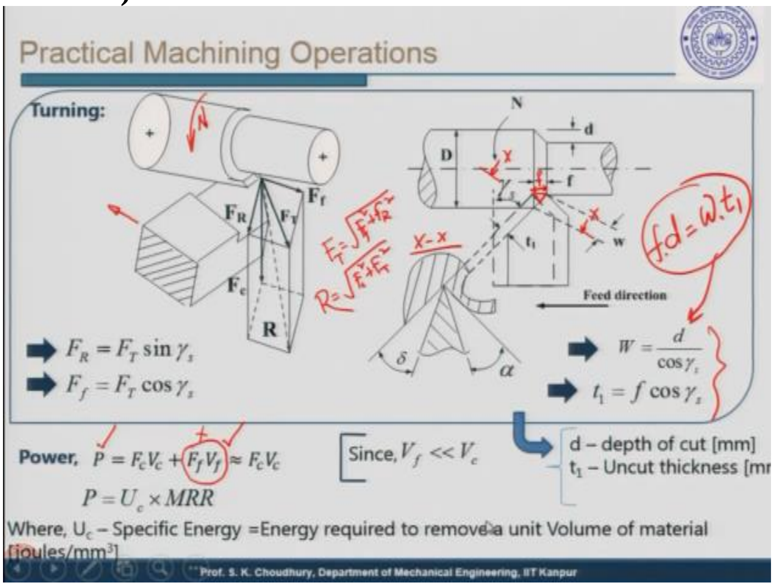

What is shown here is the turning process. This is the pictorial view or the 3-dimensional view. This is the work piece and the tool is here, tool is mounted on the tool post which is not shown here. The work piece rotates; let us say this is the N rpm and the material is removed as the tool is being fed along the axis of the work piece; this is axis of the workpiece.

During the discussion in previous sessions, I explained that this is the feed force which is along the feed direction, that is why it is called the feed force. This is the radial force which is radially directed and they are summed up on the horizontal surface, this is the F_T which is the summing of the F_R and F_f.

F_T is the thrust force, this is $F_T = \sqrt{F_f^2 + F^2_R}$. So, this is the thrust force and the cutting force will be here in the vertical direction and from this point to the front point below is the resultant force so the resultant force will be equal to $\sqrt{F_c^2 + F^2_T}$.

Bigger diameter is the initial diameter of the work piece and the smaller one is the diameter which is being obtained after the tool has moved from this point to this point. The tool has moved from this point to this point with one revolution of the work piece. Therefore, this is the feed value whereas, the direction of the feed is as shown in the slide.

Now, from here to here, shown in the slide, is the width of cut and if you take the cross section here like this, you will get this view or the sectional view. Let us say this section we will take from here through this tool like this. So, this is the cross sectional view, let us say X-X. If we take the section through this, this is the tool not fully shown, it is hatched because it is sectioned and this is the work piece, not fully shown here.

This is the chip being formed; the chip will be formed that you will be able to see if you look at the perpendicular to this face. You cannot see it here, but if you take this section, then the chip will be visible and therefore, if you take the tangent to this chip and then with respect to this rake face of the tool, this will be the rake angle, α and with respect to the flank face, flank angle is here, which is made between the flank face of the tool and the already machined workpiece surface.

So, these are the angles that I have shown you earlier also. The geometrical parameters from the triangles from here let us say w which is the width of cut is equal to $w = \frac{d}{\cos \gamma_s}$ this in fact I already told you earlier, this you can find out from this triangle. γ_s is here which is the side cutting edge angle given in ASA or coordinate system of tool nomenclature.

Similarly, t_1 is the uncut thickness this is equal to $t_1 = f \cos \gamma_s$. That you can find out from this triangle, this small triangle, as shown in the slide.

As you can see that the product of feed and depth of cut is the same as the product of width of cut and the uncut thickness. Now, as far as the forces are concerned F_R is the radial force, this is $F_R = F_T \sin \gamma_s$ γ_s is the side cutting edge angle and the $F_f = F_T \cos \gamma_s$. This is the relationship of the forces with respect to thrust force, F_R is the radial force, F_f is the feed force and F_T is the thrust force on the horizontal plane.

Now the power which is as I said is the product of F_c and the $\underline{V_c}$. Here, as you can see that this is the product of $F_c V_c$ and + $F_f V_f$. That is, power $P = F_c V_c + F_f V_f$. That means we have to consider the feed velocity, V_f along with the cutting velocity. However, in practice V_f is much less than the V_c.

Since V_c is much more than the V_f therefore, we ignore it and the result that you get while considering that the power is a product of F_c and the V_c only, this is not so much of erroneous value. Power can also be expressed through the specific energy, U_c and the material removal rate, *MRR*.

Specific energy is the energy required to remove a unit volume of material as it is given here and this is given in Joules/mm^3. This is the MRR, which is the product of area and the velocity. Since it is turning, so, the area will be the feed, *f* multiplied by the depth of cut, *d*.

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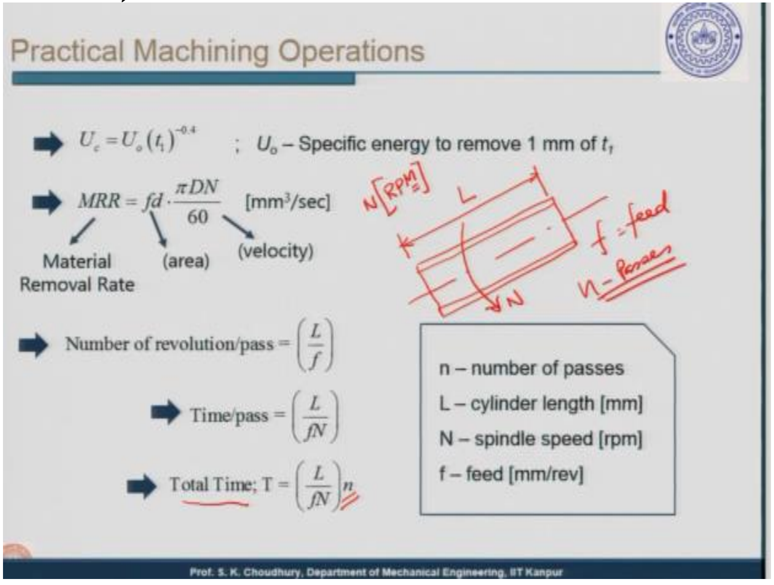

Velocity is the cutting velocity; this is $\frac{\pi DN}{60}$ and 60 is because the *N* is in rpm, revolution per minute. So, minute we are converting to second. The specific energy, U_c can be expressed as $U_c = U_0 (t_1)^{-0.4}$ where U_0 is the specific energy constant.

specific energy constant, U_0 is defined as the specific energy to remove 1 *mm* of uncut thickness, t_1. Suppose, we have a rod which is being turned. Let us say a cylindrical work piece having length of L.

And this is being machined in *n* number of passes with the feed of *f*, and *N* is the revolution per minute, in that case the number of revolution per pass will be given by $\left(\frac{L}{f}\right)$, you understand that the number of revolution per pass will be inversely proportional to feed, *f* because *f* is the advancement of the tool in millimetre or linear advancement of the tool with 1 revolution of the work piece.

It will be, therefore, inversely proportional to *f*; more the *f* , less will be the number of revolution per pass. It will also depend on *L* because more the *L*, more will be the number of passes, this is also obvious because it will take more time, the time per pass. Therefore, it will be dependent on the N that is, if it is rotating at a higher speed, the time taken will be less and vice versa.

So, it is inversely proportional to *N*. Therefore, the total time taken, *T* will be $\left(\frac{L}{fN}\right)n$ where *n* is the number of passes. This means suppose we have to have the depth of cut as *d*, and this depth of cut could not be taken in one go.

In that case, it can be machined in 2 or 3 passes depending on what is the value of the depth of cut. If the value of the depth of cut is large enough, in that case we need several passes. Now, several passes also required when we need to have the surface finish higher. Initially you take the larger depth of cut in the first few passes because in the first few passes you do not bother about the surface finish. Focus will be more on the material removal.

That we will explain when we will discuss the topic on the surface roughness, surface finish. Now during the final pass or final 2 passes you take relatively less depth of cut, so that the finishing operation can be performed and the required surface finish can be achieved. Therefore, in the few passes the entire depth of cut will be removed and that number of passes has to be included here to find out the total time.

This is important because you have to find out the total time required so that you can estimate the cost of this part. More time it takes to machine, the cost will be more and that will be discussed in the economics of machining chapter.

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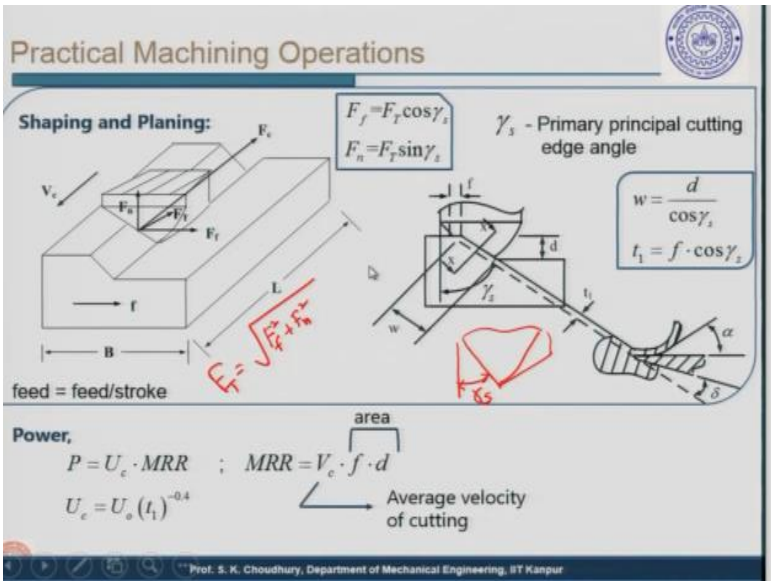

Now, let us see in case of shaping and planning. In case of shaping and planing, you can see that the forces which are acting during the process is different than in case of turning. First, let me tell you few things about shaping and planing. I will tell you in more details in the laboratory, we will show you the shaping machine in action, I mean how the shaping machine works.

Both the shaping and the planing operations are used to get the flat surfaces as well as the inclined surfaces, or groove etc. Now, the tool that is used in the case of both shaping and planing is very similar to the turning tool, we can see that. Now, the difference between the shaping and the planing machine is in the quick return mechanism.

For example, when the tool moves forward, it removes the material, then it goes back to the initial position, ready to take the second cut or the second pass. During that movement, that is, when the tool moves forward and goes back, this is called a stroke. During 1 stroke, that is tool moving forward and going back, the work piece is given a certain amount of feed.

So, after one stroke of the tool, the work piece will be positioned for the next cut and the tool moves again in the forward direction. This way the entire flat surface will be machined. You can see from the diagram that this flat surface has already been made. So, in case of shaping operation, the tool moves forward and backward and the workpiece is given an incremental feed in between each stroke.

Now, during the backward movement, the tool does not remove material. Therefore, the tool moves backward at a higher speed. For this purpose there is a quick return mechanism which makes the tool move forward at a certain speed and move back at a higher speed.

This quick return mechanism is different in case of planing and shaping. In case of shaping, the tool reciprocates, it moves forward and goes back. In case of planing, it is opposite, that is, the work piece moves to and fro and the tool is given a feed because in case of shaping, normally the smaller work pieces are machined and in case of planing the work piece lengths or the size of the work piece will be much bigger.

Therefore, you cannot make the tool travel at that bigger length. Tool is in that case is stationary for planing, and the work piece reciprocates. The stroke then will be the work piece movement forward and backward. After one stroke the tool will be given a feed perpendicular to the direction of this stroke.

For example, the shaping process is shown here. Shaping tool reciprocates and the feed is given in the direction perpendicular to the movement of the tool.The forces which act here on the shaping and the planing are different now, here it is the feed force, feed force will be also along the direction of the feed. This is the normal force F_N and the normal force is perpendicular to the already machined surface, this surface.

Sum of F_N and F_f will be F_T meaning that $\sqrt{F_f^2 + F_N^2} = F_T$ like in case of turning but in turning it was the radial and the feed force here it is the feed force and the normal force. The cutting force will be directed perpendicular to the this direction and along the V_c ,V_c is the cutting velocity.

The cutting velocity in this case is the movement of the tool because tool reciprocates, it moves at a relatively lower speed while moving forward and at a higher velocity it moves back. So, this is the cutting velocity and the feed velocity is given to the work piece. $F_f = F_T \cos\gamma_s$ as in case of the turning and similarly, $F_N = F_T \sin\gamma_s$.

Now, in this case the γ_s is this angle and in case of shaping it is called the primary principle cutting edge angle. This is the different than the γ_s in case of turning. Here, this is the primary principal cutting edge angle because this is the principal cutting edge for the tool.

This is the schematic diagram and here you can see the geometrical parameters, such as feed which represents the movement of the work piece here because the feed is given to the work piece along the direction of perpendicular to the V_c in 1 stroke, this is the feed because as I said the tool moves forward and after it goes back then only the feed is given to the workpiece.

This is the feed f. Similarly, this is the depth of cut. I will discuss the other parameters which are here in my next session of discussion. Thank you for your attention.