Fundamentals of Manufacturing Processes
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Lecture – 38
Metal Removal Processes: Types of Chips & Power Consumption

Hello, I welcome you all in this presentation related with the subject fundamentals of the manufacturing processes and we are talking about the metal removal processes. In the last presentation I have talked about the actual chip formation approach. And we have seen that the shearing takes place a longer particular zone, not a at one plane and there are the 2 types of the deformation occur during the machining.

One is like the deformation occurring around the along the shear plane, and another deformation which is also shear deformation which occurs in the chips basically. The chips which are sliding over the rake face and when they slide under the pressure the secondary deformation takes place at the chip tool interface, and apart from that the chip formation actual chip formation is also affected by the work material and the cutting conditions.

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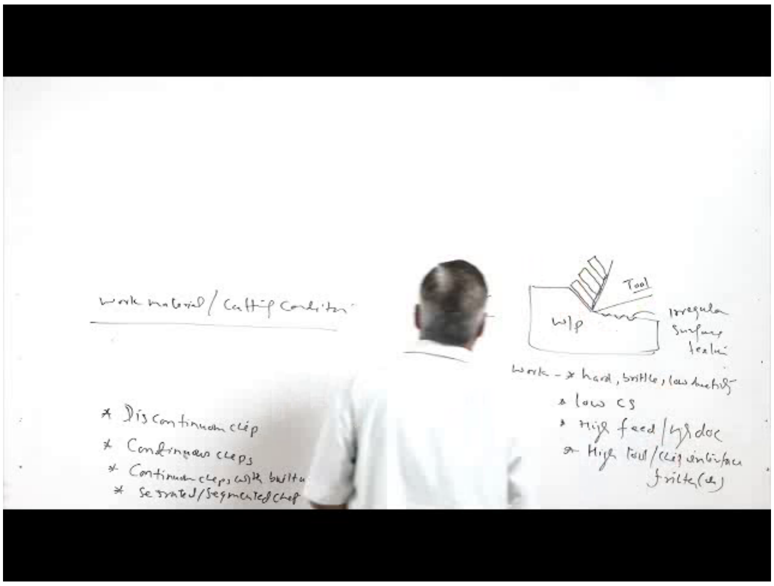

So, we will see that how the work material and the cutting conditions affect the chips which are being formed. So, basically we need to talk about the types of chips. So, in these there are 2 basically the components. One is the metal being machined. This is one aspect which significantly affect the type of chip which is being formed. And another is cutting conditions. So, among the cutting conditions, we have a cutting speed, we have a feed and dept of cut. All these 3 significantly affect the type of chip which will be formed. They basically there are 4 types of the chips which are commonly observed One is like discontinuous chips, the second is continuous chips, third is a continuous chips with built up edge, and 4th is serrated or segmented chips.

So, this these are the 4 types of the chips which are commonly observed. So, if we see the discontinuous chips are formed under a specific set of the conditions. Like say during the machining when the hard and brittle material is machined. So, what we will see that chips are being formed in form of the a small fragments like this. So, these will be separated from each other during the machining. So, when the discontinuous chips are formed, when the work material is hard brittle and of the low ductility.

So, this is about the work material, then among the cutting conditions which are favour such kind of the chips includes the like the low cutting speed and the high feed rate and high depth of cut also favour. The discontinuous chips formation and 4th is the high tool chip interface friction.

So, when the chips are moving on the face of the tool under the heavy frictional forces. So, means the mu is high, at the tool chip interface then it will also be leading to the discontinuous chips also. So, this is tool, this is work piece which is hard and brittle. So, the chips will be coming in form of very fragmented and very small size. So, when such kind of the chips are formed what we will see? Very irregular kind of the surface irregular surface texture is produced when the discontinuous chips are produced during the machining. Machining of the cast iron typically produces such kind of the chips.

Another one is the continuous chips. So, the conditions which a favour the continuous chips include continuous chips.

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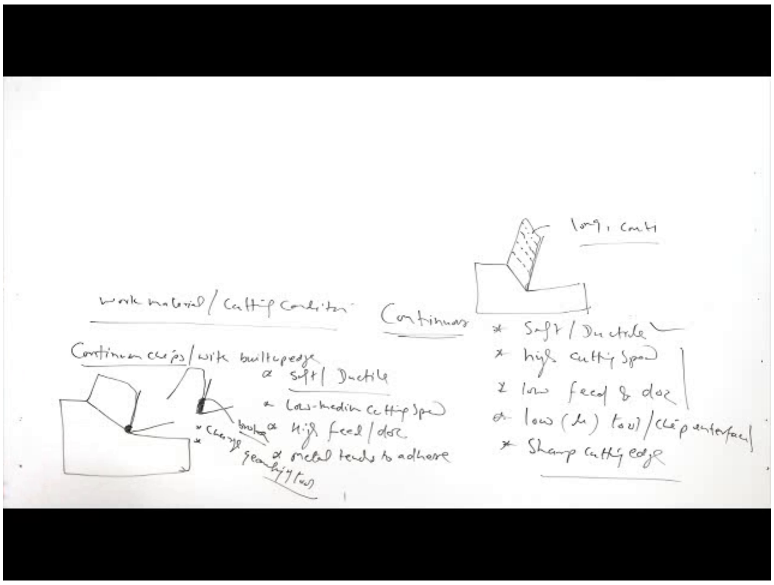

So, the condition required for requirement for this is material is soft and ductile. So, it favours the formation of the continuous chips. Apart from this when the continuous chips are formed when the cutting speed high cutting speed, while the low feed and depth of cut are used. Apart from that the low the mu value at the tool chip interface. So, means the chips are flowing smoothly over the face of the tool, and when it happens what we will see along the face of the tool, the chips will be flowing smoothly over the face of the tool.

So, continuous chip of this kind will be produced. These are just like say that the that the deformation features all the chip is the long and continuous. A such kind of chips although sometimes wrap around the machined work surfaces as well as around the tool so that leads to the deterioration of the surface finish apart from the, the con apart from these factors related with the cutting parameters work material and the frictional aspect between the tool and chip. The sharp cutting edge also favours the formation of the continuous chip. So, these are the 2 types of the chips.

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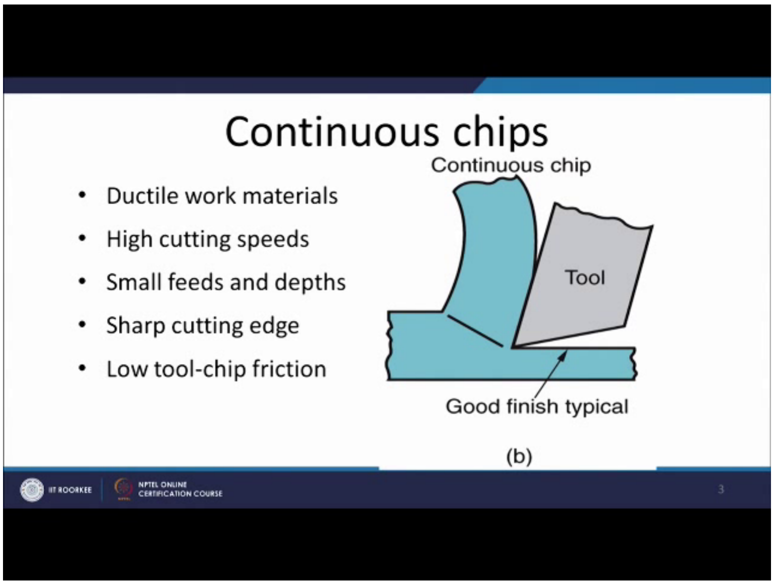

And the conditions under which these are formed, then we will see the built up continuous chips with the built up edge.

So, the continuous chips, the chips are continuous but with the built up edge. So, this kind of the chip is formed again when the material is soft and ductile, but the cutting conditions are unfavourable, such as low to the medium cutting speed and high feed and the depth of cut is used. So, these conditions will favour. At the same time metal tends to means the work material tends to adhere or cold weld with the cutting edge. So, when it happens what we will see the tool and the work piece. This is the machine surface. So, when the chips are formed these chips are also continuous, but sometimes the metal gets soft metal gets deposited on the cutting edge in course of the machining.

So, since the chips are continuously rubbing the built up edge. So, we will see that the actual phenomena which will be happening. The soft metal is getting embedded or adhered with the cutting edge this will inform of like this. So, this will be changing the changing geometry of the tool. This is one thing which happens. And since the cutting edge grows gradually as a function of time. So, it will be modifying the geometry of that tool. So, as soon as the cutting edge built up edge grows up to a certain limit under the pressure of the flowing chips it gets broken. So, once the chip is broken the sorry. Built up edge is broken it will be going with the chip.

So, the built up edge once the broken from the cutting edge is transferred to the 2 things. One is the part of the built up edge which is formed at the cutting edge like this part of it will be going to the surface of the work piece.

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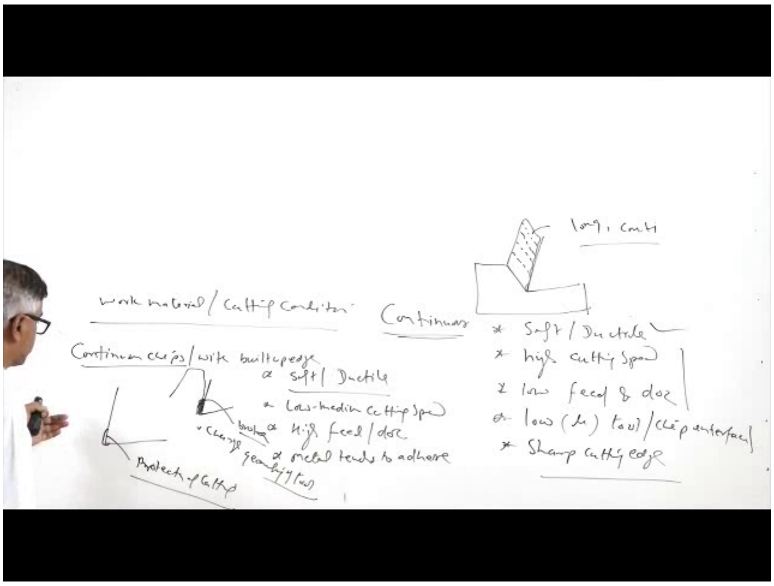

So, and the a part of it will be going with the chip which is flowing over the face of the tool. So, basically part of the built up edge is carried by the chips, and part of the built up edge is transferred while when this kind of breakage of the built up which takes place, sometimes it breaks a piece of the tool surface also. So, in that way it adversely effects to the tool, but at the same time if we see the built up edge is deformed plastically adheres and the cold welded. So, it gets hardened and protects the cutting edge also.

Apart from the modifying geometry it may also leads to the protection of the cutting edge. And so, the cutting edge interaction directly with the work pieces isolated while the built up edge interacts with the work piece during the machining. So, this situation may lead to the improvement in the life of the tool. So, these are the conditions which will be favouring the formation of the built up edge. Built up edge a generally lowers the surface finish and increases the surface roughness, because part of the built up edge is transferred to the work piece.

So, this is what we can see here, the ductile material, low to the medium cutting speed, and the chip tool into a friction leads to the bonding of the Chip material with the rake phase leads to the formation of the built up edge like this.

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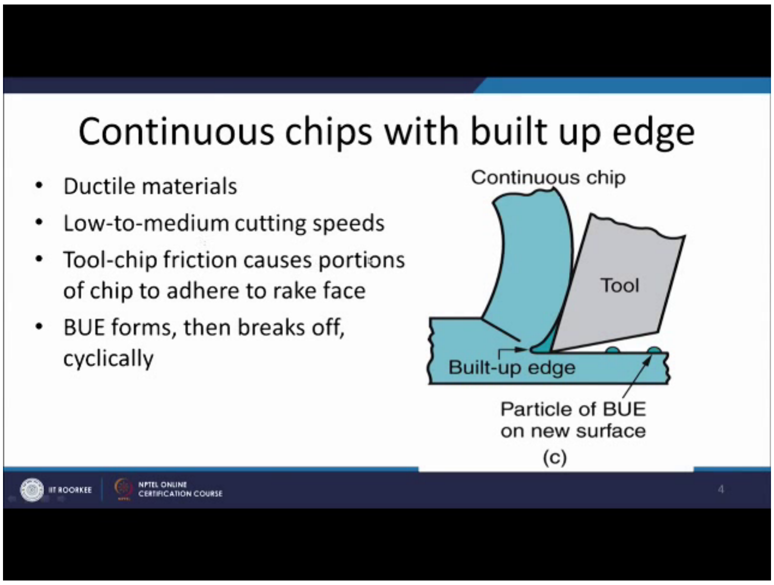

And this built up edge grows gradually and eventually it gets broken, than and when it breaks it is transferred to the chip as well as to the work piece. So, when the built up edge is transferred to the work piece, it adversely effects the surface roughness. Mostly it is a this kind of the chips are formed when the material is soft, ductile and unfavourable cutting conditions. Exist like low cutting speed high feed and depth of cut.

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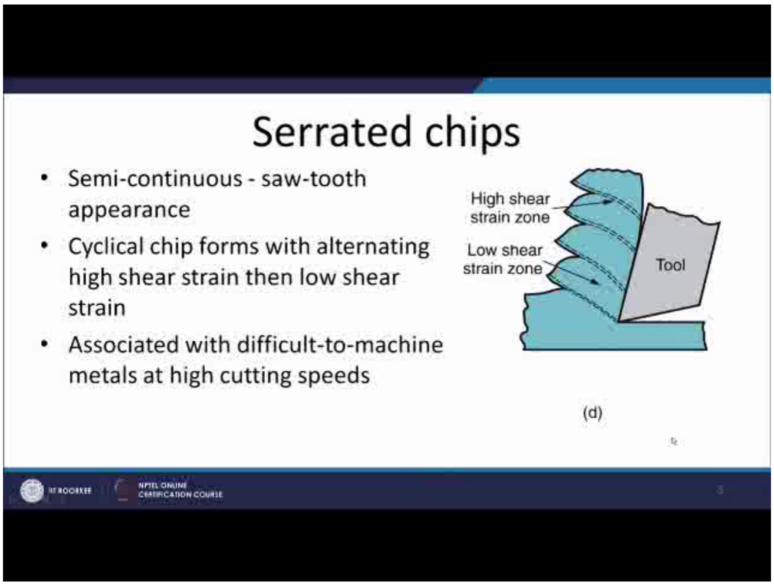

The 4th type of the chip is the serrated chip or segmented chip. This kind of the chip offers typically saw toothed feature. Saw toothed means like if we see any hexa it will have the built blades like this, and which will be performing the cutting.

So, similar kind of the feature is also present here, like this. This is the saw tooth feature which is present. And when this kind of this kind of chip is formed especially when the difficult to machine materials like super alloys, nickel alloys, titanium, stainless steels are machined under the high cutting speed conditions. So, under these conditions the 2 types of the zones are formed during the chip formation. One is of the low shear strain zone another is a high shear strain zone, and which in turn leads to the formation of this saw toothed geometry. So, these are the 4 types of the chips which are formed during the machining, depending upon the cutting conditions and the type of work piece material which is being machined.

Now, we will see the kind of the forces which will be generated during the machining and the power consumption aspects. So, cutting forces and the power consumption during the machining. So, how we can analyze and how we can look into this aspect. So, for this again we need to see the typical analysis is carried out for the orthogonal cutting conditions when the cutting edge is perpendicular to the direction of the cutting velocity.

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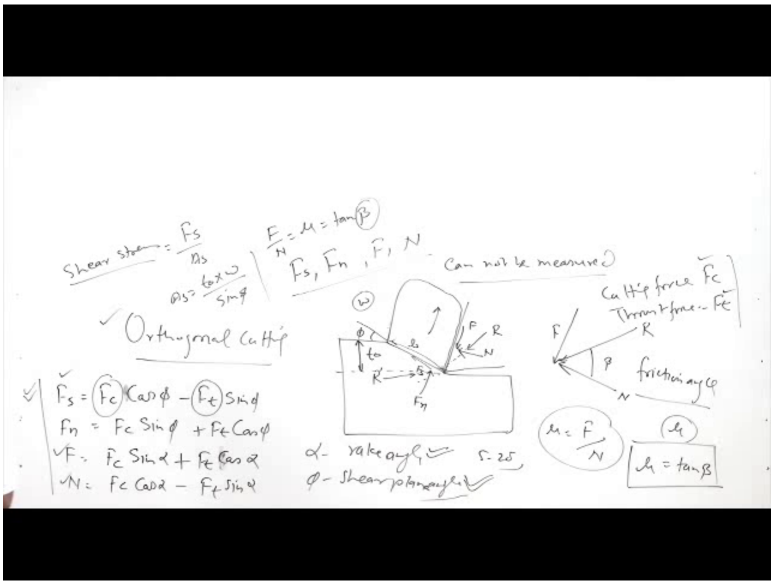

So, here if we see this is the work piece, this is the shear plane, this the rake face, this is the flank. And this is how the chips are being formed and flowing over the face of the tool. This plane is termed as phi or shear plane angle. And this is the machined surface.

So, we know the shear stresses will be acting on to the shear plane to cause the shear deformation. So, F s we can termed as the shear force. And normal to this one additional force will be acting which will be written as F n normal to the shear plane angle. And resultant of these 2 will be acting like this R. So, combination of the shear force and the normal force these 2 shear force F s and the normal force F n on the shear plane the resultant force of these 2 will be the say R dash. Similarly when the chips are flowing over the face of the tool frictional effect comes into the picture over the tool face.

So, the frictional effect comes into the picture. So, friction force will be acting in direction opposite to the direction of the flow of the chips, and a one normal force will be acting perpendicular to this chip tool a interface. So, this is the friction force, and this is the normal force. And these 2 will also we having one resultant force which is say R. So, these 2 R's like R and R dash. They should be acting they should have a specific feature, which is that R should be equal to R dash. They should be equal in magnitude, they should act in opposite direction and third is opposite direction, and third is they should be collinear for ensuring that entire cutting system is under equilibrium and the metal is being removed continuously. So, of the friction between the.

So, to describe this situation this is the friction force F and this is the normal force resultant force R will be expressed like this. So, angle between the normal force and the friction force, a normal force and the resultant force is expressed as a beta which is called the friction angle. And used for calculation of the coefficient of the friction. So, here if we have to calculate the shear stress shear stress acting on the shear plane facilitating the removal of the material by forming the chip, what we need to do? The shear force is to be divided by the shear area. So, shear area will be calculated by this length which is called l s or shear plane length, and the width along the width of the width along which cut is taking place w.

So, if we have to calculate the shear area, shear area will be obtained we need to consider the uncut chip thickness t naught. So, the t naught multiplied by the w that is the width along which is the cut will be taking place divided by the sin phi. So, t naught into the w, t naught is the uncut chip thickness that is the depth of cut, and w is the width over which cut will be taking place, and sin phi is the angle at which shearing will be taking place. So, this is what we can show here the t naught into w divided by shine the sin phi.

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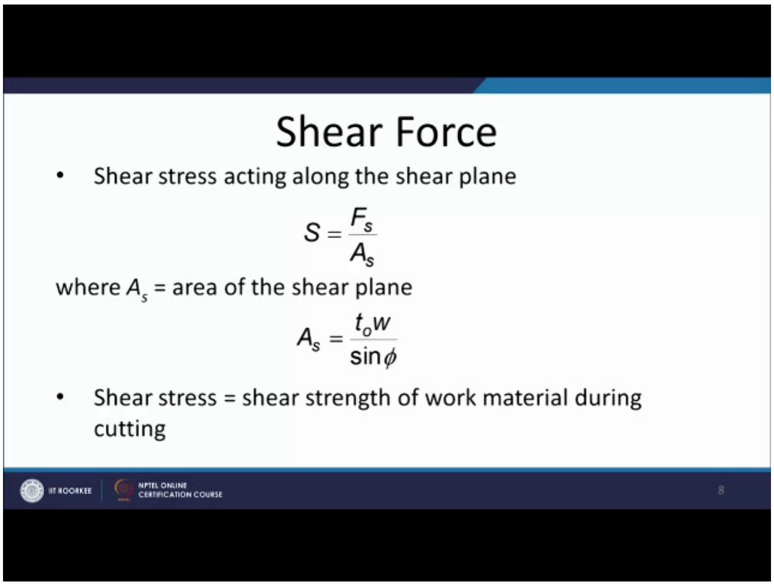

This will give us the shear area. So, this shear area is shear stress can be calculated from the shear force divided by the shear area.

So, these are the forces F s is the shear force, F n is the normal force acting on the shear plane, F is the friction force and F is the normal force acting on to the at the tool chip interface. So, these are the 4 forces, which actually will be acting during the machining, but these can not be measured. What we can measure is during the cutting is the cutting force F c and the thrust force, thrust force F t. These F c and F t can be calculated can be measured during the machining with the help of the tool dynamometer. So, basically F c and F t are the measurable parameters and using these 2 forces we can calculate the F s F n F and n.

But for this one typical merchant theory is used for calculating these forces. So, if we try to find the relationship here the mu is basically the F by n, the friction force regard divided by the normal force and mu is also express as tan beta tan, mu is equal to the tan beta for the friction coefficient. So, as. So, the coefficient of friction mu is equal to the tan beta is the friction angle. So, it is the angle between the normal force and the resultant force which due to the friction force and the normal force. So, considering these equations.

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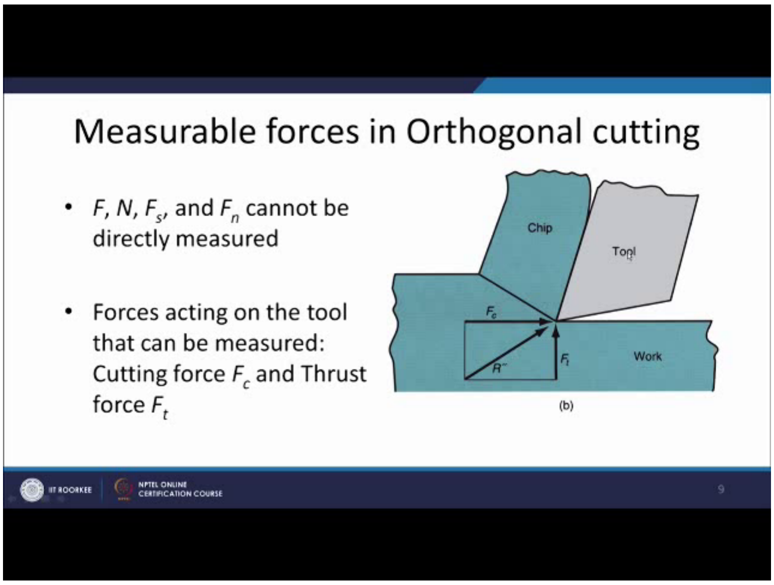

If we move further like say this is the condition that the chip, work piece, the tool, shear plane and the cutting force acting in this direction, and the thrust force is acting in this direction and resultant of these 2 will also be R dash. These are these 2 are the measurable forces which can be measured with the help of the cutting tool dynamometer.

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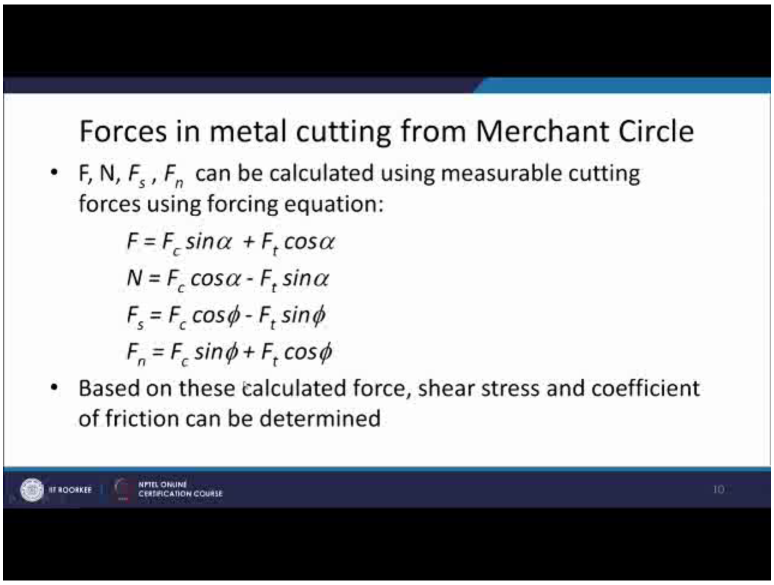

So, the facts force is acting on the tool which can be measured or F c and F t, and these 2 forces can be used for calculating the further other forces like F s, F n, F and n. So, like the friction force F can be obtain can be obtained using the equation, like F c sin alpha plus F t cos alpha. And the normal force can be obtained through the F c cos alpha minus F t sin alpha. These equations are derived through the merchant circle since it requires very elaborate the diagram.

So, just so, under the simplified conditions for the orthogonal cutting, these are the equations which are used for calculating the friction force normal force F n the normal force acting on to the shear plane and the shear force. Similarly the shear force can be calculated using the F c cos phi cos phi minus F t sin phi, and the similarly F n can be calculated using the F c sin phi plus F t cos phi. So, what are these alpha? Is basically the rake angle and phi is the shear plane angle. So, shear plane angle calculation of the shear plane angle, we have already discussed in the last presentation. And the alpha is that where rake angle would be positive negative normally the for the tough tools it is given as a 5 to 20 degree.

So, using since the F c and F t are the measurable parameters which can be measured with the help of the lathe tool dynamometer. So, these can be used for calculating the F s, F n friction force and the normal force. Using these equations further we can calculate the shear stress acting on the shear plane, because we have already seen that fx divided by as will be giving us the shear area where as is equal to t naught into the w that is width of cut divided by sin phi. Phi can be calculated using the alpha value and the uncut chip thickness and the chip cut chip thickness the so, those are the things which can be used for calculating the shear force. Similarly the ones if we are aware of the norm friction force then F divided by n will be giving us mu.

So, using this we can calculate the friction angle beta. So, once if you are aware of the F and n, we can calculate mu. And using mu we kin we can calculate the coefficient of the friction or the friction angle. Based on this approach of the merchant theory, the merchant had analyzed and he had obtained the conditions for the shear plane angle and why does the shearing will be occurring along a one particular plane for a given set of the conditions. So, he had optimized basically he had established one equation with the help of this merchant theory, and he had obtained that the conditions for conditions which will be leading to the minimum energy requirement for shearing can be obtained through the say through the values of the friction angle and the rake angle.

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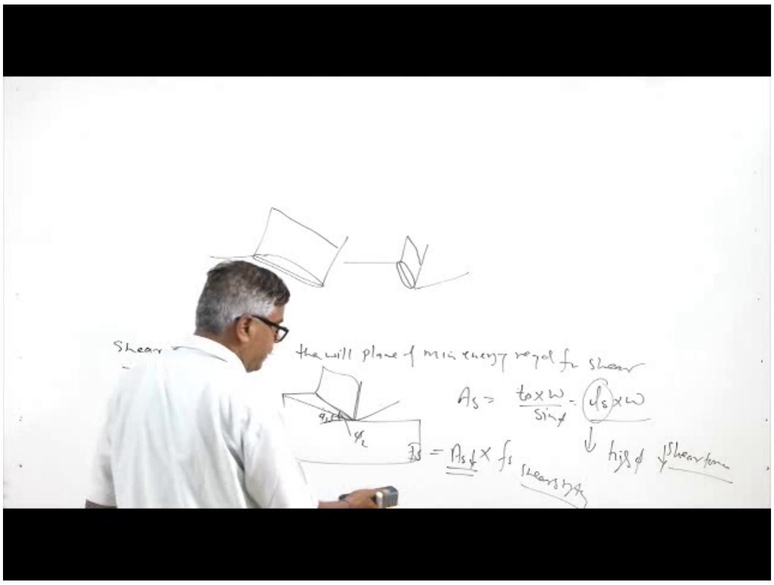

So, this he states that shear plane angle along which sharing will take place, this will be the plane of the minimum energy required for shearing. So, means the plane for a given material given set of the conditions, the shearing will occur along a particular plane like this. And which this plane this may be like this, or this plane may be of further lower value. So, depending upon the phi value may be phi 1 or phi 2. So, if the phi 1 is lower and phi 2 say is higher, this is phi 2 and this is phi 1. So, if the phi 1 is lower than the phi 2, then what it will lead to the like if the shear plane angle is low.

Then under the identical cutting conditions the shear area will be wide while in the case when the shear plane angle is high under the identical conditions it will leel it will be leading to the shorter shear area. So, it is always good to have the phi value as high as possible so that the shear plane length can be reduced. Since the shear area as is the function of the t naught into the w divided by sin phi, which is basically l s into the w. Ls is the shear plane length, and if the shear plane length is getting reduced by using the high value of the phi then it will be reducing the shear force required Because of the reduction in shear area under that identical conditions.

So, if a if the as is reduced since the as multiplied by the F s that is the shear strength of the material which is fixed. So, reduction in the as will be leading to the reduction in the shear force required. If the shear force required gets reduced due to the reduction in the shear plane length or the shear area, then it will be reducing the power which is required for the machining purpose. So, it is always preferred that the shear plane angle is high. So, considering these things in mind the merchant had the derived one equation of in such a way that the shearing will take place along a particular plane, which will require the minimum amount of the energy.

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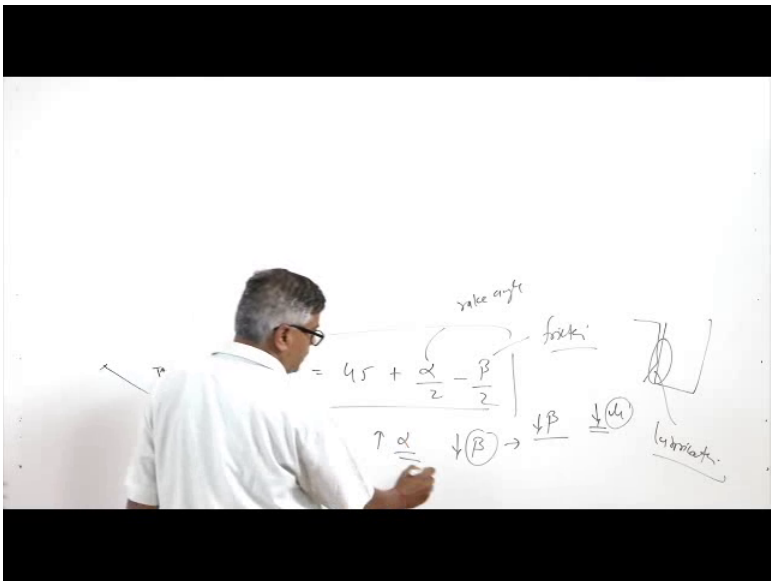

So, 45 plus alpha by 2 minus beta by 2. So, where alpha is the rake angle, and beta is the friction angle. So, this gives us the shear plane angle corresponding to the corresponding to the minimum energy requirement. So, as we have just seen that when the shear plane angle is low, shear plane length is more under the identical conditions as compared to the case when the shear plane angle is high. So, the high shear plane angle results in the lower shear plane length, and this in turn will be reducing the F s value, and which in turn will also be reducing the power required for the shearing purpose. So, if we see this equation the alpha value, if we increase the alpha value you means the fight can be increased by increasing the alpha or by reducing the friction.

Friction angle beta. So, beta is what is the friction angle. So, this we need to reduce for reducing the friction angle we need to reduce the friction coefficient. If the friction coefficient between the chip and the tool is to be reduced, then we need to lubricate the chip tool interface. So, basically use of the lubrication between the chip and tool interface means at the tool chip interface helps to reduce the friction, which in turn will be reducing the beta, and the reduction in beta value will be increasing the phi. So, it is always good to use the higher value of alpha, and overvalue and better to have the lower value of the beta by having the proper lubrication at the chip tool interface So that the higher shear plane angle can be achieved. So, in light of the above if we see that we have got the cutting force which is required for the metal removal, and we have the cutting velocity.

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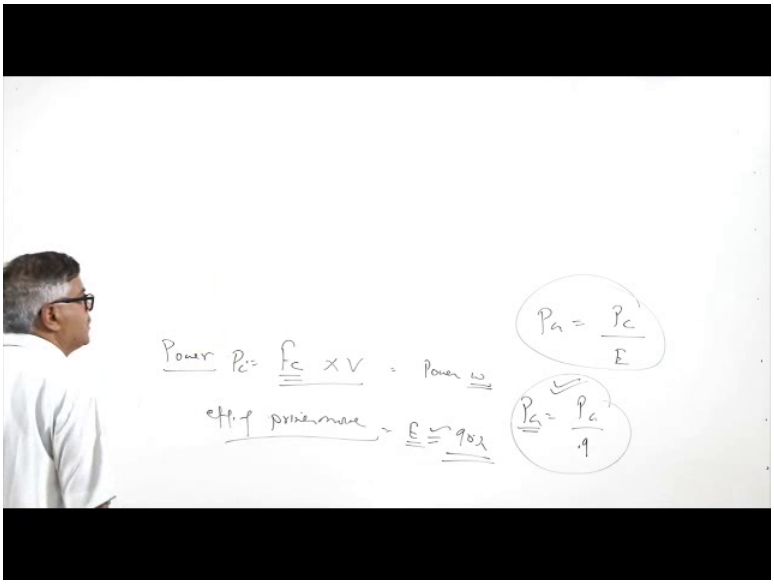

So, the power for machining can be obtained from the F c that is the cutting force multiplied by the cutting velocity. So, if F c is in Newton, and cutting velocity in meter per second, then it will be giving us directly the power required in watt. So, this is one thing like the cutting force multiplied by the cutting velocity will give us the power required for the metal cutting, considering the efficiency of the prime mover or the driver prime mover or the driving system.

So, if E is the efficiency of the system then we can calculate the gross power required P G. So, like say the pc is the power required for cutting then P G is the gross power required which means the P G divided by P G is equal to pc that is the power required for cutting divided by the efficiency. So, if the system efficiency is one than means the 100 percent then the gross power required to be delivered to the machine tool will be equal to the power required for cutting. Since the efficiency is not always 100 percent or this is generally less than the 100 percent, say normally it is considered 90 percent.

So, 0.9 we need to divide. So, the E is normally considered 90 percent for calculation of the gross power to be supplied to the machine tool for calculating the, for ensuring that machining takes place. So, the gross power is obtained for power required for cutting divided by the efficiency of the prime mover system. So that is how we can calculate the power required for the machining purpose.

So now, I will summarize this presentation. In this presentation we have talked about the 4 different types of the chips which are formed for the different types of the work materials and then the different set of the cutting conditions, apart from that we have also seen that how can we obtained the different forces acting in the metal cutting zone. And how can we obtained the power required for the machining purpose.

Thank you for your attention.