Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology – Part -1

Module – 43

By
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Hello and welcome to this manufacturing process technology part 1 module 43.

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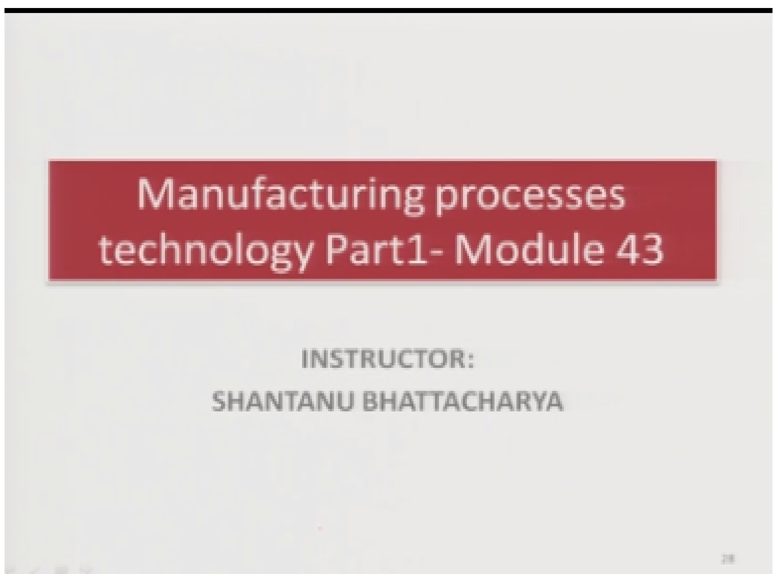

So brief recall about what we did in the last lecture we were talking about various temperatures which have arrived at during the cutting process in either the tool side or the work piece side of the cutting zone. And we in fact actually suggested a model where which you could actually predict the temperature of the various fronts and then also estimate what is the overall cutting temperature in the cutting zone you know through some experimental and some modeling based mechanisms.

Today we are going to look at actual numerical design of the temperature of the cutting zone and I am just going to make.

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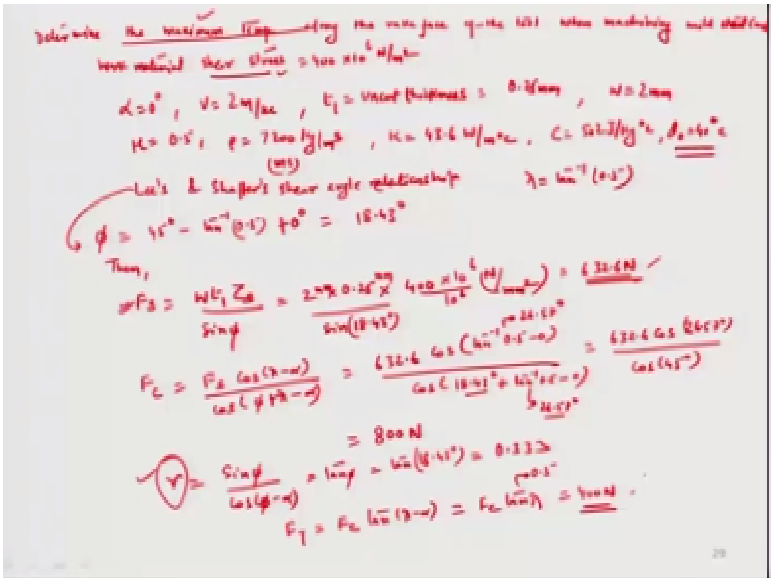

$$\rightarrow \varnothing = 45^o - \tan^{-1}(0.5) + 0^o = 18.43^o$$

$$\rightarrow F_s = \frac{w t_1 \tau_s}{\sin \varnothing} = \frac{2 * 0.25 * 400 * 10^6}{10^6 * \sin 18.43^o} = 632.6\, N$$

$$\rightarrow F_C = \frac{632.6 \cos 26.57^o}{\cos 45^o} = 800\, N$$

$$\rightarrow r = \frac{\sin \varnothing}{\cos \varnothing} (as\, r = 0) = \tan \varnothing = 0.333$$

$$\rightarrow F_T = F_C \tan(\lambda - \alpha) = 0.5 * 800 = 400\, N$$

$$\rightarrow F = F_C sin\alpha + F_T cos\alpha = 392\, N$$

Sort of case here where we have to determine the maximum temperature along the rake face of the tool when machining mild steel given the following conditions work material shear stress is around 400 $*10^6$ N /m^2 this is the ultimate shear stress of the work material the total amount of rake angel that the tool makes with the vertical is 0 in this particular case the velocity with which cutting is happening is 2 m/s we also given the the uncut thickness t_1 as 0.25 mm we are also provided the width of the cutting zone as I think I had illustrate it in the last lecture the zone you know for the total width coming either out or going in to the page you know for the two dimensional view that we showed.

So that is 2 mm there is a coefficient friction μ which is 0.5 a total amount of 7200 kg /m^{3}density the density of the mild steel of the material whatever is being used in this particular case it is mild steel, we also have been given the values of thermal conductivity of the mild steel sample as 43.6 watts /m$^{0\,C}$ the total specific heat capacity of the material as 502 J /kg degree C the ambient temperature where this whole process is taking place where you can assume this to be the base line temperature is about 40^0C.

So it has been sort of given that you know the particular case would like to deploy Lee and Shaffer's the shear angle relationship, and we are ask to find the maximum temperature of the rake face of the tool surface okay. So first of all let us try to put down the Lee and Shaffer's relationship here is 5 = $45^0 - \lambda$ tan inverse of μ, μ is 0.5 so λ the friction angle is basically tan inverse of 0.5 plus the rake angel α and this comes out to the equal to 18.43^0.

$$\rightarrow \varnothing = 45^o - \tan^{-1}(0.5) + 0^o = 18.43^o$$

Then we would like to find out the shear force F_S which can be given from the equation $F_S = w\, t_1\, \tau\, s$ / sin of φ in this particular case the w is given out to be 2mm. the total uncut chip thickness has been given to be 0.25mm. the total shear stress of the material that is the ultimate shear stress of the material has been given as 400 x 10^6 N /m^2. So I have to simply divide this by 10^6 to make it N/mm^{2,} so the units can be consistent this is mm this is mm and this has to be divided further by sing of φ which is φ of 18.43^0 and this comes out to equal to 632.6 N, so that is who much shear force is needed to do the machining operation.

$$\rightarrow F_s = \frac{w t_1 \tau_s}{\sin\varnothing} = \frac{2 * 0.25 * 400 * 10^6}{10^6 * \sin 18.43^o} = 632.6\, N$$

We also use the relationship cutting force F_C = the shear force F_S cos of λ – α / cosign of 5 + λ – α so that is F_C and F_C in this particular case can again be written down as 632.6 n times cos of tan inverse of 0.5 – 0 and this write here is 26.57^0 divided by the cos of 45 which can be broken down in to the cos of φ obtained earlier has 18.43^0 + λ which is about 26.57^0 tan inverse of 0.5 26.57^0 – of α which is actually going to 0^0 in this particular case.

So this comes out to be 632.6 times of cosign 26.57^0 divide by cosine of 45 ∑ 18.43 and 26.57, so the F_C the total cutting force comes out to be equal to 800 N. let us try to find out the chip thickness ratio are which is actually given as in this particular case as sin φ divided by cos of φ – α, α being 0 = tan of φ, φ being 18.43^0 so this becomes tan 18.43 ^{0} which is actually 0.333 so that is how you defined the chip thickness ratio are in this particular case you already know that ft the total tangential force is dependent on F_C tan of (λ – α) from the force relationships earlier through merchant circle.

$$\rightarrow F_C = \frac{625 \cos 26.57^o}{\cos 45^o} = 800\, N$$

$$\rightarrow r = \frac{\sin\varnothing}{\cos\varnothing}(as\, r=0) = \tan\varnothing = 0.333$$

So this becomes equal to F_C tan λ, tan λ being equal to 0.5 and so therefore the F_T becomes equal to 400 N. so these are all needed as you may recall in finding out the expression for the temperature there are various zones primary secondary etc from which contributes to the heat flow and rise in temperature.

$$\rightarrow F_T = F_C \tan(\lambda - \alpha) = 0.5 * 800 = 400\, N$$

$$\rightarrow F = F_C \sin\alpha + F_T \cos\alpha = 392\, N$$

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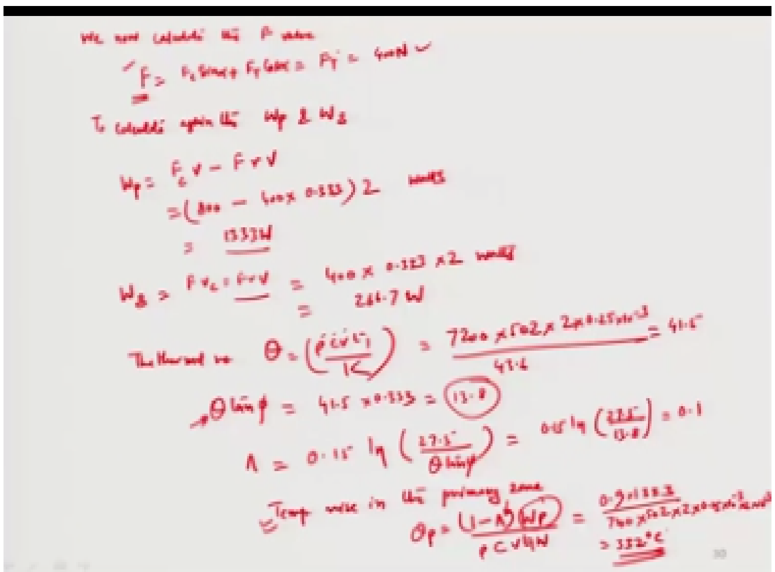

$$\rightarrow W_P = F_c v - Frv = (800 - 400 * 0.333) * 2 = 1333\, W$$

$$\rightarrow W_S = F v_c = Frv = 400 * 0.333 * 2 = 266.7\, W$$

$$\rightarrow \Theta = \frac{\rho c v\, t_1}{k} = \frac{7200 * 502 * 2 * 0.25 * 10^{-3}}{43.6} = 41.5$$

$$\rightarrow \Theta \tan\varnothing = 41.5 * 0.333 = 13.8$$

$$\rightarrow \Lambda = 0.15 \ln\left(\frac{27.5}{\Theta \tan\phi}\right) = 0.15 \ln\left(\frac{27.5}{13.8}\right) = 0.1$$

$$\theta_P = \frac{(1-\Lambda) W_P}{\rho c v\, w t_1} = \frac{(1-0.1) * 1333 * 1000 * 1000}{7200 * 502 * 2 * 0.25 * 2} = 332\, o_C$$

We now calculate the F value from the force relationship sustained earlier through merchant circle f is basically related to F_C sin of α + F_T cos of α so I can say in this particular case α being

0 it should be equal to F_T and F_T came out earlier to be equal to 400n so the force of friction F is basically 400 N in this particular case. So calculate again the primary and the secondary zone power consumption which we earlier defined as W_P and W_S we already know that W_P was recorded as cutting force times velocity minus of the friction force times the chip thickness ration times of velocity.

So we want to actually in this case do the same thing with cutting force already calculated earlier as 800 N minus of the friction force which we just calculated in the last step as 400 N times of the total chip thickness ratio which is 1/3 in this particular case times of the velocity the velocity here is 2 and so that can be recorded as watts, so joules per second and this comes out to be equal to about 1333 w. in a similar manner we calculate ws the our consumption the total power consumption at the secondary shear zone which is actually given with or given by FVC or FrV.

$$\rightarrow W_P = F_c v - Frv = (800 - 400 * 0.333) * 2 = 1333\,W$$

$$\rightarrow W_S = F v_c = Frv = 400 * 0.333 * 2 = 266.7\,W$$

So in this particular case that comes out to be equal to 400 times of 0.333 times of 2watts and this power can be calculated as 266.7 watts. So having set that let us now try to calculate what is the thermal number so the thermal number in this case the number θ as you may recall earlier is actually given as a ratio of ρ cv t_l/ k. please recall the derivations detail derivations in this area in the earlier lecture. So this can be calculated as 7200 times of 502 the specific heat capacity times of 2m/s velocity times of the thickness which is $0.25*10^{-3}$ you have to convert the thickness from mm to m is all units a SI and this you have to divide with the thermal conductivity 46.3w /m^0 C.

$$\rightarrow \Theta = \frac{\rho c v t_1}{k} = \frac{7200 * 502 * 2 * 0.25 * 10^{-3}}{43.6} = 41.5$$

So this thermal number than calculates as 41.5 let us also calculate what is the θ tan φ this terms comes out to be equal to 41.5 times of again tan φ which is 0.333 just as does in the earlier step. so the ratio θ tan φ comes out to be 13.8. We already know that we have to calculate the fraction of primary heat which goes in to the work piece which was defined as capital λ and this was recorded as 0.15* a natural log of 27.5 / θ tan φ this was as for the derivation made in earlier module.

$$\rightarrow \Theta \tan\varnothing = 41.5 * 0.333 = 13.8$$

$$\rightarrow \Lambda = 0.15 \ln\left(\frac{27.5}{\Theta \tan\phi}\right) = 0.15 \ln\left(\frac{27.5}{13.8}\right) = 0.1$$

So this comes out to be now equal to 0.15 times of ln 27.5/ 13.8 this is about 0.1, let us calculate what is the primary rise or primary temperature rise in the primary zone, so the temperature rise in the primary zone is defined as θ p = 1- λ the percentage of heat which goes in to the or friction of heat which goes in to the work piece times of the primary zone power consumption divided by ρ c v t_1 w.

So in this particular case we will have almost 10% of the total power going in to the work piece so about 90% is retained by the tool in the primary one or either by the chip or by the tool, so 0.9 times of W_P which we calculated earlier as 1333 watts divided by value of the densities 7200kg /m^3 times specific hat capacity which is 502 Joules /kg^0 C times the velocity which is 2 m/s times the uncut chip thickness is 0.25* 10^{-3} times of 2 again x 10^{-3}.

$$\theta_P = \frac{(1-\Lambda) W_P}{\rho c v\, w t_1} = \frac{(1-0.1)*1333*1000*1000}{7200*502*2*0.25*2} = 332 o_C$$

So this becomes close to about 332^0 C so the total temperature rise in the primary zone because of the primary shear of the power consumed it happens to be about 332^0 C.

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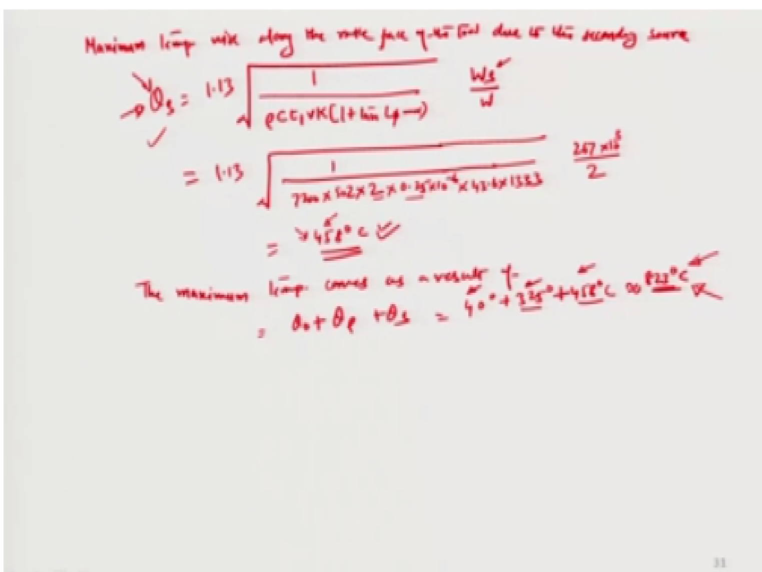

$$\theta_S \approx 1.13 \sqrt{\frac{\Theta t_2}{l}} \left(\frac{W_S}{\rho c v\, w t_1} \right) = 1.13 \sqrt{\frac{1000*1}{7200*502*2*0.25*43.6*1.333}} * \left(\frac{362*1000}{2} \right) = 458\, degree C$$

$$\theta = \theta_o + \theta_P + \theta_S = 40 + 325 + 458 = 823^o C$$

Now let us calculate the maximum temperature rise along the rake face of the tool due to the secondary source is give by θ_s = 1.13 √ 1/ ρ c $t_1$vk [1+ tan (φ-α)] times of total amount of power consumed in the secondary zone W_S divided by the width of the cutting zone w so we try to calculate what is the maximum rise of the temperature among the rake face because of this contribution from the secondary zone and that temperature comes out to be equal to 1.13 times of 1 divided by 7200 * 502 * 2mm * 0.25mm * 10^{-6} because this has to be converted both of them have to be converted in to be as times of 43.6 * 1333 watts whole under the root.

So it is 1/x t W_S which is coming out to be 266 or 267 watts from the last step divided by width of the cutting zone which is 2* 10^{-3} so this comes here okay and that happens to be calculated as 458^0C. so now we have the case that w have calculated the contribution of the temperature because of the secondary power the contribution of the temperature because of the primary cutting and so the maximum temperature comes as a result of the ambient θ_0 plus the contribution because of the primary plus the contribution because of the secondary power consumption and so you can record this as 40^0 plus 325^0 as from the primary plus 475 ^{0} C approximately 823 ^{0} C.

So I would like to specially recall the values of the primary and the secondary power as you can see here a temperature rise because of the secondary power is in this case recorded as greater than the temperature that is resin because of the primary power and one of the reasons probably is that you know because when we are talking about the secondary power it is actually between the chip and the tool surface and the chip is very small.

So it get heated up to a certain level of temperature very fast and so most of the heat dissipation in the secondary zone happens to be going in to the tool whereas in the work piece because of the larger mass of the work piece still there is some dissipation of heat because of which the cutting zone does not have so much of contribution you know in terms of temperature rise.

Because part of the heat has dissipated in to the large work piece which is thermal mass in this particular case. So the secondary temperature is always you know the secondary contribution is always little higher and particularly we are talking about the maximum secondary in this case mind you there is a distribution of temperature based on how the chip length that is interacting with the rake faces placed with respect to the rake face obviously the point which will have maximum pressure of the chip on the rake surface would have this temperature rise because of highest friction normal force being the highest.

And as the chip curls upwards and try to leave rake face temperature would definitely reduce so this is how you kind of classify or try to calculate numerically how you can you know really estimate the temperature of the cutting zone because of the contribution of the various components. So having set that now let us actually go back in to the whole machining process and try to look as what are the effects because of this temperature or what would really be the thermal map on the tools surface or the work piece surface or the chip surface.

And then because of such temperature rises what are the consequent effects on the chip formation process or for example on the surface finish process which would be obtained in the machining. So just to recall the total mechanism of chip formation and the associated get release happens in this way.

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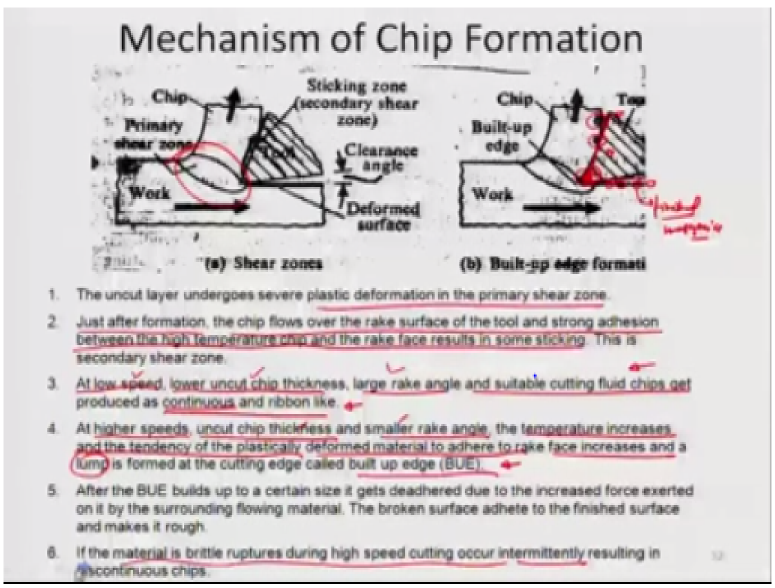

That the uncut layer undergoes severe plastic deformation in the primary shears zone you can see here this is the primary shear zone right about here just after formation the chip flows over the rake surface of the tool and strong a adhesion between the high temperature chip and the rake face results in some sticking action you can see this is a small you know points which are resulting from the sticking of the chip which is at a certain pressure and you can see the maximum pressure is somewhere here and as the chip bends you know able to deform from its work piece the pressure kind of gets in a distributed manner and it may not be equal at all points the maximum point may be where the chip actually is having you know the rake face as a tangent you cann do it.

So this is the secondary shear zone where these heating because of the rubbing action of the chip with respect to the tool rake face will take place at low speeds lower uncut thickness large rake angel and suitable cutting fluids the chips get produce as continues and ribbon like. I am going to come to this just by showing you some high resolution images of the chip formation process. So basically it is very obvious that if you have lesser depth of cut and you cutting at a low speed and then you know using kind of large rake angle and if you can have suitable heat dissipation by applying or cool in then it on the chip comes out like a ribbon in one continuity.

And this hardly any breakages that as the tool is moving or grazing along the surface of the work piece it is continuously producing the chips, there are no stresses or there are no very high stresses for the material to get embrittled and you know it is to get formulated in to different pieces. So at higher speeds uncut chip thickness and smaller rake angle the temperature increases and the tendency of plastically deform material adhere to the rake face also increases.

And a lump actually is formed which also known as a built up edge and you can see here that this built up edge is basically very determent to the overall surface finish because when this built up edge is a sort of an extended tool you can say which you now the tool kind of you know adhere to some of the some of the material from the surface of the chip and the material is severely plastically deformed so it is strain hard and quite a bit because of that.

And because of this hard and nature it kind of grazers and when it becomes brittle to an extent that it leaves start leaving residue it is starts leaving this residues on the flank face of the tool you know and which is actually the finished work piece surface. So this is the finished work piece surface. So there is a tendency that whenever this BUE happens it generally spoils the surface finish, so BUE typically happens when the depth of cut is probably quite large and using a smaller rake angel okay and there is a larger temperature increase because of that and you are cutting at a super high speed okay.

So there is a tendency of the plastically deform material to be heated to an extend that it starts sticking and building up this edges. So one principle fundamental principle in machining is that built up edge should be avoided because that leads to a detrimental surface finish. Although you may think suitable either because of the built up edge the virtual hardness of the tool probably increase and BUE may results in some kind of increase in the or enhancement in the tool life but in general situation people are more interested about what is the work face surface finish that you are getting and then in that case sharper the tool the better it is and try to avoid the BUE in this manner.

So on one hand it is a trade of really that as the tool life would increase because of BUE the surface finish would really gets spoiled you know and so you can go to an extent of making a decision of whether it need really the BUE for a particular application or not. So if the material is little bit brittle and it ruptures let us say during the high sped cutting intermittently this results in discontinues chips okay.

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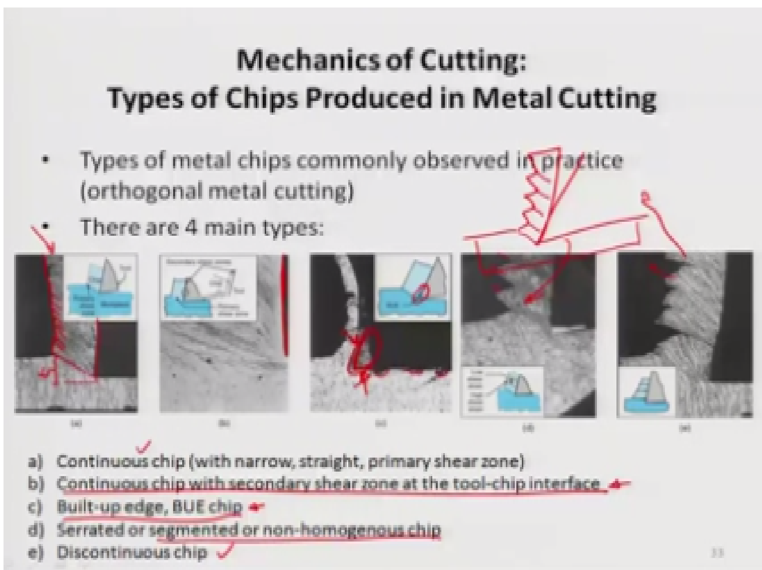

And discontinues chips can be recorded here for example I can show you this different cases where we are talking about the formulation of the continues chip you can see that this is the really the chip which is getting formulated and it appears as the chip is like you know a pack of cards which is moving with respect o each other relatively because there is obviously a lot of shear in this particular zone and the but it is one continuity. So they not braking down or there not you know coming out as species and it is like one continues ribbon like structure which is coming out which obviously corresponds to a high cutting speed or small depth of cut.

So if you really wanted to see what is the depth of cut in this case you have to draw the shear plane here.

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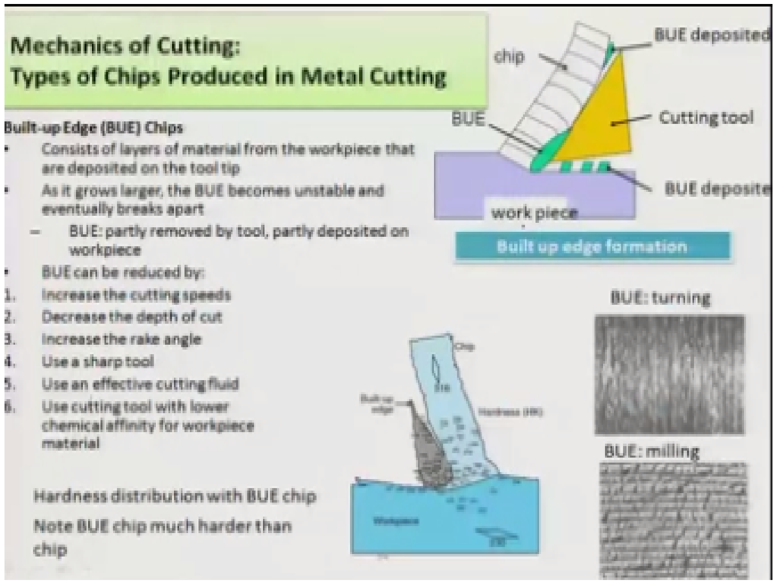

And kind of imagine you know the depth of cut as an extension of the point that the end of the shear plane with respect to the work piece surface. So that is the t_1 value here so it is relatively very small, uncut chip thickness and it always results in this kind of a continues chip orientation you can have a continues chip with secondary shear zone at the tool chip interface this you can see here very well that.

So you can have a continues chip with the secondary shear zone at the tool chip interface . you can see the tool chip interface here particularly where there is a complete stick, you can I mean not sticktion but a complete gape glosser of the chip on the surface of the tool and the conditions are pretty much similar toward continues chip otherwise would have with narrow straight primary shear zone in this particular case this probably corresponds to a even lower depth of uncut chip thickness where whatever is coming out of the material is sort of in such a continues manner that it hardly separates you know it just comes in a ribbon like manner and slides over a considerable portion of the tool rake face.

There are cases of built up edges where particularly the situation where there are relatively larger depth of cut you can see this built up edge right here coming at the end of the tool and you can see this schematic here which says what exactly going on. so what has happen is that because of the high power consumption and the higher rate of temperature increase and severe plastic deformation rate as well the material gets stain hardened heavily and results is virtual tool face.

And the tool as know as a higher hardness right so and then it actually starts along with that the tool plaughning the material of because of its enhanced strain hard and condition and you can see that because of this formulation of the built up edge now the tool life is relatively made higher because the built up edges kind of sticks to the tool and you know it will like to protects the rake face of the tool but it is detrimental because after while it is starts breaking down and you can see these small portions here which are actually a result of whatever revenants has come out from the built up edge and it does not leave a very good surface finish on the complete surface.

There is a case of serrated or segmented or non- homogenous chip because of the severe plastic deformation again there is a pack of card like motion of the chip and you can see the discontinuity which arises here discontinuous still not taken place, but there is definitely a serration. So this is recorded as a surface you know of the chip something like this okay where there are shear planes formulated on the chip surface coming out of the from the tool rake face side okay and this is how it would actually look like.

And supposing the plastic deformation rate is much higher these serrated chips now get this continuous okay. So this actually the first what is continuous deformation where disseverations probably come off from one other, they are not able to hold together and that is how you actually visualize high resolution pictures of the different you know type of situation related in the cutting zone.

So having set that I would like to end this module now but in the next module I will also give you a detail about how the temperature would be distributed and what are some methods which you can use for doing some heat transfer or cooling on the face of the chip and the tool so that you have a higher tool life particularly and also to some extent a smoother surface finish. So with this I would like to end this module here, thank you so much.

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