Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology –Part-1

Module- 44

by
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Hello and welcome to this manufacturing process technology part 1 module 44.

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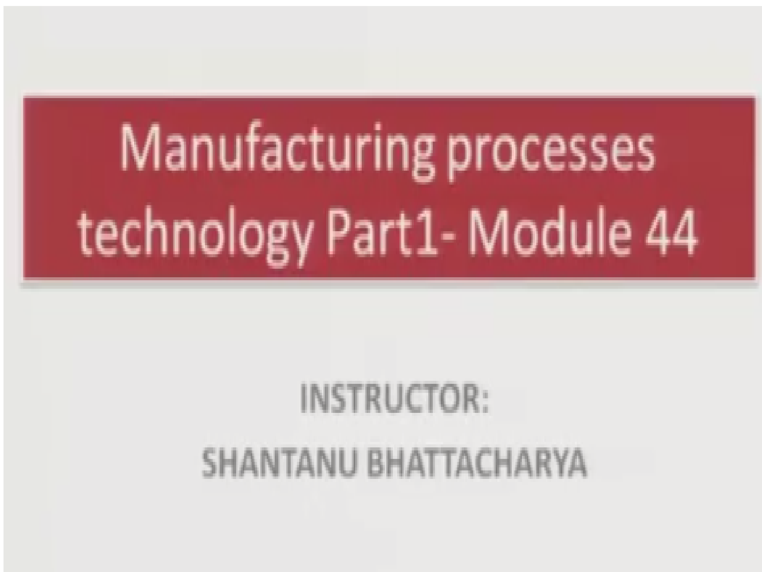

We were talking about the various different kind of chips that were produced like the continuous, discontinuous one with built up edge so on so forth in case of machining.

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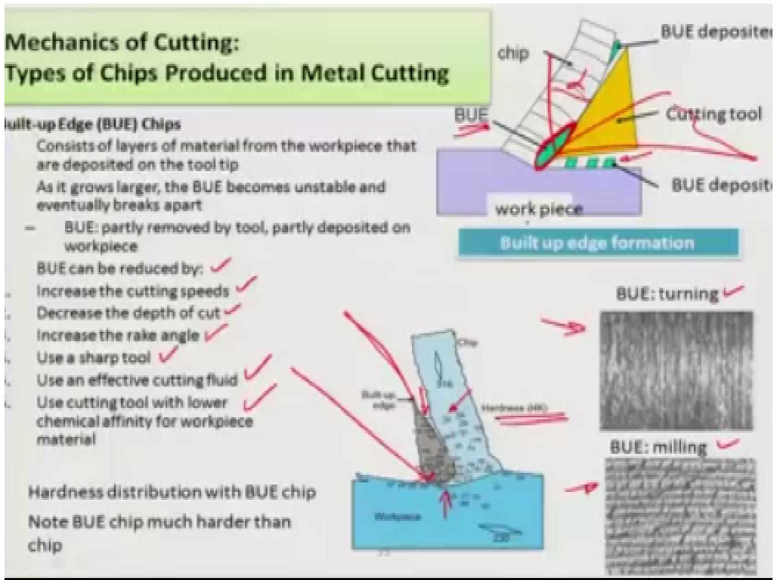

So let us actually now look at a little sort of different aspect here I think we had discussed about the built up edge in great details and said that here is going to be the residue formation on the surface. On one hand which will result in sort of a bad surface finish for the material on one hand and on the other hand as you can probably see that because of the built up edge formulation on the top of the so, because of the built up edge formulation on the top of the tool it acts like a virtual material of higher hardness and starts grazing the work piece thus protecting the tool life okay, so it is a trade-off really between the surface finish.

And increase the tool life that you are sort of involved in when you try to depositor when you try to analyze the situation when machining happens with built up edge, so built up edge which can obviously be reduced because you know most of the time the requirement is that of a higher surface finish, so you can decrease the built up edge by increasing the cutting speed for example decreasing the depth of cut increasing the rake angle you know.

So if you are having some kind of a grazing rake angle this right here is the rake angle so if alpha is more and this tool is somewhere you know which is like sort of grazing the surface you can see that probably you can increase the rate at which you know chip formulation is happening at lower temperatures or lower using lower powers, you can use a sharper tool again to remove the built-up edge completely you can use an effective cutting fluid so that there is sufficient amount of heat transfer and the chip does not really weld whatever is formulated here although it is highly strain hardened it does not weld anymore to the tool surface so that the BUE condition may come.

So using tool with lower chemical affinity for the work piece material is another important you know way out for sort of preventing the built up edge from happening, so if I looked at the harnesses and these are all the HK values of the chip as well as the built up edge and the work piece, so you can see this built up edge to be formulated as a part of the tool maybe you know so this is the tool actually.

And you can see the harnesses of this region the built up edge region is really very high even higher than the hardness of the work material and obviously that is the reason why it grazes onto the work material so hardness is as high as 704 for example okay, 704 HK Knops hardness is recorded here in case of this built up edge whereas if you look at the standalone chip again the chip does not have hardness more than about half the value about 372.

And so is true for the work piece surface, so no reason because of all this the built up edge is kind of ploughing on the surface and is able to successfully cut metal as a virtual tool surface, so the figures here show some high-resolution pictures of what happens you know when the turning or milling processes happen and what happens because of the built up edge in turning and milling operations.

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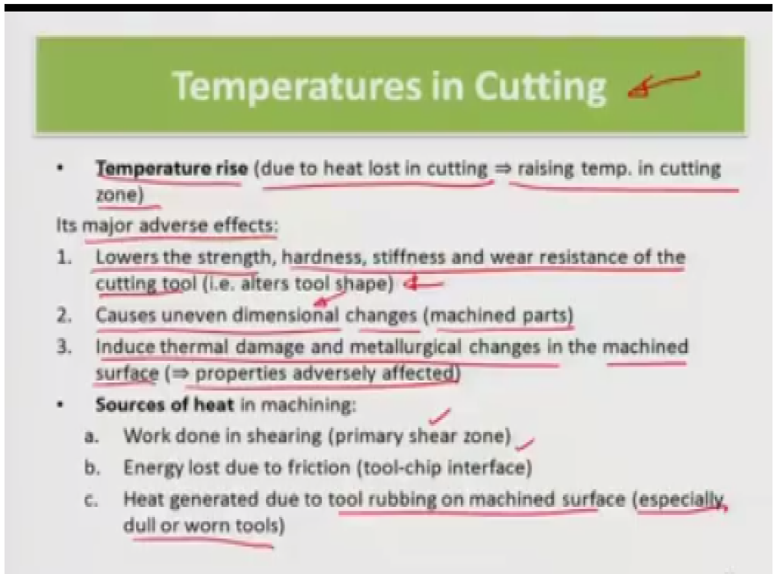

W also need to explore the temperature rises due to heat lost in cutting and I think I had theoretically modeled this earlier and also help you solve numerically the temperature rise in the cutting zone now the major adverse effects which happens because of a temperature rise is that you know it lowers the strength the hardness the stiffness the way resistance of the cutting tool itself okay so the tool life is the most which is affected.

And in fact we are going to do some formulations to sort of optimize the cutting conditions so that the tool life can again be enhanced and you do not need tool changing any more or minimum times tool changing requirements are there so that you can you can actually do machining at a lower cost, so another important bad effect that temperature rise would have is that it causes uneven dimensional changes particularly in the machining parts think of it.

All the metals are amenable to change dimensionally when subjected to higher temperatures they all have coefficient of thermal expansion and so therefore there can be overall change in the dimensions while the cutting process is on which can be again you know affecting the assemblies into which these parts would be going after the machining operations are performed, so they can induce thermal damage and metallurgical changes in the machine surface properties can adversely affected because of that.

And sources of heat in machining if you look at really the primary shear zone the tool chip interface and the sort of a you know tool rubbing on the machined surface using particularly tools which are burnout or not having high sharpness etc, so this is a sort of a you know recall of what we had also seen earlier in terms of a model that what impact the temperature rise would have onto the machine surface in question.

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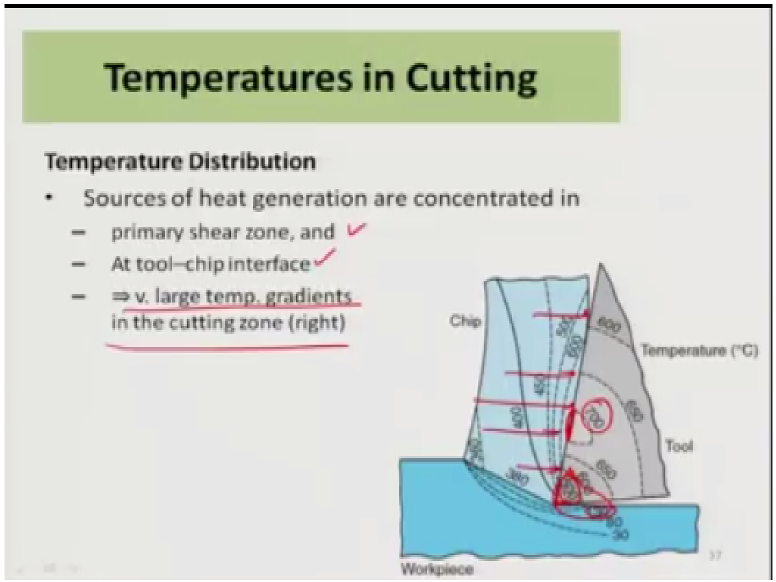

So if I look at the various temperature distributions which have been found out in the primary zone the tool chip interface you can see that you know there are very large temperature gradients particularly in the cutting zone if you look at the gradient here for example the temperature line the isotherm here which is recording hundred and thirty degree Celsius is just closely spaced to the two temperature which is about 500 degree Celsius.

And if you look at the same here you can see the tool where the maximum chip pressure happens and you already have seen it theoretically how because of the chip pressure there is a variation in the temperature so the maximum temperature rise is more or less similar to 700 degrees okay and this probably leads to some kind of a plastic welding between portion of the chip onto the tool surface okay. So the distribution happens in a way that there are very large temperature gradients in the cutting zone you know 500 to 130 in 130 in a matter of just a few microns and because of that again this points here have the tendency to formulate what you call the built up edge again.

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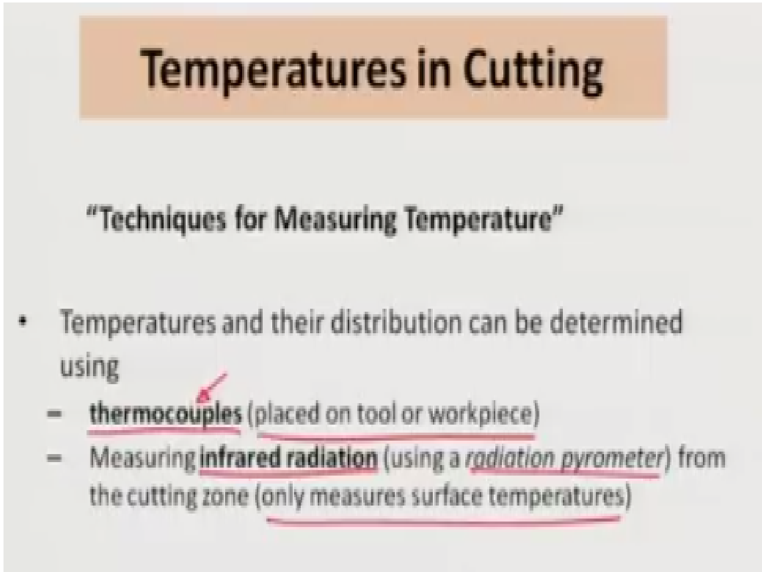

So the measurements of such temperatures or temperature distributions can be you can be can be experimentally made by using thermocouples which can be either placed on the tool or the work piece surface on a non-contact manner through infrared radiation so you can use a radiation pyrometer for example from the cutting zone which only measures the surface temperature you cannot go into measuring the depth temperature obviously thermocouples can be placed in a manner at a certain depth within the tool where you can actually get this complete isotherm.

You can see here for example you have temperatures even within the tool like in this particular portion on this particular portion so that can only happen when you have an embedded architecture for doing measurements and there are experiments where embedded thermocouples are put into the tools for carrying out experimental determination of the temperature isotherms.

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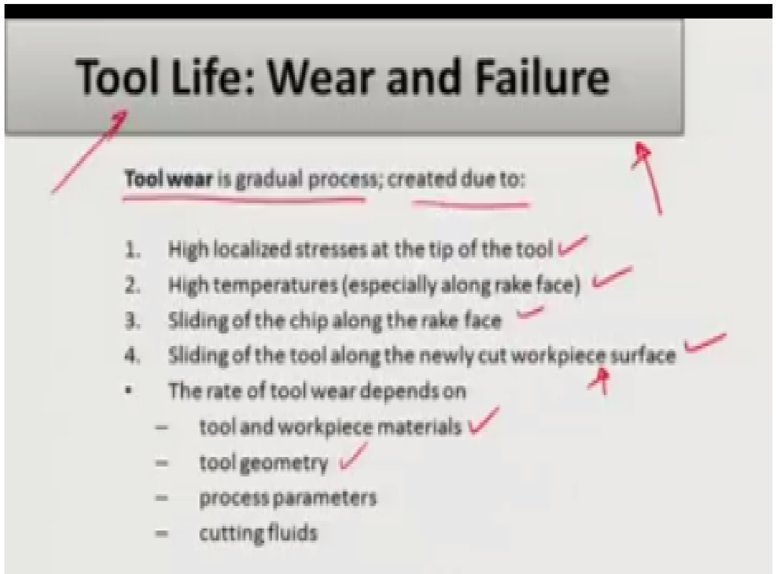

The other issue which I wanted to really emphasize is that because of all these temperature rise and you know severe plastic deformation of the chip material formulation of built up edge there is an effect on the tool life you know particularly because of the wear and failure in many cases of the tool or in some cases sort of a protect length layer which happens because of which the tool I may increase okay.

So tool wear is gradually it is like a gradual process which is created due to high localized stresses at the tip of the tool also because of high temperatures especially along the rake face sliding of the chip along the rake face sliding of the tool along the newly cut work piece surface and this normally happens in case of tools which have particularly worn-out the Charlie's level is in decreased.

And this is called the flank face where which one has to avoid because it results in a bad surface finish and that should be avoided generally in the machining process, so the rate of tool wire depends on tool and work piece materials depends on the tool geometry that you are using.

What is the kind of the tool geometry which typically includes all the tool angles or even certain things related to the change in shape because of flank wear etc. The tool wear and tool life also depends on process parameters particularly cutting conditions that are very significant to the change in the wear rate or the tool life and then finally on cutting fluids because these are used to normally do the heat transfer in the cutting zone.

So that the overall temperature does not go to a value where the built up edge formation etc starts to take place okay, so these are some of the dependent parameters which govern how what kind of tool life can be there or what kind of wear characteristics of the tool would occur.

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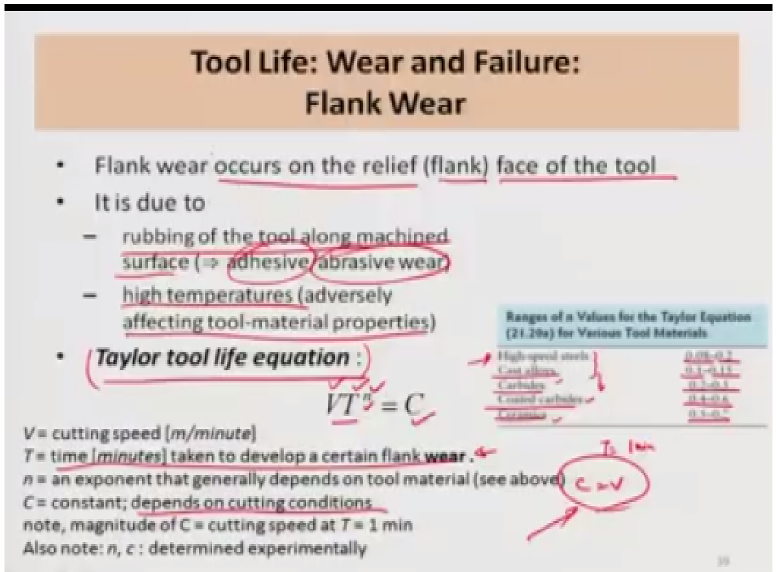

$$\rightarrow V\,T^{n}=C$$

So there is an empirical relationship given by Taylor which basically tells about the relationship between the tool life and the cutting speed in meters per minute and this is also better known as Taylor's tool life equation so the tool life T in minutes taken to develop a certain flank wear where flank wear is really the wear which occurs on the relief face of the tool or the flank face of the tool due to rubbing of the tool on the machined surface and typically this wear is also the adhesive or abrasive wear.

And also because of high temperatures you know adversely affecting tool material properties so as for the Taylors tool life equation VT^n = constant C it depends on really the cutting conditions and if you look at some of the ranges of you know this exponent n in case of Taylors equation for the various tool materials, so for high speed tools steels steel tools for example the N varies between 0.08 to 0.2 forecast alloys varies between 0.1 to 0.15.

Carbides it varies between 0.2 to 0.5 coated carbides 0.4 to 0.6 ceramic 0.5 to 0.7, so obviously as the n is more and more you can see that the tool material is getting harder and harder okay. the only difference is in case of cast alloys versus high speed steel which comes here, so note that in this Taylor's tool life equation the exponent n and the coefficient C are basically determined experimentally and you can say that C is really the cutting speed corresponding to a tool life of 1 minute so if T were equal to 1 minute then C = V, so that is how we define the tool life constant in case of the Taylor equation.

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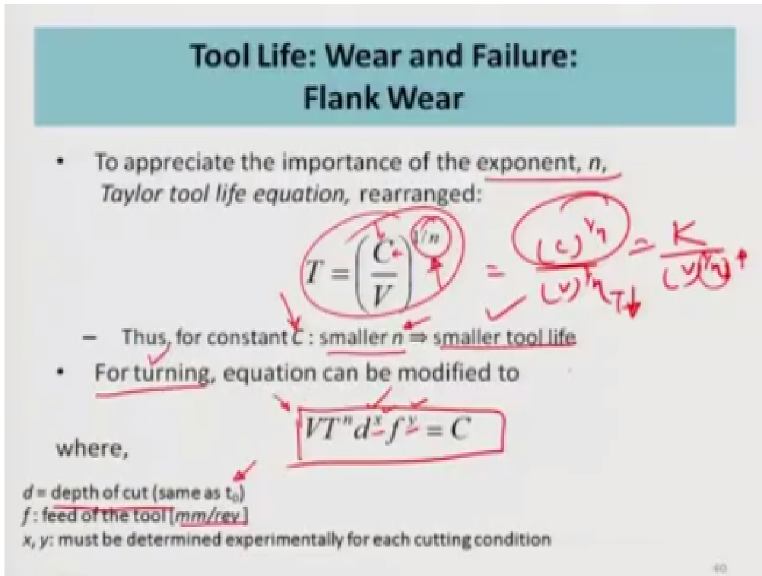

$$\rightarrow T = \left(\frac{C}{V}\right)^{1/n}$$

$$\rightarrow V = \frac{C}{T^n d^x f^y}$$

To appreciate the importance of the exponent n if I can just simply rearrange the Taylor's equation it results in $T = C/V^{1/n}$. so thus for a case where C is constant let us say for a certain set of tool a certain cutting conditions certain set of cutting conditions including the tool and the material if I have a smaller *n* which means you know higher this coefficient 1/n so you should have a smaller tool life.

So that is more so because if I just looked at this part of the equation here obviously as we have already told that the C is constant so this equation can be written down as $C^{1/n}/V^{1/n}$ and the $C^{1/n}$ is any event a constant $K / V^{1/n}$ so if n is a smaller and 1/n is bigger so obviously the tool life going to go down okay, so which makes sense which is being represented in this particular equation.

So tool life equation can according to be monitored for different processes for example for a turning operation the equation may be modified slightly to a form $V T^n d^x f^y = C$, d obviously is the depth of cut so it is same as the initial cut of initial cut thickness or you can say this is t_1 or t_0

as we had earlier taken in merchant circle and F is the feed of tool in millimeters per revolution okay.

And again the coefficients x and y are determined experimentally for each cutting condition and it is more like an empirical relationship just like the original Taylor's tool life equation of V to the power $VT^n = C$.

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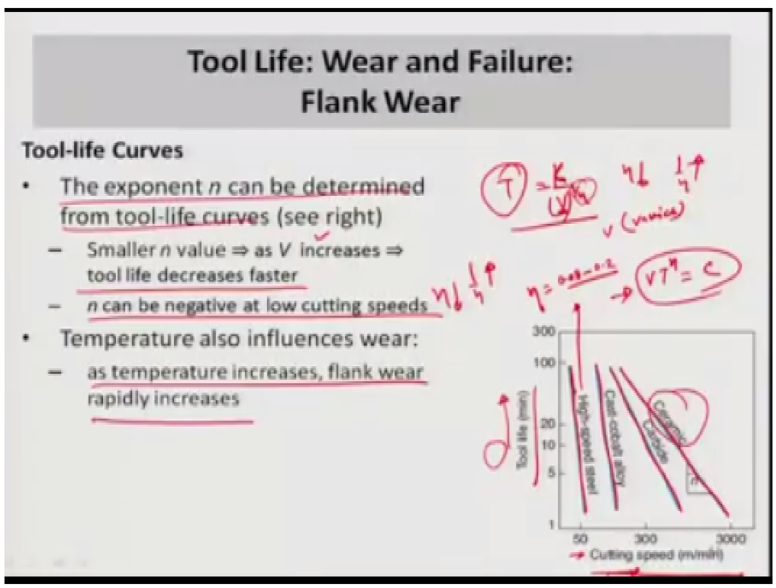

Extending this logic further the tool life curves can be plotted for different values of n the exponent n can be determined from the tool life curves really you can see here you already know that C/ V or some constant K which is $C^{1/n}/V^{1/n}$ = tool like T obviously if n is a smaller value and 1/n is quite large then if V varies let us say V increases or V just varies so for a larger coefficient here the tool life should be able to vary more.

So if supposing V increases in this particular condition and n is really small or 1/n is really big then the tool life should decrease much faster in comparison to the condition where and n was bigger and 1/n was relatively smaller, so therefore you can have a higher slope situation here that for little variation in the cutting speed you have a higher variation in the tool line just because of the decreasing value of n or increasing value of 1/n.

So therefore this line for example corresponds to high speed steel which probably has a range of 0.08 to 0.2 n value this is cast alloys, cast cobalt alloys this is for examples carbide this for example set up ceramic where I think I had earlier mentioned just about one or two slides back that for example in the carbides case it is 0.2 to 0.5 that is value of n . so n has increased here really coated carbides and ceramics they are even higher 0.4 to 0.6, 0.5 to 0.7.

And so therefore this falls in line with the logic here that the ceramic tool just because the n value is higher there should have a lower variation in tool life in comparison to a increase in cutting speed as compared to let us say carbide cast cobalt alloy and high speed steel. so once again just trying to bit rate here that as the n decreases and 1/n increases a smaller amount of variation V would result in a larger amount of variation in T.

Which actually is determinant of this tool life so n can also be negative at a low cutting speed a situation where an increase in speed would also result in supposing n is very small and 1/ n is actually large so an increase in speed would result in increasing tool life, temperature also influences whereas the temperature increases the flank were rapidly increases, so- so far we have kind of seen what are the various possibilities and how you can obtain the n values from prodding the tool life with respect to the cutting speed and determining it from the tailors equation $VT^n = C$.

This equation is particularly significant when we talk about machining conditions and optimum machining conditions particularly used to find out what is the overall cost of the machining process or overall time in the machining process and this particularly holds true for CNC systems where there are many such inserts and there is a tendency of the inserts to be repeatedly where doubt because of high speed machining processes.

And you have to actually either grind them or increase the sharpness of these tools before reuse so there the optimization of the criteria as which are followed for the optimization are totally dependent on the tool life equation and we would like to present one such case here.

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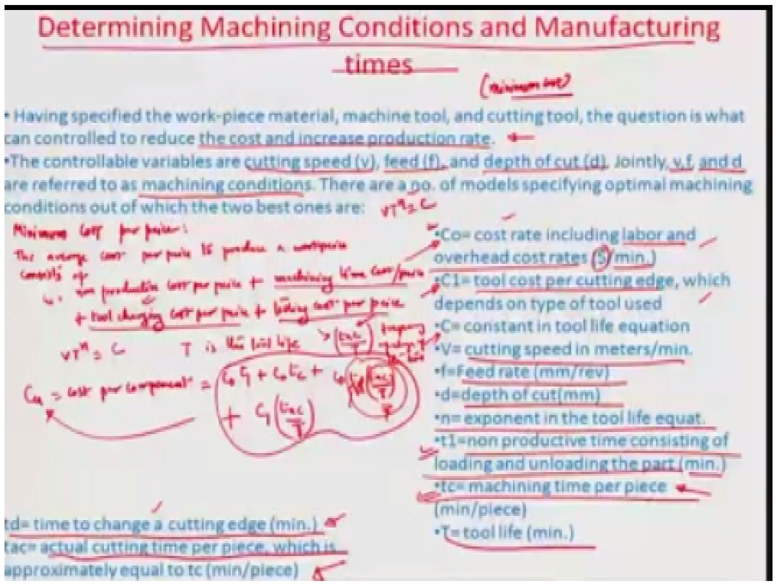

$$\rightarrow V T^n = C$$

Where we want to determine the machining conditions and manufacturing times having specified the work piece material machine tool and cutting tool the question is what can be controlled to reduce the cost and increase the production rate and the controllable variables in this case are cutting speed for example V the feed F the depth of *d* jointly the velocity cutting velocity the cutting feed and depth they are referred to as machining conditions.

So there are a number of model which specify the optimal machining conditions out of which the two that I am going to teach here is one is the minimum cost model so this is actually the minimum cost model and the other is actually the again minimum time model which is related to the total manufacturing time, so let us suppose that in a particular case of machining you have a cost rate which includes labor and overhead cost rates could be some unit of currency per unit time.

So you also have a tool cost per cutting-edge which depends on the type of tool that you use. it maybe an expensive tool which has slightly higher to life okay, so C1 will be higher in that particular case C is obviously a constant in the tools to life's equation $VT^n = C$, V is the cutting speed in meters per minute let us assume F to be the feed rate millimeters per revolution, d to be the depth of cut millimeters.

And we are just trying to evaluate probably a CNC turning process in this particular case *n* happens to be the exponent in the tool life equation and t_l is the non-productive time consisting of the loading and unloading time for the part in the machine as reported in minutes and t_c is the machining time per piece in minutes per piece. The actual cutting time per piece may be slightly different than the machining time per piece.

Because you know this if you are talking about a CNC system involves the absolute positioning in the point of machining and some displacement of the tool all the way to the start of the work and therefore the t_{ac} actual cutting time per piece may be slightly different then the t_c but in all the cases that we would be considering here we will probably consider them to be similar they are not very much different because obviously all the controllers are designed to have almost optimum minimum possible idle time.

And that is how the path planning in the motion controllers are done, T is the tool life in minutes and t_d is the time to change a cutting edge cutting edge means an insert therefore if you wanting to change an insert because of its where you need about t_d time to change that insert in the machine so having said that let us actually bring out what is the kind of cost of labor overhead tooling so on so forth which is used or in sort of machining.

And then try to optimize or minimize the cost you know in this particular case so the minimum cost per piece in this case, consists of the following costs so the average let us say the average cost per piece to produce a work piece consists of non-productive cost per piece Plus machining time cost per piece Plus tool changing cost per piece plus the tooling cost per piece given the Taylor's tool life equation which is $VT^n = C$, a constant.

So obviously the C_u which is also the cost per component that you are manufacturing on this high-throughput system comprises of this non-productive cost which is actually very well written as the non-productive time which is involved in loading unloading of the sample onto the machine times of the total amount of cost rate of the labor overhead etc, which happens to be multiplied with time t_l to give the overall cost.

So this is C0 t_1 the cost per component also includes the machining time cost per piece so the total amount of machining time in this particular case is taken as t_c okay and during this time the total amount of overhead cost that is spent is basically again C0 per unit time, so I can say C0 t_c as the total amount of machining time cost per piece + and the tool changing cost per piece and here we have to bring in the tool life.

Because we know that T is the tool life and the actual cutting time t_{ac} in this case supposing involves more than one tools, so really the t_{ac} /T would be the frequency of change of the tool and so that many number of times that means t_{ac} /T times you have to spend the time to change cutting tool in each case and the total such time spent would be equal to t_d times of t_{ac} /T where t_d is the frequency t_d is the time per cycle of change and t_{ac} /T is the cycle frequency of the change per say.

And during that time you are again spending the labor and overhead costs so I just multiply this with C0 so this gives you an idea of what kind of time because every time there is a change and there are n such changes because you know that you have to extinguish n tools in order to consume this whole one pieces cutting time which is t_{ac} so n times of t_d really is the total time and C0 n times of t_d is really the total cost which is involved.

So this is the total changing cost per piece and then we have a tooling cost per piece which is actually equal to again the tool cost per cutting edge and you are actually including around n cutting edges for the cutting process given by t_{ac} /T the frequency you know and this times of C1 basically gives you the total amount of tooling cost per piece and so this summation here of all these terms together give you what you call the cost per component.

$$C_u = C_0 t_1 + C_0 t_c + C_0 t_d \left(\frac{t_{ac}}{T} \right) + C_1 \left(\frac{t_{ac}}{T} \right)$$

Now let us actually try to see whether what is the optimum solution so that the tool life probably can change accordingly and the overall cost can come down for certain conditions of machining.

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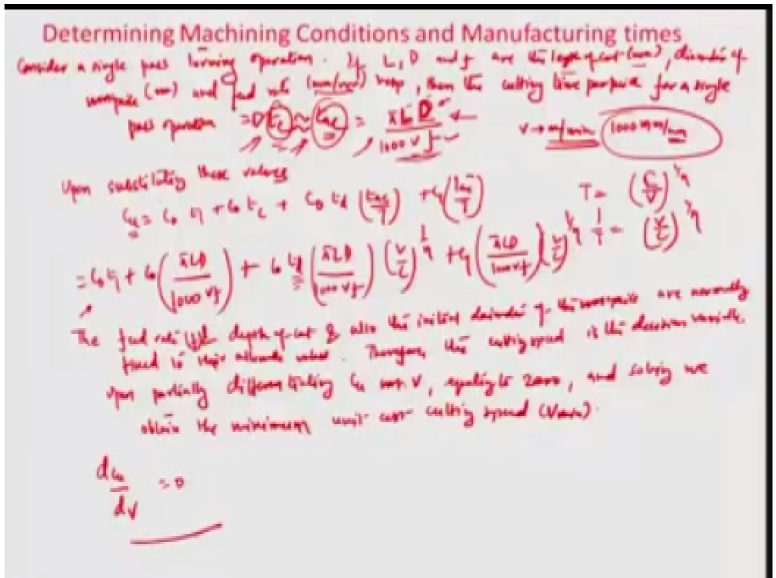

$$C_u = C_0 t_1 + C_0\left(\frac{\pi LD}{1000\,vf}\right) + C_0 t_d\left(\frac{\pi LD}{1000\,vf}\right)\left(\frac{V}{C}\right)^{1/n} + C_1\left(\frac{\pi LD}{1000\,vf}\right)\left(\frac{V}{C}\right)^{1/n}$$

$$\frac{dC_u}{dV} = 0$$

And so the first thing that I would like to illustrate here that if we consider a single pass turning operation right and supposing we also further consider that L capital D and *f* are the length of cut in mm, diameter of the work piece again in mm and feed weight in mm per revolution respectively then the cutting time per piece for a single pass operation can really be given as t_c which will approximately consider to be t_{ac} in this case.

Considering the controller to be optimized for the composition setting etc for the tool and so that becomes equal to πLD. we remember the D actually and the length of cut both are in L millimeters divided by 1000 *vf* where V is the velocity again and this velocity as had been recorded earlier is in given in meters per minute, so we can always have this equal 1000 millimeter per minute and f is basically the feed rate which is millimeters per evolution.

So obviously the πLD gives you an idea of the total surface area which is removed and that times of that divided by thousand vf gives you an idea of how much time in a single pass would be taken to remove of this much amount of so the t_c here actually is represented as the more or less the t_{ac} so the cutting time and the actual cutting time are similar to each other and they are given by this equation πLD / 1000vf.

L and D are both in millimeters velocity being in meters per minute has to be converted into thousand millimeters per minute and F again is the feed rate in millimeters per revolution, so this really shows you the cutting time or in a simple single pass turning operation and upon substituting this values as well as tool life equation in the cost per piece-- equation as obtained in the last line.

We get already the C_u was defined as C0 t_l + C0 t_c + C0 t_d times of t_{ac} /T + C1 t_{ac} /T obviously we know what is the actual cutting time or t_c value here from geometrical parameters length of work piece diameter of the work piece the feed rate and the velocity of the cut and cutting speed and also we know from the tool life equation that T can be written down as $C/V^{1/n}$ meaning there by 1/T can be recorded as $V/C^{1/n-}$.

So having said all this we substitute these values back into the cost equation so we have C 0 times t_l + C0 t_c which is again π LD/1000 vf + C0 t_d the time to change a cutting edge in minutes times of Tac again which is we π LD/1000 vf times of 1/T which is $V/C^{1/n}$ C1 times of again t_{ac} which is π LD/1000 vf times of $V/C^{1/n}$ so on so forth, so that is what you know about cost per piece.

And having again set this and there is of course a t_d term here which means the time to change the cutting edge so now the feed rate and depth of cut for any turning operation single pass turning operation are normally fixed so the feed rate and which is key defined by f in this particular case and the depth of cut and also the initial dia of the work piece and normally fixed to their allowable values whatever they may be.

On therefore the cutting speed really is the decision variable upon partially differentiating C_u with respect to V equating to zero and solving, we obtain the minimum unit cost cutting speed, $V_{min.}$ so let us now do this by substituting dc_u/dv =0 and try to see what is the implication of that what is the final form of the equation between emerge.

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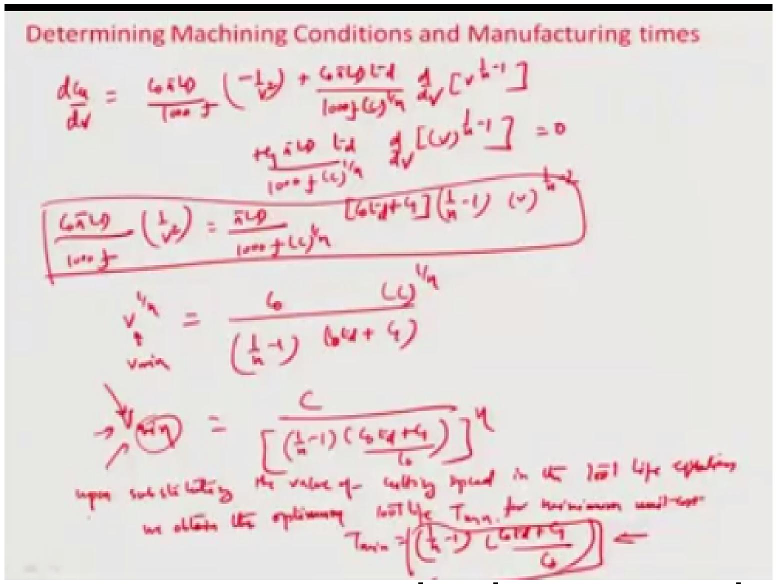

$$\frac{dC_u}{dV}=\frac{C_0\pi LD}{1000f}\left(\frac{-1}{V^2}\right)+\frac{C_0\pi LDt_d}{1000f(C)^{1/n}}\frac{d}{dV}\left[V^{\frac{1}{n}-1}\right]+\frac{C_1\pi LDt_d}{1000f(C)^{1/n}}\frac{d}{dV}\left[V^{\frac{1}{n}-1}\right]=0$$

$$\frac{C_0\pi LD}{1000f}\left(\frac{1}{V^2}\right)=\frac{\pi LDt_d}{1000f(C)^{1/n}}\left[C_0t_d+C_1\right]\left(\frac{1}{n}-1\right)\left[V^{\frac{1}{n}-2}\right]$$

$$V^{\frac{1}{n}}=\frac{C_0(C)^{1/n}}{\left(\frac{1}{n}-1\right)\left[C_0t_d+C_1\right]}$$

$$V_{min}=\frac{C}{\left\{\left(\frac{1}{n}-1\right)\left[\frac{C_0t_d+C_1}{C_0}\right]\right\}^n}$$

$$T_{min}=\left(\frac{1}{n}-1\right)\frac{C_0t_d+C_1}{C_0}$$

Actually based on that so the dc_u / dv in this particular case can be written down as C0 π LD/1000 f times of $-1/v^2$ + CO π LD t_d / 1000F $C^{1/n}$ d/dv $V^{1/n}$ -1 + C1 πLD/ 1000 feed f $c^{1/n}$ times of t_d times of d/dv($V^{1/n-1}$) and that becomes equal to 0. so C0 πLD/1000f times of $1/V^2$ = πLD/1000f$C^{1/n}$ times of C0 t_d + C1 times of 1/n-1 $v^{1/n-2}$ and. therefore we can obtain a condition from this equation that $V^{1/n}$ becomes equal to C0/ ((1/n)-1) times of C0 t_d + C1 times $C^{1/n}$.

In other words V minimum which is corresponding to this value of V becomes equal to the constant C/[1 /n -1 times of C0 t_d + C1 / C0]^n upon substituting the value of cutting sped in the tool life equation we obtained the optimum tool life I can say this is T minimum corresponding to the minimum unit cost model as T_{min} is 1/n – 1 times of C0 t_d + C1/C0 okay, so that is how you obtain the time minimum and the velocity minimum where the term min corresponds to the velocity corresponding to the minimum cost of machining.

So this is how actually you try to optimize and I am going to show with problem examples how V can be determined using Taylor's tool life equation to do this optimization, we will subsequently talk in the next module about another way of determining the cutting conditions based on minimum time of manufacturing so then you can actually consider in various cases the optimum cost at the optimum time models to report the various cutting parameters, so with this I would like to end this particular module and I look forward to again provide some optimization related issues in the next module followed by the start of welding or joining processes module, thank you so much.

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