Fundamentals of Manufacturing Processes

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Lecture – 39

Material Removal Processes: Heat Generation

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.

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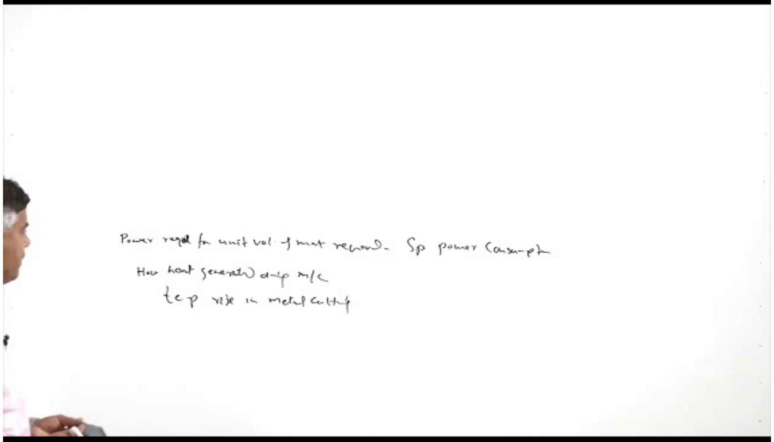

Power reqd for unit vol. of mat removal - Sp power consumptn

How heat generated dng m/c

tep rise in metal cutting

In the metal removal processes, we have talked about the cutting forces generated during the machining and the power consumption required during the machining or the power which is consumed during the machining.

So, in this presentation basically will be talking about that what is the power required for unit volume of the material removal.

So, this is one thing. This is termed as specific power consumption and another aspect about which will be talking is that how the heat generated during machining and how does the temperature rise takes place. So, the temperature rise in metal cutting will also be covered. So, there are few general equations, empirical equations which have been developed over a period of time. So, about those will also be talking.

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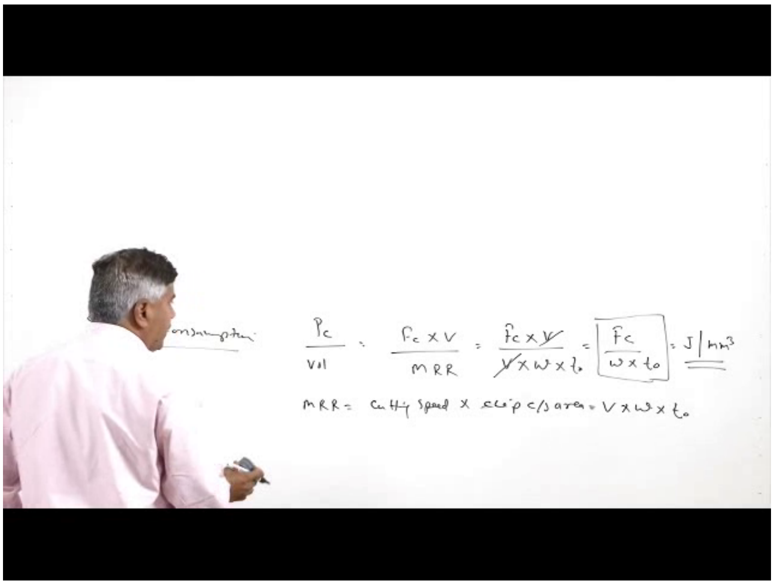

onsumption: $\frac{P_c}{Vol} = \frac{F_c \times V}{MRR} = \frac{F_c \times \cancel{V}}{\cancel{V} \times w \times t_0} = \boxed{\frac{F_c}{w \times t_0}} = J/mm^3$

$MRR =$ cutting speed × chip c/s area $= V \times w \times t_0$

So, as we know that to a define the specific power consumption, for a specific power consumption as I have just shed said that a specific power consumption is the power which is required to be delivered to the machine tool for ensuring that unit volume of the material is removed. So, we need to consider first the power consumption and then the volume of the material removed for a given volume of the material removed.

So, if a power consumption can be obtained through the metal cutting force or the cutting force multiplied by the cutting velocity. And the volume of the metal removed in unit time can be calculated using the MRR, metal removal rate. So, metal removal rate we know can be obtained from the cutting speed or the cutting velocity multiplied by the uncut or we can say chip cross section area.

So, cutting velocity say is v and chip cross section area is obtained from the w is the width of the cut and t naught is the uncut chip thickness. So, product of these 2 will be giving us the value of the MRR. So, v multiplied by w that is width of cut and t naught is the uncut chip thickness. So, these will be used for calculating the specific power consumption which is Fc the cutting force multiplied by the velocity divided by the velocity into the w into the t naught. So, here v and v will be cancelled. So, it will left with Fc, w is the width of cut and t naught is the initial thickness or depth of cut or uncut chip thickness.

So, this is how when we obtain we get basically the specific power consumption in joule per mm cube. For the different metal systems the specific power consumption is found to be different as well as the cutting conditions also leads to the difference in the; a specific power consumption.

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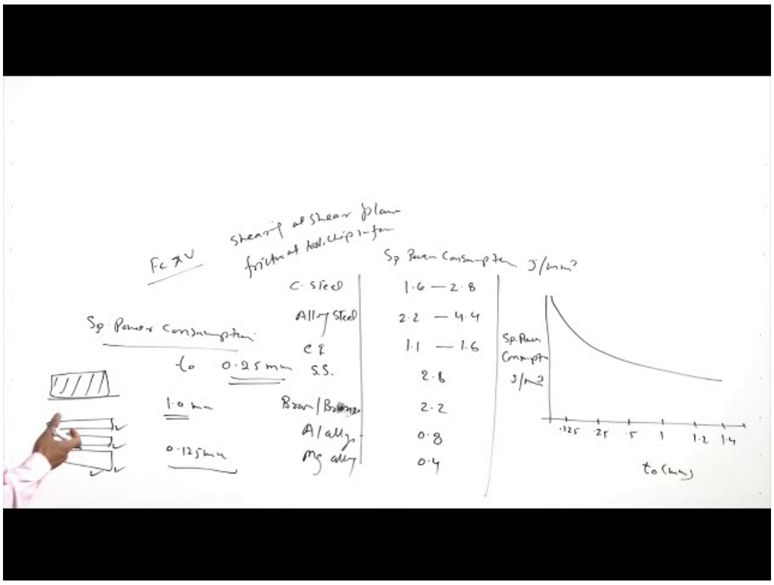

	Sp Power Consumption J/mm³
C. Steel	1.6 — 2.8
Alloy Steel	2.2 — 4.4
C I	1.1 — 1.6
S.S.	2.6
Brass / Bronze	2.2
Al alloy	0.8
Mg alloy	0.4

So, experimentally people have established their specific power consumption for the different metals for certain range of the cutting conditions. Say for uncut chip thickness of the 0.25 mm t naught when the data has been generated and it has been observed it has been observed that with the change of the thickness, a change of the uncut thickness leads to the significant change in the a specific power consumption.

So, first we will talk about the kind of the data which is available on the specific power consumption for the different metal systems. Considering say simple carbon steels, this specific power consumption is found to vary from 1.6 to 2.8; it is in joule per mm cube while for the alloy steels. So, it is largely governed by the hardness and the energy which is required for machining purpose.

So, for alloys steels it varies from the 2.2 to 4.4 joule per mm cube, while that for the cast iron it varies from 1.1 to 1.6 and for stainless steel like it is 2.8. And if we see the copper alloys like brass and bronze it is and the and bronze then it is found around 2.2 joule per mm cube for aluminum alloys it is around 0.8 and for the magnesium alloys it is found further lower like say 0.4. These are the values just to have the idea when the uncut chip thickness is this much.

So, since the specific power consumption is significantly influenced by the uncut chip thickness or the depth of cut. So, we need to consider that what happens when the higher thickness is used like 1 mm uncut chip thickness or what happens when 0.125 mm uncut chip thickness is used. So, in general when the uncut chip thickness is reduced a specific power consumption increases while in case of the increase in thickness uncut chip thickness it reduces the specific power consumption. So, in order to calculate the specific power consumption for the different uncut chip thicknesses, a few correction factors have been identified.

So, like say for very low value of the uncut chip, chip thickness 0.125 t naught in mm in X axis and say it is in increasing order this is corresponding to say 0.25, 0.5, 1, 1.2, 1.4 etcetera. So, and so this; what has been observed that uncut chip thickness with the increase in uncut chip thickness, the specific power consumption which is expressed in joule per mm cube it decreases. So, there main reason for this is that the shear work since the Fc involves the 2 means Fc into v involves the 2 components, 1 is the shearing at the shear plane and another is the work required to overcome the friction at the tool chip, friction at tool chip interface.

So, when we work with the greater thicknesses like this, this is the chip, uncut chip thickness then in that case this entire volume is removed in one go and there is sliding of the only one surface area, one only one slay, one slide one chip will be sliding over the face of the tool but when the same thickness is cut in number of steps then every time the material the chip will be flowing over the face of the tool. So, every time the frictional energy will be required to overcome during the machining. So, maybe the shear works. So, this requires the shearing number of times as well as the; it is also required to overcome the friction at the tool chip interface every time.

So, because when the chip thickness is more, the shearing is required just once while in case of the finer chip thicknesses, the shearing will be required number of times. So, because of these 2 differences the shear work as well as the work to be done to work of the friction at tool chip interface both increases with the increase of, with the reduction in chip thickness and therefore specific power consumption in general increases with the low chip thickness has low uncut chip thicknesses.

So, this is what this is the trend which can now be observe here and some kind of correction factors also have been identified say the value for 0.25 is 1 for which these values have been identified.

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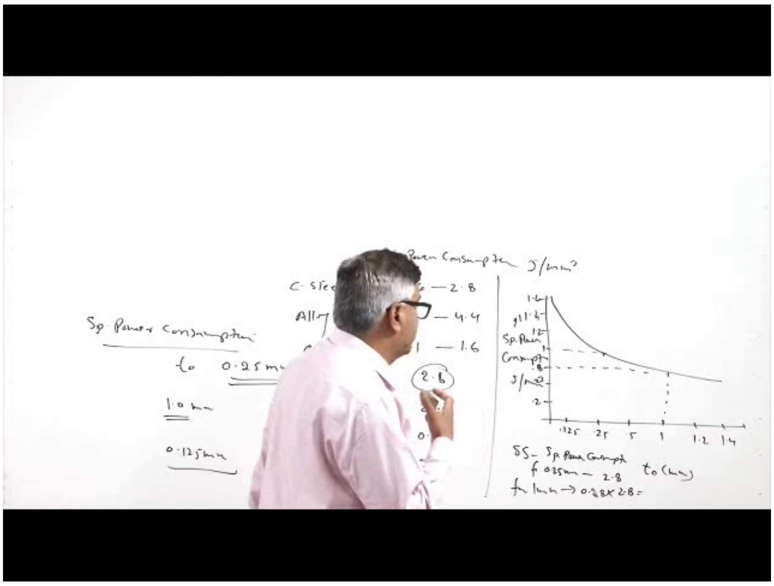

And when we work with the lower chip thicknesses and the power consumption increases, when we work with the higher thicknesses the power consumption decreases. So, correction factors like 0.2, 0.4, 0.8, 1.2, 1.4, 1.6. So, what we see these correction factors need to be multiplied by these values say for the cast iron or for the stainless-steel value is 2.28.

So, for a stainless steel; a specific power consumption for 0.2 mm uncut chip thickness is 2.8. So, what if the cut chip thickness, so what will be the case when the cut chip thickness is more say it is 1 mm? So, in that case what we need to do we need to obtain the corresponding value of the correction factor. So, when we work with the higher chip thicknesses, the correction factor will be lower, higher uncut chip thicknesses then correction factor will be lower. So, in that case for 1 mm uncut chip thickness the correction factor is say point 0.8. So, this needs to be multiplied with the 2.8. So, what our power will be getting that will be India, whatever expressive power a consumption will be getting that will be corresponding to the 1 mm thicknesses.

So, this effect of the uncut chip thickness on a specific power consumption is termed as the size effect in machining, means size effect with regard to the uncut chip thickness on the a specific power consumption. So, whenever the power is consumed during the machining it consumes lot of the energy and that energy part of that energy is converted into the heat and part of the energy goes with the chips in form of the elastic strain.

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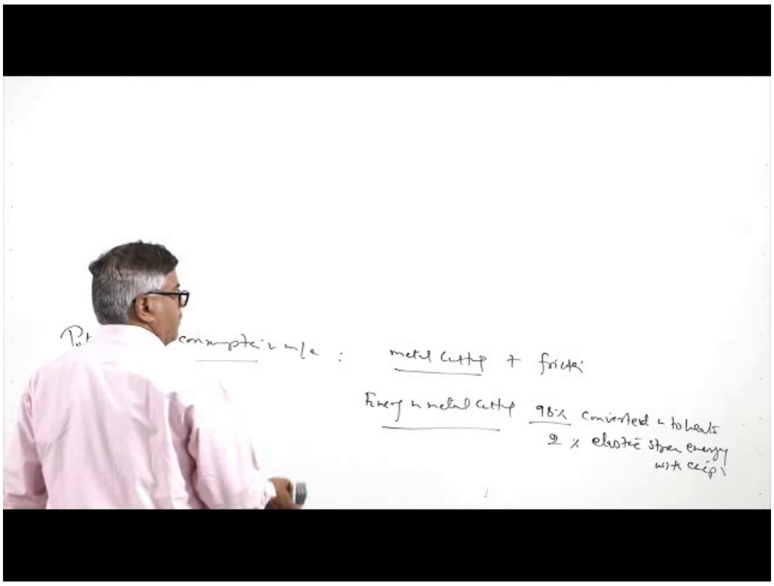
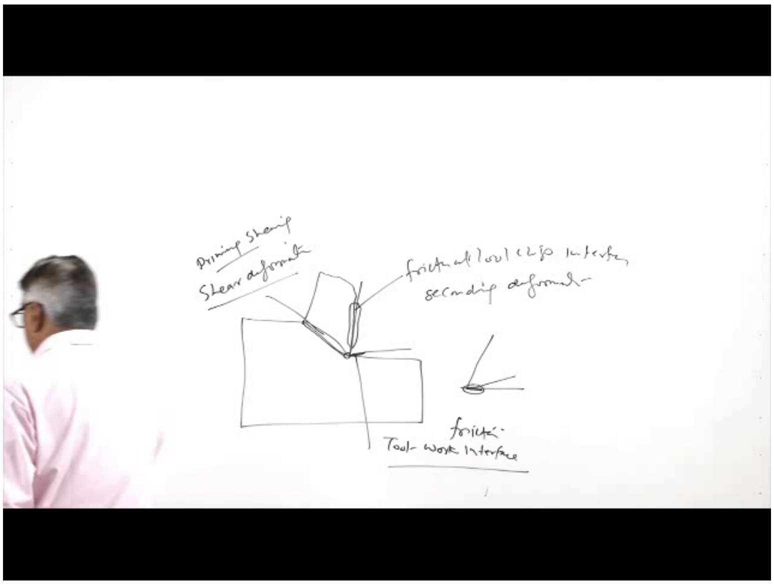


So, say that total power consumed in consumption in machining. So, what will be happening, most of the power is used in the metal cutting plus some power goes in the like the; to overcome the friction of the moving parts. So, whatever energy being consumed in the metal cutting energy in metal cutting is being consumed, most of it is converted into the heat. So, about 98 percent of the energy consumed in the metal cutting is converted into heat. And while the remaining approximately 2 percent remains as the elastic strain energy, strain energy with the chips which will be going into the work, which will be going with the chips itself.

So, this energy which is being consumed in metal cutting during the machining most of it is converted into the heat and that heat appears as a temperature rise of the tool during the machining; temperature rise of the tool as well as temperature rise of the work piece. (Refer Slide Time: 13:41)



So, if we see is schematically here like say this is the shear plane, this is the rake face of the tool, this is the flank and this is the chip which is being found flowing over the face of the tool or this is the machined surface and this is the work piece.

So, I will see this is the plane along which the shear deformation will be occurring. So, the energy is consumed in the shearing. So, energy consumed in shear deformation at the shear plane, this is called primary shearing and part of the energy is also consumed in overcoming the friction as well as the secondary deformation. So, friction at tool chip interface is the one area as well as the secondary deformation which is taking place due to the friction occurring at the tool chip interface the deformation occurring in the chips; so, secondary deformation.

So, these are the 2 areas, apart from this the rubbing between the flank and the work piece also contributes because this cutting edge gradually wears out. So, this area of the tool starts rubbing with the machined surface of the work piece. So, the friction between the tool work interface also contributes to the generation of the heat. So, the friction at this area also contributes to the heat generation.

So, so these are the 3 zones where heat is generated and that leads to the rise in temperature of the tool as well as the work piece.

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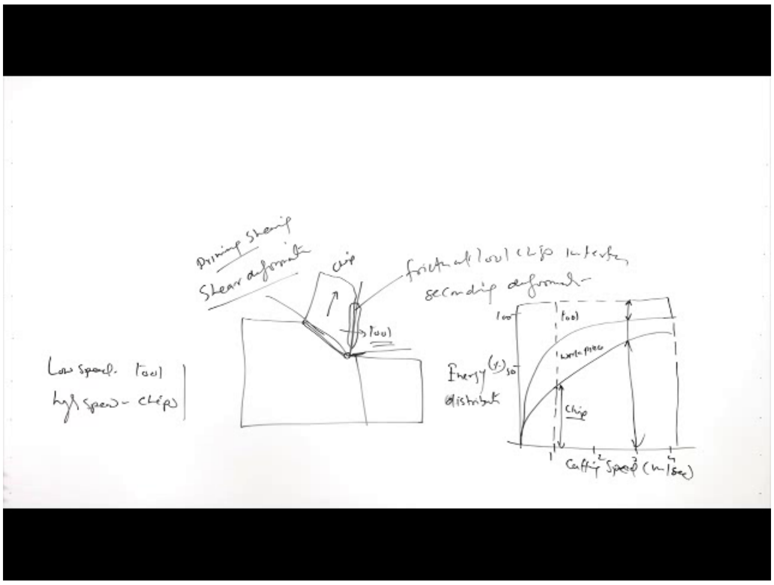

So, if we try to relate the entire the energy consumption with the as a function of the speed. So, cutting speed in Y axis, sorry in X axis in meter per minute if it is mentioned and the energy consumed, energy distribution, energy distribution as a percentage like say the 50 percent and the 100 percent.

So, here what we will see that like this. So, 1, 2, 3, 4 meter per second this is in meter per second. So, when we work at low speed most of the energy is ah, the distribution of the energy goes in like this. So, if we consider it in this manner. So, what it shows, yeah. So, if we take any condition. So, corresponding to particularly speed. So, this will be swing the energy going with the chip. This is the energy with the work piece and this is the energy with the tool.

So, according to this at low speed tool takes lot of energy while at a high speed the chip takes away most of the energy being generated. So, at low speed if we see, at the low speed the energy going with the chip is were less and more with the tool as well as more with the work piece. So, increase in speed basically energy reduces; energy being distributed to the tool, energy being taken away by the tool is less at high speed while it is more at more will be going with the chip.

So, whatever is the energy being converted energy is being supplied during the metal cutting most of it goes with the chips at high speed, but most of it goes to the tool at the low speed. So, considering this aspect at the low speed, the tool takes most of the energy while at high speed the chips will be carrying away most of the energy.

So, considering this since the; whatever energy is being consumed, whatever energy is being consumed in the machining most of it is converted into the heat also. So, that will be appearing as a rise in temperature of the tool, rise in temperature of the work piece as well as that of the chips also. So, unnecessary rise in temperature of the tool adversely affects the tool life because of the accelerated wear processes as well as softening of the tool materials.

So, over a period of time; so, the energy; so, if we see the energy, the over a period of time people have developed the experiments for measuring the temperature of the tool and the work piece.

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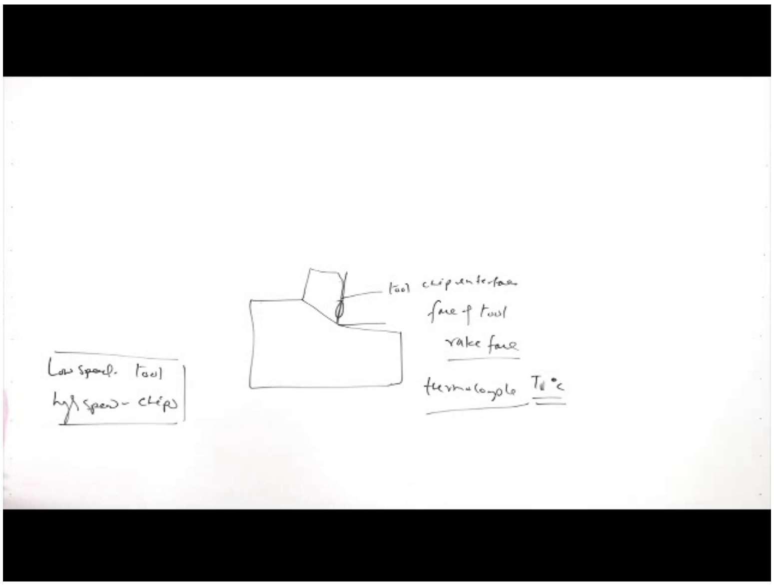

So, like say in 1 typical example normally this is the rake face, this is the tool, this is the work piece, this is the sheer plane angle, this is the machine surface. So, the temperate, the zone of the interest with regard to the temperature generation is basically the tool chip interface. Basically, it is the face of the tool over chips will be sliding.

So, it is the rake face which is of the interest. So, using the thermocouples temperature at the tool chip interface is measured in this zone so that the rise in temperature of the tool can be established. Purpose of this is related with the life of the tool because rise in temperature leads to the change in hardness, the increased chemical reactions, increased diffusion and these mechanisms will be leading to the deterioration in the tool performance. Therefore, it is important to consider the rise in temperature of the tool.

So, 1 equation which has been developed for identifying the rise in temperature of the tool chip interface. So, that equation goes in like this where 0.4 multiplied by the U divide by rho C,.

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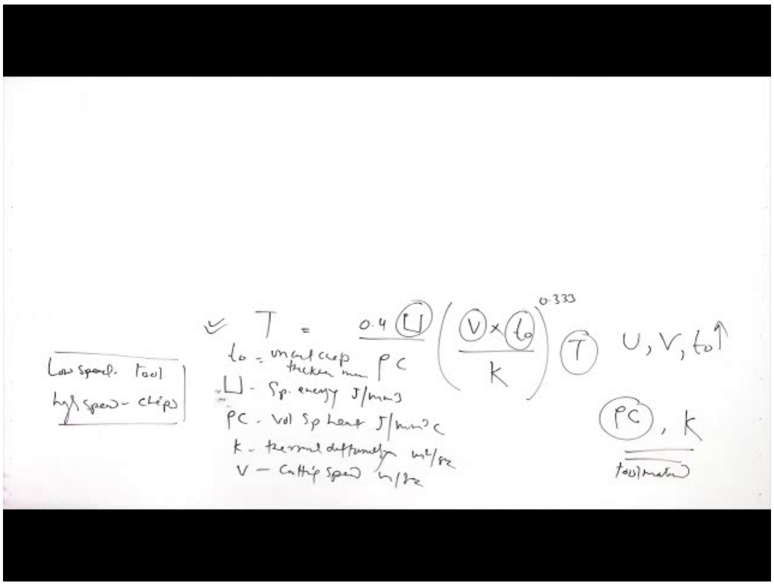

$$T = \frac{0.4\,U}{\rho C}\left(\frac{V \times t_0}{k}\right)^{0.333} \quad T \quad U, V, t_0 \uparrow$$

Low speed - tool
high speed - chips

t_0 - uncut chip thickness mm
U - Sp. energy J/mm³
ρC - vol Sp heat J/mm³ C
k - thermal diffusivity m²/s
V - Cutting speed m/s

ρC, k
tool material

Then we have cutting velocity into the initial plate, initial uncut chip thickness and the K raised to the power 0.333. So, this is the 1equation which has been developed by measuring the temperature at the tool chip interface for a wide range of the materials as well as cutting conditions.

So, here the U is basically, U is the specific energy consumption. U is the specific energy consumption j per mm cube. Rho c, rho c is the volumetric a specific heat this is expressed as j per mm cube, c is the temperature, k is the thermal diffusivity. This is expressed in meter per meter square per second and v is the cutting speed meter per second and the t naught is the initial plate, initial uncut chip thickness, uncut chip thickness in mm.

So, if we see this, this equation then increase in a specific energy, increase in cutting velocity and increase in chip thickness, uncut chip thickness. So, all 3 u v and t naught, increase in all these 3 parameters will be increasing the chip tool interface while the thermal properties like volumetric specific heat and the thermal diffusivity k both will be, increase in values of both these are the tool material properties and increase in both these values will be lowering down the temperature of the tool chip interface. So, this is how we can try to identify the value of the, value of the tool chip interface.

So, if we see here the further finer details of the heat generation then with regard to the cutting speed we need to consider one thing that like during the machining increase in cutting speed how does it will be effecting the things.

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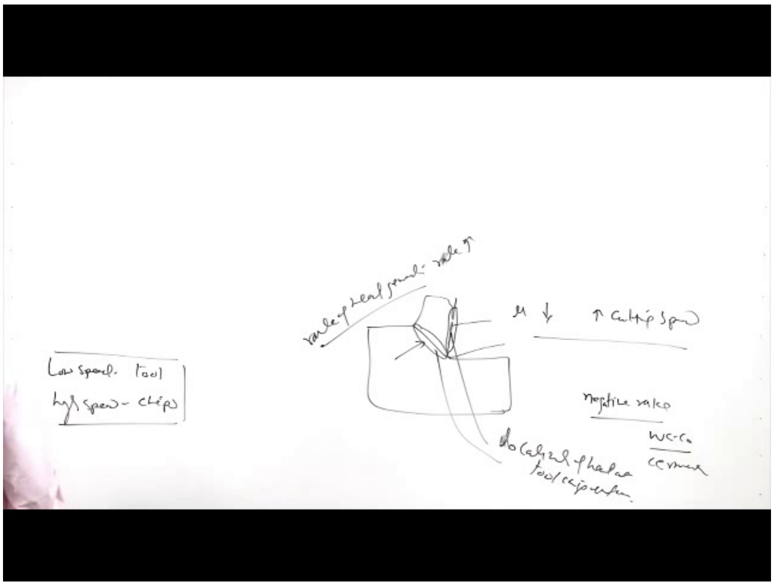

So, we need to consider in the same way. So, the shear deformation is one and the friction at the tool chip interfaces another. Considering that there is no rubbing between the tool and the work piece in that case the friction actually decreases with the increase of the cutting speed.

So, the frictional heat should reduce with the increase of the cutting speed. And unless there is a negative rectangle speed will not be having much effect on the shear deformation energy required for sharing, but those cases where the negative rake tool is used, negative rake is used like in tungsten carbide cobalt or the ceramic tool at high speed, a high-speed heat generation leads to the softening. So, increase in a speed leads to the softening of the material and of the cutting edge and that in turn reduces the energy required for the shearing.

But at low speed it does not happen, even with the positive rake it does not happen does not affect the things much. If the positive rake angle tools and so the mu it does not affect. So, what is leading to the increase in the cutting speed, what is leading to the increase in tool chip interface temperature with the increase in cutting speed? For that what we need to see is heat generation rate, rate of the heat generation per unit time because the power consumption per unit time will increase. So, so heat generation rate, generation rate increases with increase of cutting speed. So, the rate at which heat is being generated per unit time that increases. So, the tool does not get much time for transferring the heat away and this leads to the localization of the heat, localization of the heat at tool chip interface.

So, this localization leads to the rise in temperature with the increase of the cutting speed. So, this is the main reason behind the rise in temperature with the increase of the cutting speed because actually the friction and the tool chip interface decreases with the increase of the cutting speed, but the work being done to overcome the friction per unit time actually increases with increase of the cutting speed. So, that in turn increases the tool tip tool chip interface temperature. So, now, in order to control the temperature of the tool within these safe limits we need to a use the cutting fluids in such a way that the tool remains within the safe temperature limits. So, that it can offer the required to life.

Now, here I will summarize this presentation in this presentation I have talked about the specific power consumption and how the uncut chip thickness effects the specific power consumption. Thereafter I have tried to explain the different sources of the heat generation during the metal cutting and how empirically it can be calculated, means the how tool chip interface temperature can be calculated using the various properties related with the tool and work piece material as well as the cutting conditions.

So, thank you for your attention.