Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology –Part-1

Module- 42

by
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Hello and welcome to this manufacturing process technology part 1 module 42.

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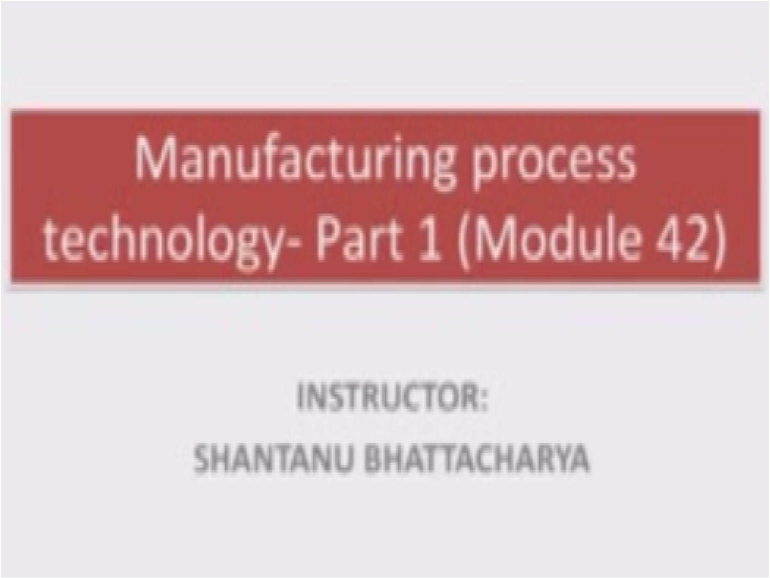

Manufacturing process technology- Part 1 (Module 42)

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We will be today discussing mostly about the temperature rise and the cutting zone because of the various portions of the power consumed in the primary, secondary and the tertiary zone of the cut. So let us actually understand the problem little clear as to what these different zones are in metal cutting so when the material is deformed elastically.

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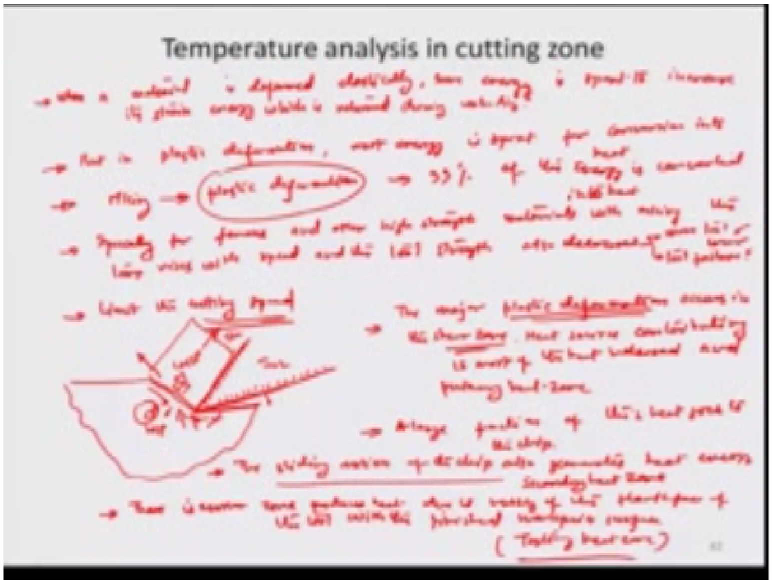

Temperature analysis in cutting zone

Some energy spends to increase its strain energy which is returned during the unloading right so some energy is spent to increase its strain energy and obviously because it is in the elastic range the material will return back so this is return during the unloading process which is returned during the unloading process. However in a plastic case or it is basically plastic deformation most of the energy is spent in converting.

Or getting converted into heat and temperature rise of the material right so you just write it down here that first in plastic deformation and by the by most of the metal machining processes are based on plastic deformation and so therefore 99% of the energy in that case is converted into heat energy, so in the plastic deformation most energy is spent for convergence to heat in case of machining because most of it is based on plastic deformation almost 99% of the energy is converted into heat.

So obviously it brings a very strange situation that because of this heat flow into the 3 components which are actually connected to each other in machining one is work piece, one is the tool and one is the chip obviously the heat is going to get its there would be a heat flow from the cutting zone into all the three components that is the chip the work piece and the tool obviously there would be a temperature rise because of that.

So if we are using a condition where because of the continuous you know power consumption of cutting there is an increase in the heat it may lead to the deformability of the tool or change in the properties of the tool and it may also simultaneously result in a you know change in the material properties of the work piece material because you know things like let us say shear stress etc vary a lot based on what is going to be the temperature of the cutting zone.

So in any event there is going to be an overall change because of this you know rise in the energy level and you know retained energy level in terms of temperature state which comes onto the chip as well which is work piece as well as the tool and it creates a situation where we need to estimate now what is going to be the temperature rise because of all this energy flow or all this power which is consumed in doing the machining operation.

So especially for ferrous metals and may be some other high strength materials like ferrous metals would machining the temperature rises the speed of machining and the tool strength also decreases so obviously it would create more tool wear and sometimes even tool failure okay if the temperature is more very high so this definitely should put limit to the cutting speed, so limit the cutting speed.

And that is why an analysis is needed then how much would be the kind of optimum speed which would be needed for all these different failure aspects would not creepen and have the machining operation carried out at a certain optimum speed, so the if we look at how the chip formulation process again takes place I am going to just draw the work zone in case of a chip formulation process.

So this right here is let us say the chip which has been created and this right here is again the tool which on which or on the surface of which the chip rest and let me just show these two boundaries of the tool face with this shaded regions this is the tool, this is the work piece, this is the chip so obviously the major plastic deformation if we look at because all the temperature rise and the heat flow is a function of where the deformation is most.

So the major plastic deformation occurs in the shear zone so when the chip is shearing off with respect to the work piece there is going to be a change in the energy here this is plastic deformation mostly converted into heat and so there would be heat coming out in both these directions from this primary shear zone. So this is because of the nature of the plastic deformation process here which is really the determinant of the material removal.

This is a heat source which contributes to most of the heat release. so heat source contributing to most of the heat released and also referred to as the primary heat zone obviously because this is the primary reason why the heat is being generated that the chip is being script of from the work piece obviously a large fraction of this heat goes to the chip it does also flow into the work piece.

Because work piece is at a lower temperature and wherever there are two different temperature states heat flow would take from the higher temperature to the lower temperature there is another reason why heat should offer and that because the chip is moving at a certain velocity with respect to this tool face right about here and so the sliding motion of the chip also generates heat energy and this energy is primarily generated in the tool face.

Because of the frictional face at the chip would have against which it has to move at a certain chip velocity V_C, so let us say the chip velocity is V_C whereas the cutting velocity here in this cutting direction is V so there may be a relationship between V_C and V which we need to obtain in order to estimate what is going to be the quantum of temperature increase because of the heat generated by virtue of rubbing action, okay.

So there is another heat zone so this is typically call the secondary heat zone, so there is another one which is really this flank okay now this flank of the tool and because of the rubbing of this flank with respect to the surface the finished surface and the we can say that this zone can produce heat due to rubbing of the flank face of the tool with the finished work piece surface upto obviously if we can have sharp at tool this rubbing action can be avoided.

But in any event this is also known as tertiary heat zone, which hardly contributes any heat because if we sharpen the tool a little bit then this problem of rubbing action of the flank with the finished work piece would be solved and there would not be any heat generated because of that, okay.

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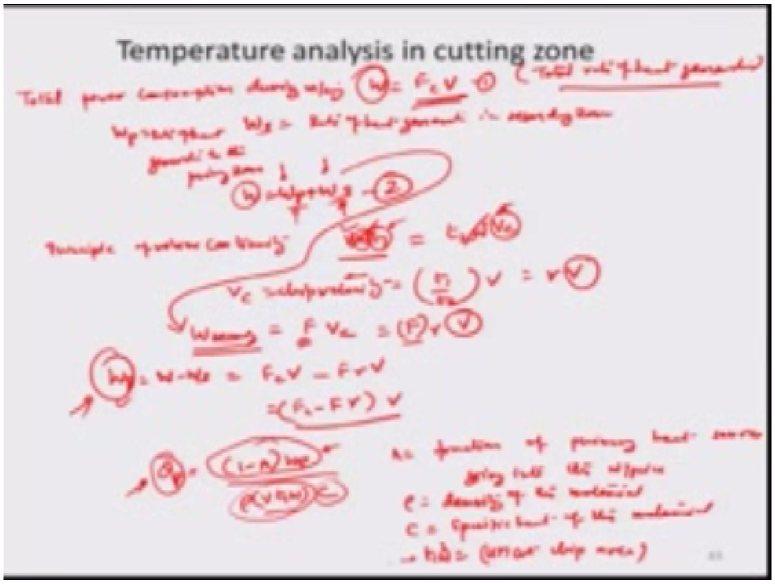

Temperature analysis in cutting zone

$$W = W_P + W_S$$

$$W_S = F\,v_c = Frv$$

$$W_P = F_c\,v - Frv$$

$$\theta_P = \frac{(1-\Lambda)\,W_P}{\rho cv\,wt_1}$$

$$\Theta = \frac{\rho cv\,t_1}{k}$$

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

$$\theta_S \approx 1.13\sqrt{\frac{\Theta\,t_2}{l}}\left(\frac{W_S}{\rho cv\,wt_1}\right)$$

$$\theta_{Sav} = \frac{W_S}{\rho cv\,wt_1}$$

$$\frac{l}{t_2} = \left[1 + \tan\,(\varnothing - \alpha)\right]$$

$$\theta_S \approx 1.13\sqrt{\frac{1}{cv\,t_1 k\left[1+\tan\,(\varnothing-\alpha)\right]}}\left(\frac{W_S}{w}\right)$$

$$\theta = \theta_o + \theta_P + \theta_S$$

So having said that now the question is, how can be estimate the different powers which are consumed in the process so obviously I think I have mentioned many times earlier doing during the Merchant’s circle diagram analysis of the forces the total power consumption of the cutting process during machining is obtained as cutting forced times of cutting velocity or the force velocity product.

And I would just assume this to be totally converted into heat so total rate of heat generation is actually this W rate of consumption of the power we can we assume that 99% of the power is consumed in you know the cutting process because obviously the forces are very large and also force velocity product is pretty large so if the rate of heat generation the primary zone and secondary zone or let us say W_P and W_S respectively.

This is the rate of heat generation in secondary zone and this is the rate of heat generation in the primary zone so then W can be recorded as the $W = W_P + W_S$ obviously there is no other source into which or from which the heat would result. we are assuming the tool to be sharp enough so that the flank where does not contribute to any rise in heat flow or something, so these are the two sources principally from which this total cutting forces supposed to be consumed. One is the frictional aspect that comes as a temperature rise of the tool face as well as the chip surface another is the primary aspect of shear which rises the temperature of the chip as well as the work piece surface. So now let assume or let is try to find out what is the chip velocity and this we find out from the principle of continuity so obviously the amount of material that is being scrapped off is a material which is removed as the chip so we say the principle of volume continuity enables us to find out what is the volume rate of removal of the material which is $V*W*t_1$. I think I had mention this earlier V is the cutting velocity in the direction of the cutting force, W is the sort of width of the cutting zone and t_1 is the uncut chip thickness.

So this much amount of volume is being removed and the same volume is converted as the chip velocity so if I have considered t_2 as the cut chip thickness and W as the width of the cutting zone so the t_2 times W times V_C, where V_C is the chip velocity would give the same rate of volume as the volume which has been scrubbed off from the work piece surface so therefore on the V_C or the chip velocity.

In this case can be estimated as t_1/t_2*V obviously the W they all go up because the width is same whether it is cutter on cut side of the deform shape or the per-deformed shape you know as the part of the material so t_1/t_2 times of V this we call as a cutting ratio times of V and secondary heat generation W_S can be recorded as the frictional force F that the chip faces times of the chip velocity which is also can be represented as the frictional force that the chip faces with respect to the tool face times of the cutting ratio R times of the cutting velocity.

So F_rV so that is the secondary rate of heat generation which can be plugged in to this equation to write about here as W_S value. let us calculate the W_P so obviously W_P would be W- W_S, W already has been recorded as $F_CV - F_r V$ so this becomes equal to F_c - F_R where R is the cutting ratio times of the velocity V, so that is what the primary zone would be enabled to provide as the rate of heat generation.

$$W_S = F v_c = Frv$$
$$W_P = F_c v - Frv$$

So once we have calculated the W_P and W_S let us see what is the impact in terms of temperature or the surface temperature and when a material particle moves across the primary deformation zone the temperature rise that would be there θ_P would be given really as the amount of fraction that is lost of the primary heating zone into the work piece okay, so 1 minus that is basically the amount of power primary power that escapes into the let us say the chip okay.

Divided by the mass rate of flow which is actually again the density of the material times of the cutting velocity times of t_1W which is the rate of volume removal of the material, so this is the mass rate of the removal of the material right, so the specific heat capacity okay. So Q = mCT as you know so if the total amount of temperature rise of the chip because of the primary power is θP then we can assume that to be a fraction of the power that actually moves into the chip.

By unit $\rho v\ t_1WC$ which means it is the mass rate of removal of the material times of the specific heat capacity of the material part of the deformation so that is giving you an indication of what is going to be the rise of the temperature because of the primary heat, so here λ is actually the fraction of primary heat source going into the work piece, ρ is the density of the material, C is the specific heat of the material.

$$\theta_P = \frac{(1-\Lambda) W_P}{\rho c v\, w t_1}$$

And t_1W is basically the uncut chip area which is the product of the width of the cutting zone times of the uncut chip thickness. So there have been the reports in the literature which is really determine this λ from dimensional analysis.

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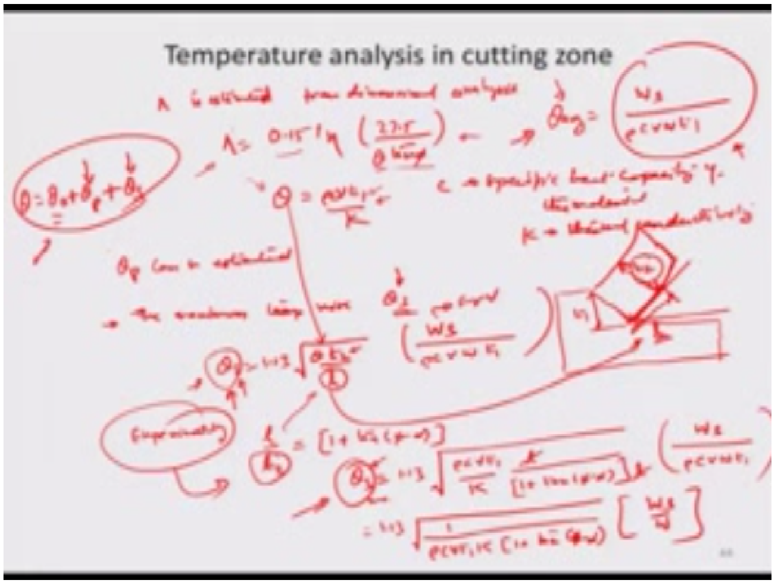

Temperature analysis in cutting zone

So λ is estimated from dimensional analysis and I am not really going into the details of this analysis because from at strand point of estimating the temperature we can actually assume this formulation okay and work out what is going to be the increase of the cutting temperature in the zone of cutting because of the primary heat component, so λ can be estimated as 0.15 natural log (27.5/ θ tan ϕ) where this parameter θ is again a non dimensional parameter which has been recorded as ρvc t_1/k.

$$\Theta = \frac{\rho c v t_1}{k}$$

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

c is the specific heat capacity of the material and k is obviously the thermal conductivity, so you have to sort of create this non dimensional quantities and try to find out what is the relationship between this fractional of heat release as well as this whole quantity here and it is found that you know with respect to experiments as well as the final non dimensional parameters which are related to each other.

It comes out that λ becomes equal to its inversely proportional to the ln(θ) this parameter here non dimensional parameter here and also inversely proportional to tan ϕ again which is non dimensional in nature. So now therefore θ_P that is the rise of temperature of from the primary zone or primary contribution can be estimated. We can similarly do the estimation of the θ_s the secondary zone and the maximum temperature rise as well as the average temperature rise.

Because of the secondary power and so in this case what we can do is, the maximum temperature rise θ_s again you know coming out of literature has been estimated to be 1.13 $\sqrt{\theta}$ t_2/L W_s the secondary power which is actually generated by F_rV as I told earlier divided by ρcv w t_1 okay. So obviously this is again the mass rate of flow okay times the specific heat capacities so the mC component and obviously the Ws signify the rate of heat generation.

$$\theta_S \approx 1.13\sqrt{\frac{\Theta t_2}{l}}\left(\frac{W_S}{\rho c v w t_1}\right)$$

$$\theta_{S_{av}} = \frac{W_S}{\rho c v\, w t_1}$$

So the rate of heat generation per unit the rate of mass flow times this specific heat capacity gives you an idea of the θs, so just because you can understand that you know there is a if you look at really how the chip is contacting the tool surface the chip really is having a length of contact okay on the tool surface let us say this is the tool that is being considered and this is the work piece surface this is the shear zone being created.

Because of the chipping is happening this is the chip processes so the chip really is trying to go out right, so as it removes the chip goes out like this okay and there is also a finite length which is contacting on the tool surface, so this length is what tis L is, the length of contact of the chip on the rake face and it basically gives you a you know an attempt to as a function of this length can record what is the θs values.

So the length is lower and lower and this point is closer to this particular you know point of engagement of the tool with respect to the work piece of the work zone actually the θs would be higher and higher that is why this inverse relationship is obtained here, so the this contact length here as again being correlated experimentally, so experimentally you know people have reported this contact length L varying in relation to t_2 which is the cut chip thickness.

Remember this again t_2 here term basically represents the cut chip so the cut ship thickness where just because this side is the t1 if you may remember from earlier analysis the cut ship thickness is after the deformation of the ship has happened actually and here the L/t2 okay is experimentally found out to be a function of ϕ and it basically is represented as 1 + tan ϕ – α okay. So this is also borrowed from an experimental result.

$$\frac{l}{t_2} = [1 + \tan(\varnothing - \alpha)]$$

So in that event if I substitute all this values and try to find out you know and try to find out the coverall form of what θ_s would take by substituting the value of ϕ etc. The θ_s maximum and this is the maximum temperature on the chip or temperature distribution on the chip because of the relatively different lengths of engagements that the chip has with respect to the tool face we can get this as 1.13 √ and we put the value of θ here as ρvc t_1/k thermal conductivity of the material times of t2.

Which again can be represented as L/1 + tan (ϕ – α) so that is how you represent θ t_2/L because √θ t_2 / L that is what it says and so this get cancelled out times of ws the amount of secondary power times of ρcv wt1, so this can again be recorded as 1.13 √1/ρcv t_1 k 1+ tan (ϕ – α) times of ws/w okay and that is how you can get the contribution from the secondary zone already you have had a contribution of the primary zone by virtue of this value of λ here as recorded here in this particular statement 1 – λ wp/ρv t_1 w C , okay.

$$\theta_S \approx 1.13\sqrt{\frac{1}{cv\,t_1 k\left[1+\tan\left(\varnothing-\alpha\right)\right]}}\left(\frac{W_S}{w}\right)$$

$$\theta=\theta_o+\theta_P+\theta_S$$

So an average temperature also can be plotted out as just simply the ratio between the rate of heat generation at the secondary zone per unit the mass rate of removal time specific heat capacity of the material so this is an average temperature rise, so this is not of much significance there may be some numerical estimation where this is of some important but what is in the normally important is to correctly estimate what is the overall temperature rise.

And the overall temperature rise here in the cutting zone is I may just look at this particular zone so there is a heat flow because of the primary heat which is generated and there is also a heat flow because of the frictional heat which is generated which is maximum at this particular point, so the maximum temperature here would actually be equal to the ambient temperature θ0 plus the increase because of the primary heat.

And the increase because of the secondary heat so that is how you can calculate the maximum temperature in this particular case, so interest of time I am going to close this module but in the next module I am going to make you teach or make you learn about how you can actually estimate and what arte the kind of values or atleast order of magnitudes which are involved of temperature rise because of this various thermal models that have been represented in this particular module. So as of now, thank you and good bye.

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