Mechanics of Machining
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Lecture - 12
Thermal Aspects Of Machining: Temperatures in Orthogonal Cutting

Hello students welcome to the course of Mechanics of Machining this is the 12th lecture, today am going to discuss thermal aspects in machining.

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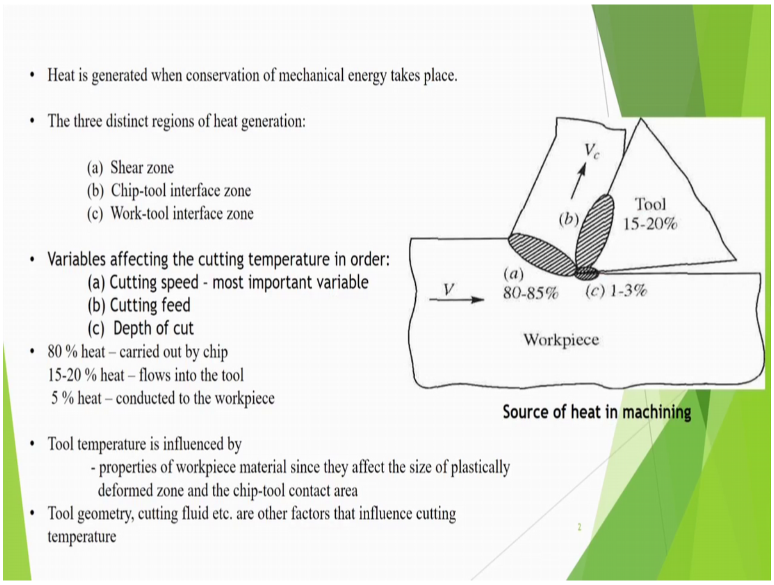

By thermal aspects we mean we will find out how much heat is generated what is the temperature heat is always generated, when mechanical energy is converted into heat. Some type of mechanical energy conversation takes place and the heat may be generated in machining at three places.

It can generate in the shear zone here it is generated and heat can also get generated at the tool chip interface, because the chip is moving on the rake surface of the tool. So, there is lot of friction that frictional work gets converted into heat, and then tool may rub against the work piece against the machine surface. Like heat is work tool interface zone here also the heat is generated and this figure shows this source of heat in machining.

Now, about 80 to 85 percent heat is generated in this particular zone that means, where actual plastic deformation takes place and chips gets separated, the in that area 80 to 85 percent heat is getting generated. Due to friction on the tool rake surface, when the chip is sliding then about 15 to 20 percent heat is generated and here there is very small amount of rubbing and that is why here the heat generation is about 1 to 3 percent.

Now, what are the main variables that affect the cutting temperature in that particular order, one is the cutting speed cutting speed is the most important variable. Suppose, we increase the cutting speed, then the heat generation will increase and accordingly temperatures will also increase.

So, cutting speed is the most crucial parameter number 2 is the cutting feed also if it increases then the temperature will increase, but feeds affect may not be as much significant as that of the cutting speed then depth of cut depth of cut also has some influence on the cutting temperature. So, it is found that whenever the heat is generated out of that heat about 80 percent heat is carried away by the chips, chips fly.

So, they carry away, you might have seen in the workshop that when you are machining some metal then the chips actually fly and they almost becomes red actually. It has if higher is some cases like a spark, they are flowing in some cases that temperature may not be that high and the those chips also becomes sometimes blue colors sometimes little dark blue color, because of the oxidation at that high temperature and lot of compounds formation.

So, 80 percent heat is carried away by chip that is a good point, so that is why may be tool we will not get that much damaged, but 15 to 20 percent heat also goes into the tool. And that reaches the temperature of the tool and as you know that once the temperature of the tool increases then its hardness will slightly reduce, that is heart strength of the tool may reduce.

So, that goes, so we have to do something to cool the tool and 5 percent heat also gets conducted to the workpiece and it raises the temperature of the workpiece. Now raising of the temperature of the workpiece has two main affects, sometimes if the temperature increases by large amount then the workpiece may undergo expansion and it may affect the machining accuracy and another affect is that because the temperature increases. So, flow stress of the workpiece reduces and it eases the cutting process.

So, tool temperature is influenced by properties of workpiece material since they affect the size of plastically deformed zone and the chip tool contact area. So, workpiece material is important some tool if it is machining soft material the temperature may not be high, and if the same tool is machining the hard material then its temperature may become very high. So, that is one thing that what type of work material you are machining that will have affect.

And tool geometry and cutting fluid etcetera are other factors that influence cutting temperature, tool geometry also has some significance we have already discussed it in our previous classes and cutting fluid also has affect. So, that is why we have to use cutting fluid or coolant, now why do we want to know the cutting temperature this is the natural question.

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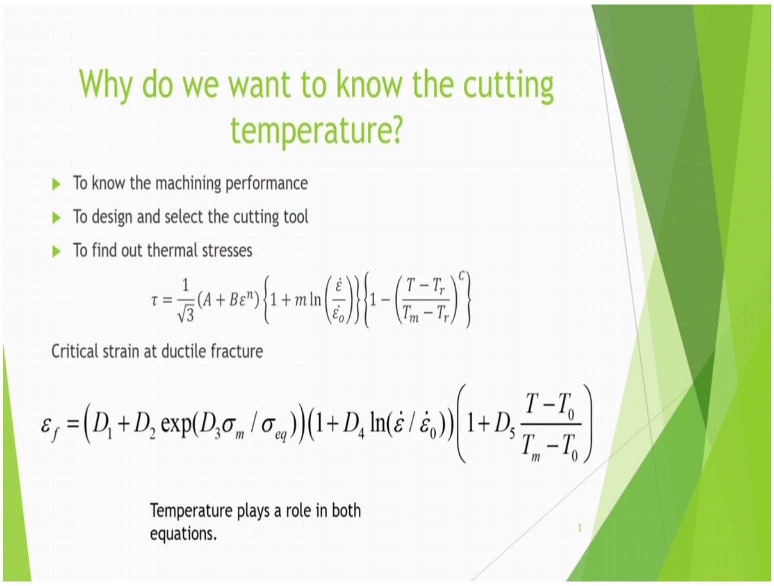

So, one answer is that to know the machining performance whether machining is being done properly or not ideally we do not need much temperature generation. If machining performance is not good sometimes you may get very high temperature, second thing is that we design and select the cutting tool based on how much cutting temperature is generated. Cutting tool has to be designed to cop up with that temperature, then we can find out the thermally stresses with the temperature and also materials flow strength depends on the three main factors one is the strain other is the strain rate and the third is the temperature.

So, there is famous Joulson Cooks equation thathave written it is based on the Joulson Cook model. Here tau is the shear strain this tau is the shear strength and this is 1 by root 3 A plus B epsilon n this is strain hardening component. It indicates that if the strain is increasing, then the strength is increasing other is the strain rate effect 1 plus m; m is some transcend depending on the material and this is logarithmic epsilon dot divided by epsilon dot 0. Epsilon dot 0 is some reference temperature you can take 1 into 10 to the power minus 3 and epsilon dot is the strain rate whose unit is per second.

So, strain rate it increases then its shear stress will increase and the temperature, temperature also if it is increasing. Then the strength is decreasing temperature as opposite effect to that of strain and strain rate, but this is the formula given. So, if you want to precisely model and find out the forces etcetera in the machining then we must know the proper value of the flow strength and for that purpose we must know the temperature also. So, that is why we need to estimate or measure the temperature.

And another thing is that when the chip separates when the chip will be separating when there will be some amount of fracture and most of the time it is ductile fracture. Particularly, if the material itself is ductile in that case there is one critical strain that is epsilon f and D 1 D 2 etcetera are constant parameter and this sigma m is the mean stress sigma e q is the equivalent stress. And this is 1 plus D 4 l n epsilon dot epsilon dot 0 and then it is T minus T 0 T T m minus T 0.

So that means, this is showing that your the strain fracture will increase depend if the temperature increases by this these parameters and this relation is there. So, this type of dimage model, we have got by which we can find out the critical strain, but we need to know the temperature also. So, temperature plays a role in both of the equations.

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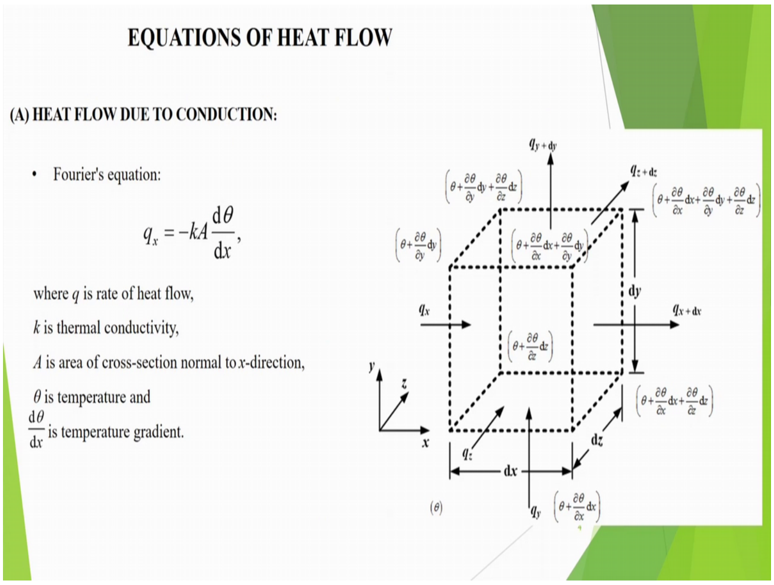

Now, let us understand that how we find out the temperature or how we do the heat transfer analysis we assume that most of the cases may be convective heat transfer and radiative heat transfer will be very small in comparison to heat transfer by conduction.

So, we first develop that heat flow due to conduction, so we can use Fourier's equation, Fourier's equation is what q x is equal to minus k A d theta by d x; where thetaam indicating by as a temperature theta is the temperatuream that symbolam using because T may confuse with time also. So, q q is the rate of heat flow k is the thermal conductivity A is the area of cross section normal to the x direction theta is the temperature and d theta by dx is temperature gradient, why we are having minus here because if the temperature gradient is negative then heat is flowing in that particular direction.

So, this is the basic Fourier's equation, but we can make a cube actually and in that heat is flowing in all directions that is it is flowing in x direction that is indicated by q x it is q x this side and qx plus dx this side then we have q and this side we have q y plus dy then on this face qz is entering and from other face q z plus dz is coming out. And the temperatures are also indicated here if had center the temperature is theta then we can have theta plus d del theta by del y into dy.

All we can have this as reference point this is the origin then in that case this equation becomes very proper that this is theta plus del theta by del y dy. And here also it is theta plus del theta by del x dx and del theta by del y dy plus del theta by del z dz ok. So, this up to first order approximation these quantities have been written.

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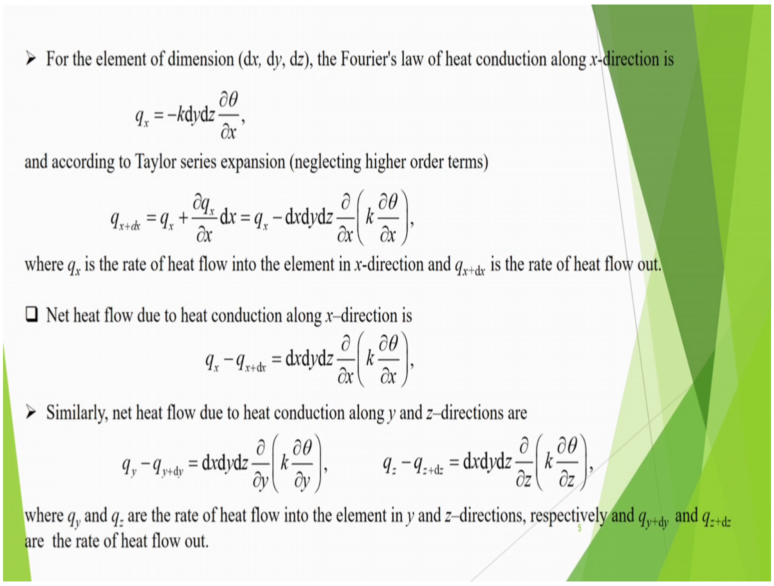

And, so for this element of dimension dx dy dz the Fourier's law of heat conduction along x direction is given like this q x is equal to minus k dy by dz, because area normal to the x direction is dy by dz. And according to Taylors series expansion if we neglect higher order term then q q x plus dx can be written as q x plus del q x del x into dx. And this can take q x can take from here and then can write it like this equation becomes like this dx dy dz.

So, q x is rate of heat flow into the element in x direction and q x plus dx is the rate of heat flow out, so that is why its sign has to be different. So, net heat flow due to heat conduction along x direction is q x minus q x plus dx and this becomes this quantity dx dy dz and this quantity. Similarly net heat flow due to heat conduction along y and z directions are given like this in the similar way we can write and qz minus q z plus dz is equal to this these expressions we have written.

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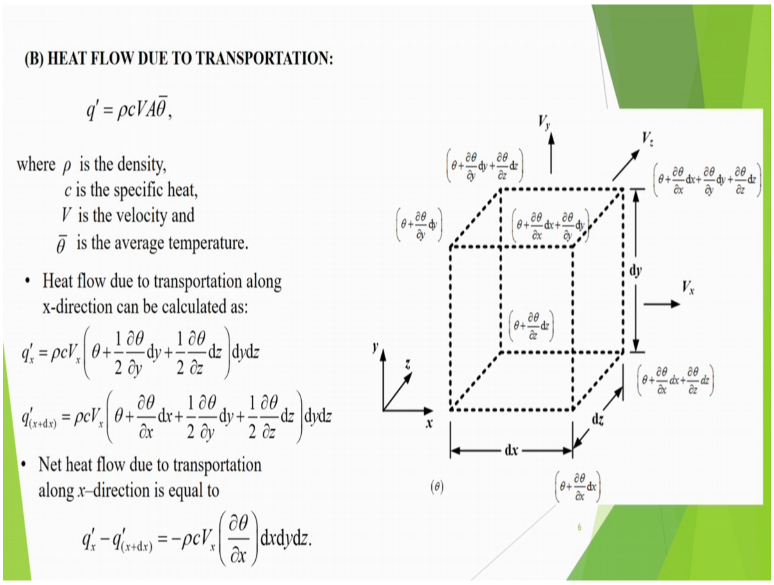

Now, we have to see the other component actually suppose some material is moving that means, transportation of the material is also taking place suppose it is a hot material and it is passing naturally it is also transferring some type of heat. So, heat flow due to transportation is discussed here this expression is q dash is equal to rho c V 8 into theta average.

Suppose the average temperature is a theta and the rho is the density c is the specific heat, and V is the velocity then rho c rho into v that will give heat flow per unit time and c is the specific heat. So, heat flow due to transportation along x direction can be calculated like this q x dash x is equal to rho c V x and this much quantity we can write.

And similarly q dash x plus dx is equal to rho c V x this one. So, net heat flow due to transportation is actually written as along x direction is written as is equal to this much q dash x because this heat is entering and this heat is coming out. So that means, heat entering is rho c V x and this much expression and heat coming out is this. So, net heat flow is minus rho c V x del theta by del x dx dy dz like that.

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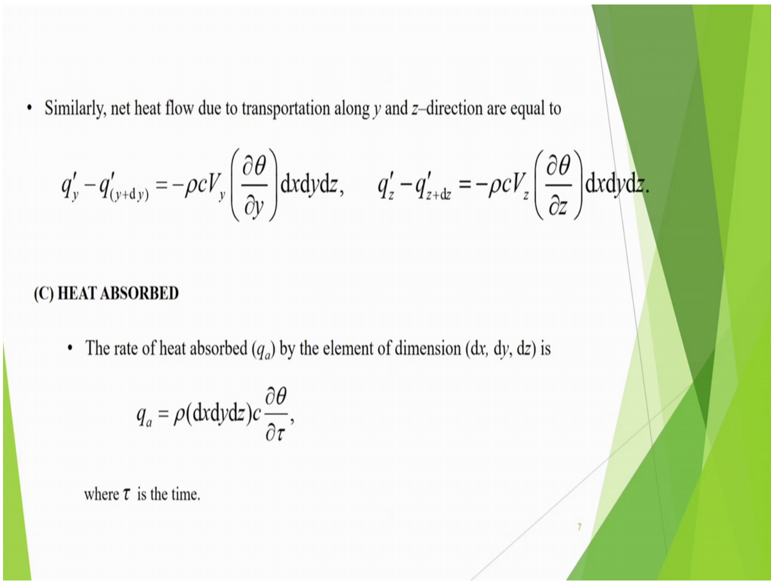

So similarly, the net heat flow due to transportation along y and z direction is given like this and similar that expressions are there then we have to see how much is the heat is absorbed by this element. So, heat will be absorbed if the temperature of the element raises suppose the temperature has risen by some amount let us say by delta theta, so rate of raise is delta theta by del tau where tau is the time.

So, rate of heat absorbed by the element of dimension dx dy dz q a is equal to rho dx dy dz times c c is the specific heat and del theta by del tau, here you can see that this rho is the density and dx dy by dz is the volume of that element. So, this quantity is total mass of that element that mass is very small, but this quantity also has to be added here.

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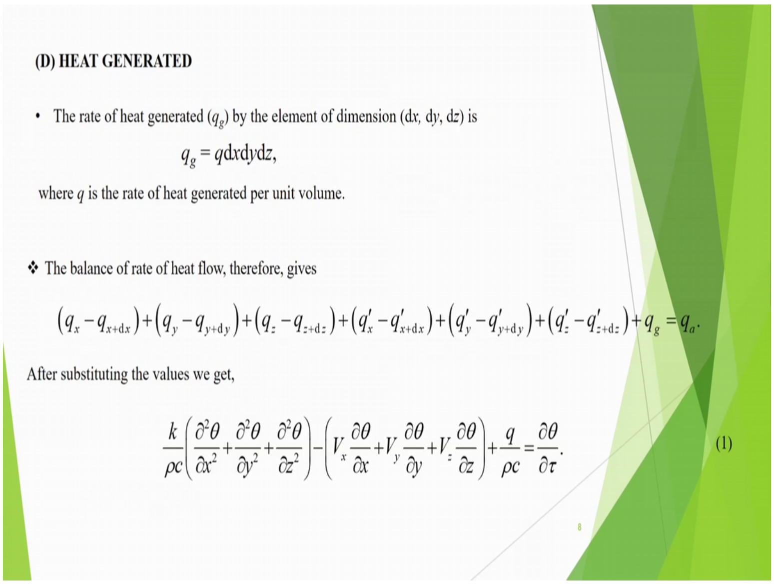

And then this is the rate of heat absorbed due to temperature increase then heat generated there may be heat generation in the element. Heat generation may be due to various reasons particularly machining it is due to plastic deformation when plastic deformation takes place then most of the heat. In fact, at least 90 percent heat gets converted into the heat 90 percent plastic work may get converted into the heat sometimes it can be 95 percent also. So, that heat generation is indicated by q j is equal to q j q g is equal to d dx dy dz where q is the rate of heat generated per unit volume.

So, if we put that thing variance of rate of heat flows gives like this am putting all type of heats here heat due to absorption heat due to generation and all these things. So, whatever there has to be heat variance that means, whatever heat generated or whatever heat has been pumped in to the element, heat generation plus whatever heat has been pumped into the element both would sum to the heat absorbed then only there will be proper heat variance.

So, if we substitute these quantities am skipping lot of steps here you can put all those values together then you can get this type of expression. So, we are getting k rho c and this is del square theta by del x square plus del square theta by del y square plus del square theta by del g square and minus because of the velocity effect, because of the transportation of the material and plus q by rho c and this is del theta by del tau this is three dimensional transient heat conduction equation

If the material is not moving then this second expression with negative sign will not be there and in that case you will be getting this total. And similarly if it is a steady heat, steady state heat conduction then del theta by del tau will be 0 and this will become like this. So, you will be getting this type of expression, now as we know that k by rho c is known as the thermal diffusivity it is the thermal diffusion.

And how fast the heat will diffuse into the material how fast it will be moving suppose k is very high that means, material is highly conductive then immediately heat which is on the surface will immediately go to the interior part it will move to the other side because conductivity is very high. So, that is why diffusion will be lost and it is inversely proportional to density and specific heat. So, this is called alpha and k by rho c has got a unit of meter square per second. Now, so, this expression is the basis we can solve this either in analytically or numerically.

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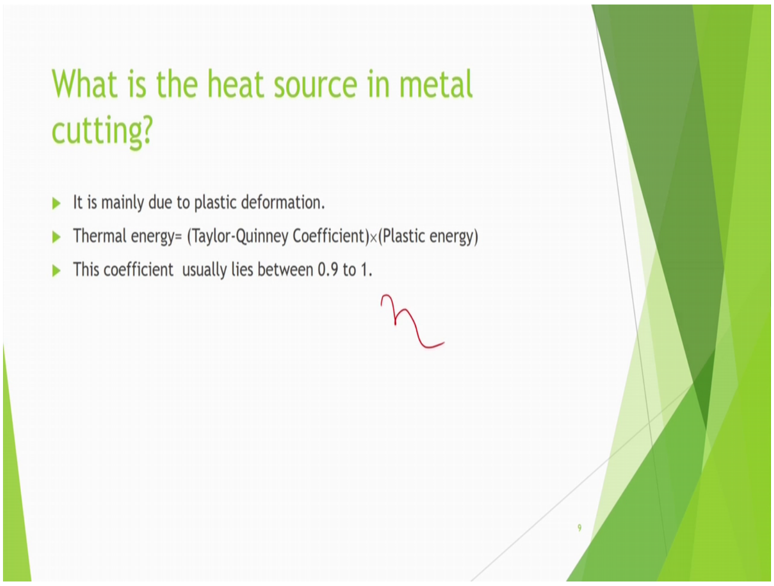

So, let me just now discuss again that what are the main heat sources in metal cutting main heat is due to plastic deformation. Due to plastic deformation work will be done and that energy of the that plastic work when we do the plastic work that means, we supply the energy. So, that plastic energy that will be converted to thermal energy in some proportion means it is not necessary that 100 percent plastic work is converted into the thermal heat some portion may be stored as internal energy like in dislocations etcetera.

So, thermal energy is given by some Taylor Quinney coefficient into plastic energy this coefficient usually lies between 0.9 to 1, Taylor Quinney coefficient is lying between 0.9 to 1 some people use symbol eta for this ok. Some people use symbol eta otherwise means there are different, different symbols, but mostly eta is used so that means, 90 percent at least 90 percent plastic work will be converted into the heat.

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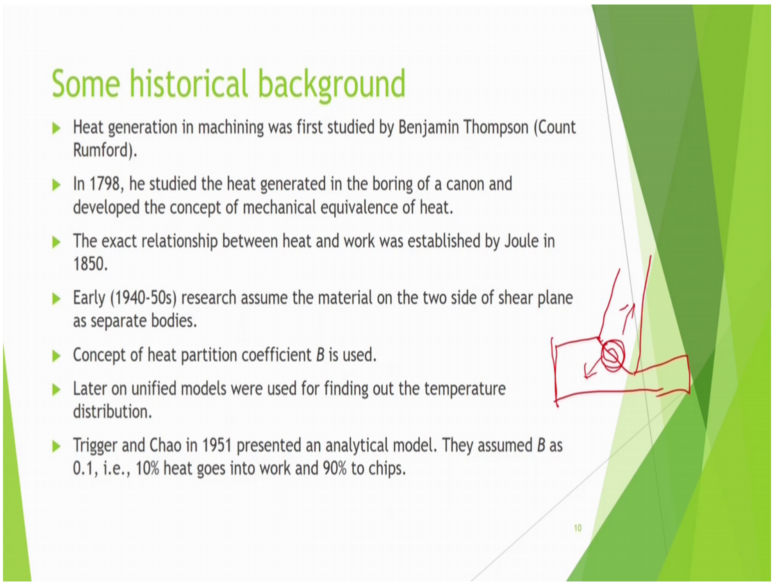

Now, let me give some historical background on the thermal studies on machining heat generation in machining was first studied by Benjamin Thompson which is also called count Rumford. In 1798 he studied the heat generated in the boring of a canon and developed the concept of mechanical equivalence of heat. He realized that when we are boring a canon or gun barrel in that case lot of heat is generated because machining is done and this heat generation he also developed some mechanical equivalence of heat means mechanical work is done. So, heat is generated, but the exact relationship between heat and work was established by Joule in 1850.

Joule has developed this in 1850 that relation we know that nowadays it is called Joules coefficient that means, which converts this heat to mechanical work to heat, so that this is convergent coefficient. So, that joules coefficient is used that is j and early 1945 research researchers assume that material on the two side of shear plane as separate bodies. So, is was assumed that material on the two side of shear plane as separate bodies and they find out that how much is the heat going.

So, they introduced a concept of heat partition coefficient B that means, whenam doing the metal cuttingam have this type of situation. So, this portion is shear zone we say that basically shear plane and this is chip is coming. So, suppose here lot of heat is getting generated in this zone, so part of it will go to the workpiece this part other part will go to the other part that is other side of the shear plane. So, these are two separate bodies and that is why in what proportion it will go that is called coefficient of heat partition that means, we can say B potion will go here and 1 minus b portion will go in the other side if the total heat is one.

Later on unified models were used for finding out the temperature distribution then people did it as a one body only Trigger and Chao in 1951 presented an analytical model. They assumed B as 0.1 Trigger and Chao assumed that B and was 0.1 that is 10 percent whatever heat is generated 10 percent of it goes into the work and 90 percent of it goes to chips actually that they assumed like that.

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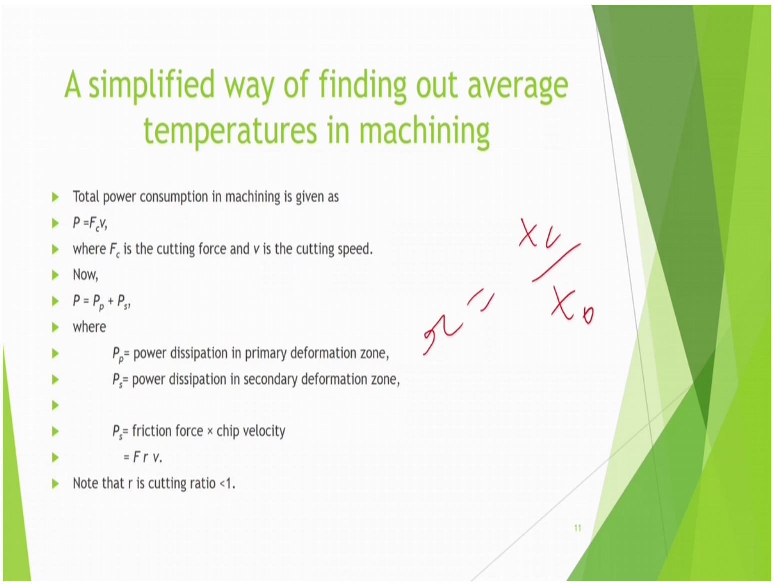

Now, let us discuss simplified way of finding out average temperatures in machining suppose total power consumption in machining is given as P is equal to F c into V where F c is the cutting force and V is the cutting speed. So, F c into V no doubt it will be equal to the cutting power and now this power total cutting power which we are supplying it broken is broken down into two components 1 is P, P that means power dissipation in primary deformation zone other is P s that means, power dissipation in secondary deformation zone.

So, we have two type of thing that means, why do we require power we supply that power through some motor which move the cutting tool and even job relative motion it causes what is that. So, that is needed because to overcome the power dissipation in primary deformation zone, and also power dissipation in secondary deformation zone and P s is equal to basically friction force into chip velocity.

But the chip velocity in orthogonal cutting can be attained easily as r into v where r is the cutting ratio this cutting ratio is the ratio of chip thickness to the ratio of uncut to the uncut chip thickness. That means, it is r as we already discussed in the previous classes r is equal to t c chip thickness and divided by t 0 that means, uncut chip thickness. So, this is known r is equal to t c by t 0 and this as you know this always r has to be always less than 1, because due to the plastic deformation there is a thickening of the chip, chip gets thickened.

Since there is a thickening then the length of the chip decreases and also you know that once the chip thickness has increased then the chips velocity. So, naturally the chip velocity because material continuity is there whatever volume is flowing in the form of raw material same goes as a chip. So, therefore, the cutting velocity chip velocity also has to reduce by that factor, so therefore, chip velocity is r times v.

So, if cutting speed is 10 meter per second and suppose you r is 0.5 then the chip velocity will be 5 meter per second. So, this is the total power due to friction at the rake surface.

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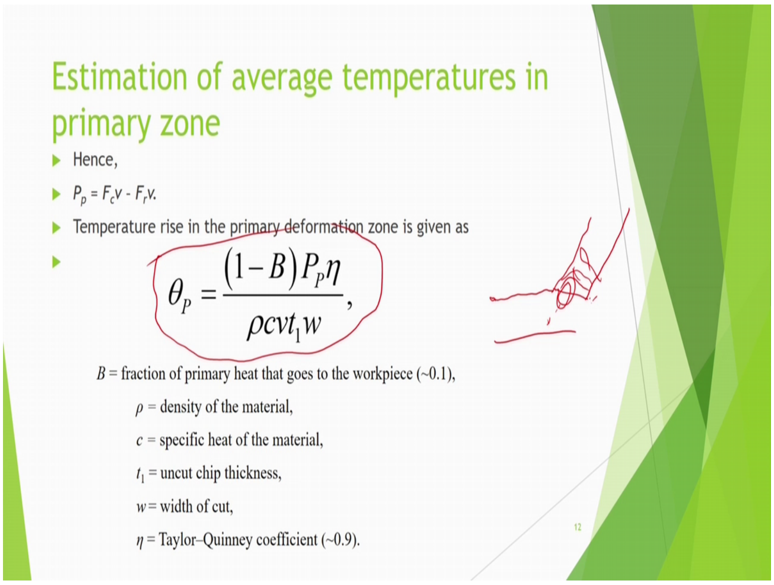

Now, estimate of average temperature in primary zone is done like that suppose we find out P p that means, power expanded during plastic deformation is F c in to V minus F r into V. So, temperature rise in the primary deformation zone is given as this theta P will be 1 minus B because beta is the fraction of primary heat that goes to workpiece say B may be 0.1

So that means, 0.9 will go into the chip, so 0.9 into P p into eta, eta is the Taylor coefficient this may also be 0.9, so we are interested to know temperature on the other side that means, on the chip side. So, that is why am telling that suppose had done like this one it is like this here and this material was going like this here the heat was generated then 10 percent of this assume it goes to this side. So, 90 percent remains here and that that 90 percent heat is going in this way.

So, that will rise the temperature of that this chip portion here that we are interested. So, rho is equal to density of the material c is the specific heat of the material, t 1 is uncut chip thickness then this is the volume flow rate v t 1 w that is volume flow rate and if multiply by density it becomes mass flow rate.

So, divide into c, so if we take this total heat divided by mass flow rate into specific heat then you can get the average temperature rise. So, average temperature rise is given by this expression it is important expression you can see it will help you to do rough estimation of the temperature of the chip 1 minus B B P eta rho c v t 1 w, here B you are assuming 0.1 and eta is also you are assuming. Because for most of the materials it is about 0.9 P, p you have to find out from this expression, above expression and rho c v t 1 these are the material properties they may be known to you w is the width of the cut.

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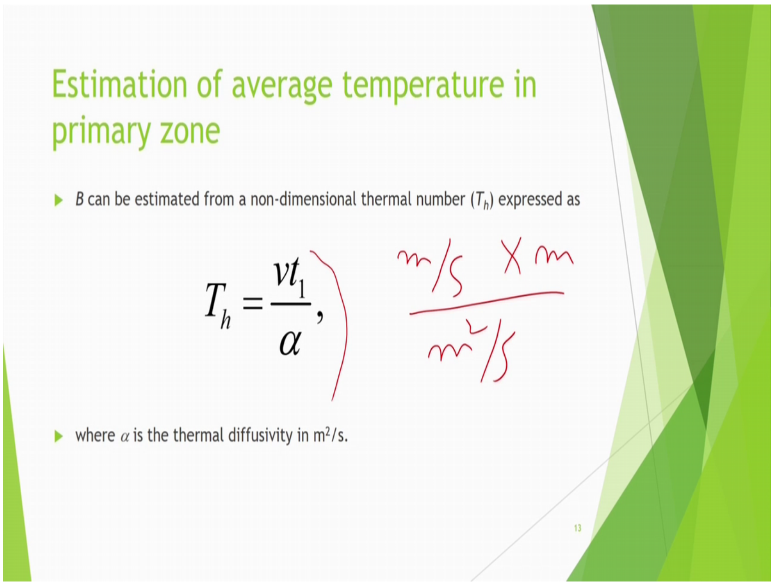

So, B can also be estimated although many people have just assumed B is equal to 0.1, but it is found that B is dependent on a non-dimensional thermal number that is T h it is expressed as T h is equal to v t 1 by alpha. So, where alpha is the thermal diffusivity in meter square per second, so what does this thermal number tell that suppose v is very high.

Then the thermal number will be very high T 1 is basically uncut chip thickness if T 1 is high then thermal number will be high. Then similarly you can say alpha, alpha is the thermal diffusivity if alpha is low then the thermal number will be high. And you can see you can check that its unit thermal number is dimensionless because v has got the unit of meter per second T 1 has got the unit of meter and divided by meter square per second. So, in the numerator also you get meter per square per second then (Refer Time: 29:27) meter also you get meter square per second and that is why it is a dimensionless number.

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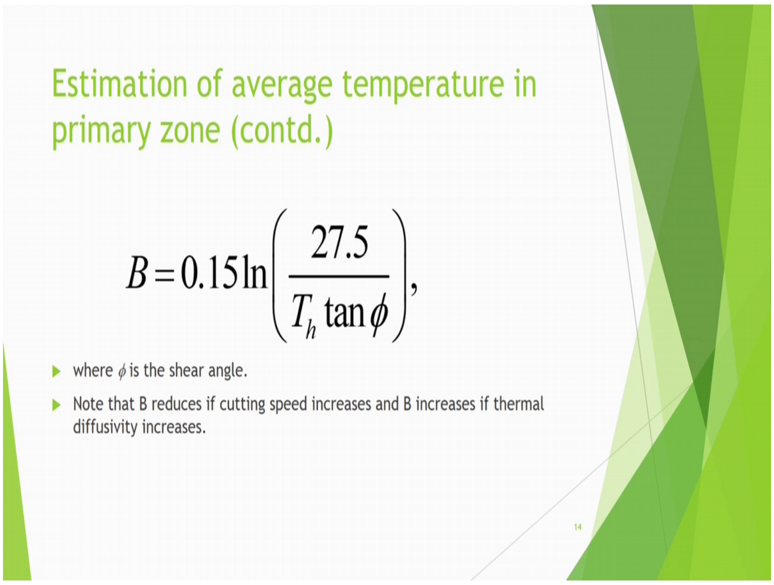

So, then it has been found that basically that fraction B that fraction of the heat going B can be expressed like this 0.15 ln natural log 27.5 divided by T h tan phi where phi is the shear angle. So, we note from this expression that B will reduce if the cutting speed increases, if the cutting speed is very then large portion will only go into chips that looks intrusion very less amount will be able to go into the work piece this is by intrusion also.

Sometimes you have seen some people can walk on the hard course nah burning fire they walk and they nothing happens to their feet they say this is miracle, but actually what happens since they are walking very fast. So, heat is not able to transfer to their body and that is the same thing happens here that suppose the cutting velocity is very high. So, the tool is moving very fast across the work piece then heat is not having enough time to go to the work piece so B reduces and this one.

Similarly, but if the thermal diffusivity increases suppose the material has got very high conductivity somehow diffusion is very fast in that case that B B will increase also that is this one. So, it is basically thermal number means B is basically inversely proportional to thermal number, so it tells me many things. Similarly, suppose in the seeing the past expression we see even if T 1 increases then also lot of heat will go only in the chip and this expression is there.

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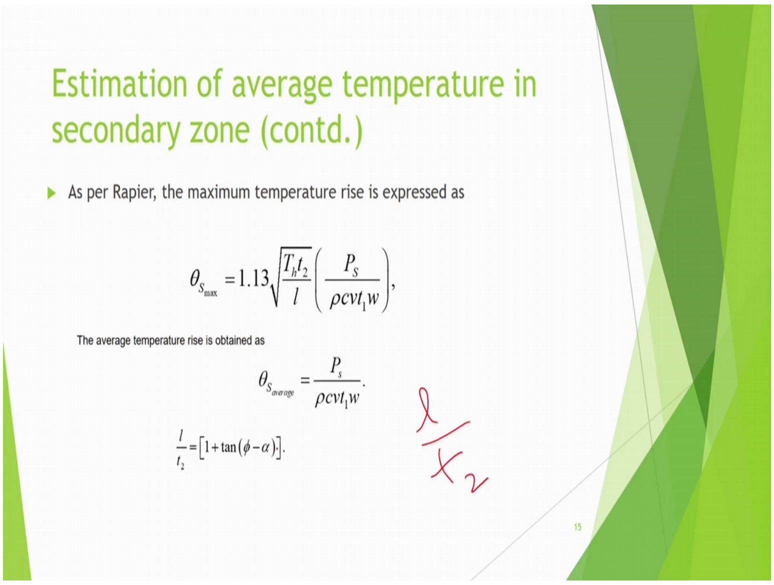

So, now we want to find out estimation of average temperature in secondary zone also. So, rapier did that complicated analysis that we are not discussing in that detail, but he has provided this expression for body which is sliding on another body that expression. So, in that case maximum temperature rise is expected to be 1.13 under root T h t 2 l this is this is thermal number and then P s by rho cvt 1 and w, so average temperature rise is obtained as P s divided by rho cvt 1 w.

So, average temperature rise is obtained like this and l by l 2 is given by 1 plus tan phi minus alpha and this 1 l by t 2 basically l by that t 2 so that means, t 2 is the uncut that chip thickness. So, l by t 2 is equal to 1 plus tan minus alpha where phi is the shear angle and alpha is the rake angle and this expression.

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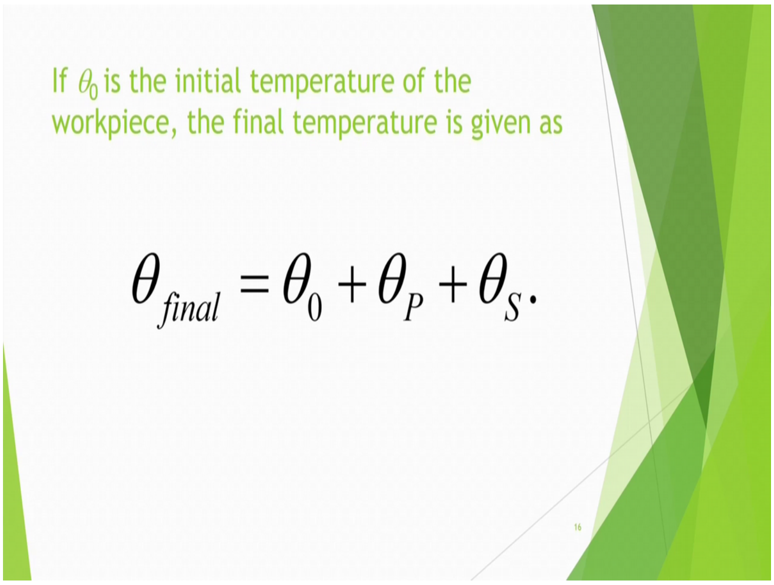

So, finally, the if initial temperature is theta 0 then the final temperature will be given by theta final is equal to theta 0 plus theta P plus theta S.

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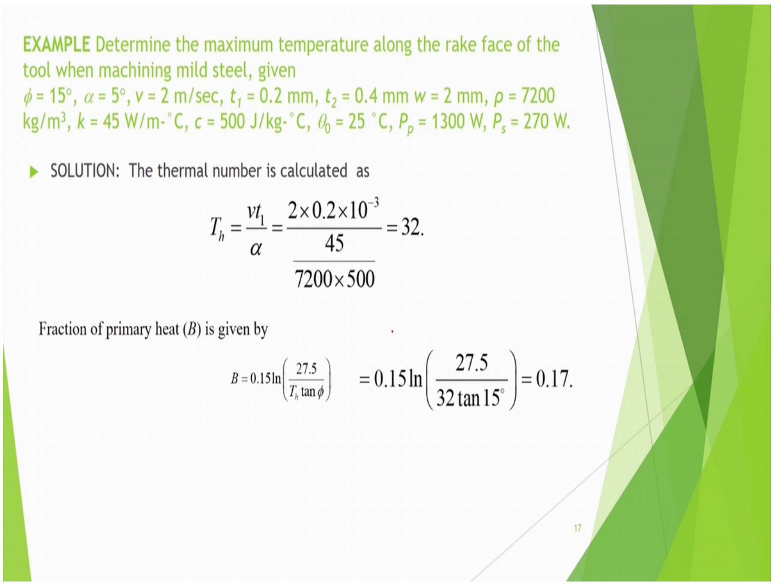

Let us understand these concepts by means of 1 numerical example; example is like this determine the maximum temperature along the rake face of the tool when machining mild steel given it has been given that phi is equal to 15 degree. Either it has been measured experimentally that shear angle or you have done by some analysis may be merchants analysis or something. And alpha is the rake angle it is also given suppose this is 5 degree v is equal to 2 meter per second cutting speed is 2 meter per second or we can say 120 meter per minute and t 1 is equal to 0.2 mm t 2 is equal to 0.4 mm. That means, t 1 means uncut chip thickness uncut chip thickness was 0.2, so chip thickness became 0.4.

So that means, cutting ratio is 0.5 P 1 cutting ratio is 0.5 and w is equal to 2 mm w is the width of the cut. And rho is equal to 7200 kg per meter cube some type of a steel it may be or some cast iron and k is equal to 45 watt per meter degree centigrade this one watt divided by meter degree centigrade and c is equal to 500 kg degree centigrade.

Specific heat is 500 these are somewhat realistic value may fit in the mild steel this is mild steel and theta 0 is 25 degree centigrade that is ambient temperature. And P p somehow you either you measure the cutting force by dynamometer or analytically you determine that there is a some cutting force multiplied by velocity.

So, supposing cutting power comes out to be 1300 watt that means, you can find out the cutting force and then you can multiply by the velocity. So, you get 1300 watt and similarly P s come 270 watt assume that you know that what is the coefficient of friction then you calculate the thermal number. So, thermal number is calculated as T h is equal to v t 1 by alpha you have to use consistent unit use better use a si unit, so everything is in meter second kilo grams etcetera.

So, here we put 2 into 0.2 into 10 to the power minus 3 because it is 0.2 mm actually, so into 10 to the power minus 3 convert it into meter and divided by 45 because 45 k alpha is k by rho c. So, 45 which k and rho is equal to 7200 and c is equal to500 so this thermal number comes out to be 32.

So, since the thermal number is 32 then the fraction of primary heat v is given by v is equal to 0.15 natural log and this is 27.5 divided by t h tan phi. So, plug in those values 0.15 ln 27.5, 32 tan 15 degree phi is 15 degree and this comes out to be 0.17. So, what it means that 17 percent heat in this case is going to the workpiece and remaining 83 percent is going to the chip.

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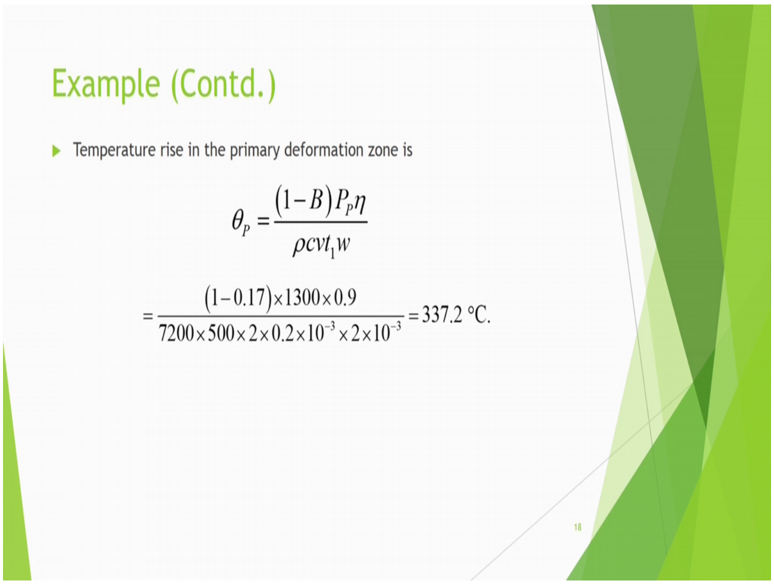

So, this we have done, so temperature rise in the primary deformation zone we know this is the formula that means, 1 minus 0.17 that means, 0.83 fraction is going here. So, P p was 1300 eta is the Taylor coefficient that is 0.9 rho have put 17 7200 c is 500 v is 2 meter per second t 1 is 0.2 into 10 to the power minus 3 and w was 2 millimeter.

So, 2 into 10 to the power minus 3 and this comes out to be 337.2 degree centigrade that means, this will be the temperature rise in the deformation zone particularly on the chip side. That means, chip has attained basically this high temperature p 3 means that means, this temperature increase has taken place in the chip ok. So, it earlier temperature was it was 20 degree centigrade then it has become 357.2 degree centigrade because 337.2 degree centigrade is the temperature rise.

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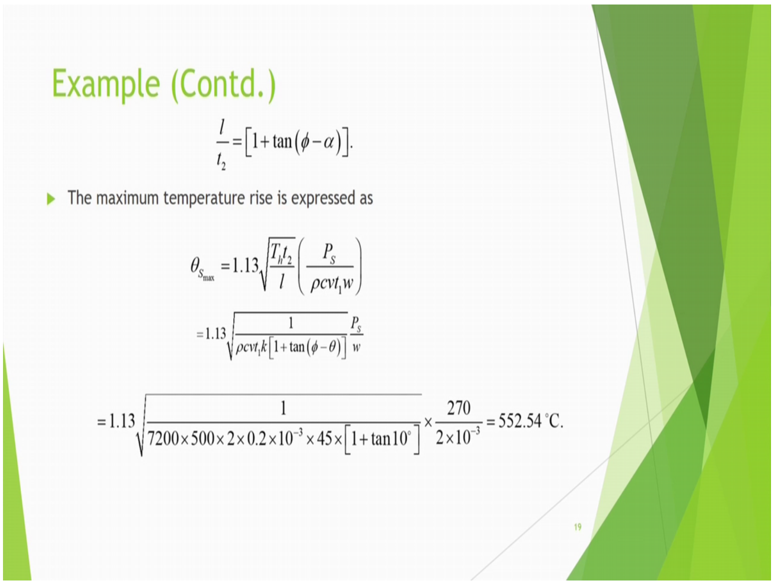

And now if we find out this one that, we can find out maximum temperature rise. So, we in the secondary zone there is one formula l by t 2 is equal to 1 plus tan phi minus alpha. So, by this formula can find out what is l or an express it in that form l is equal to this one can put the expression here this is t 2 and this one.

So, theta it is like that, so in this expression we put the value 1.13 and then we put here value of P s and we put all these quantities. And once we put these quantities here then we find out this expression rho c v 2 and this one and you calculate then we find out 552.54 degree centigrade, so maximum temperature rise here is this much.

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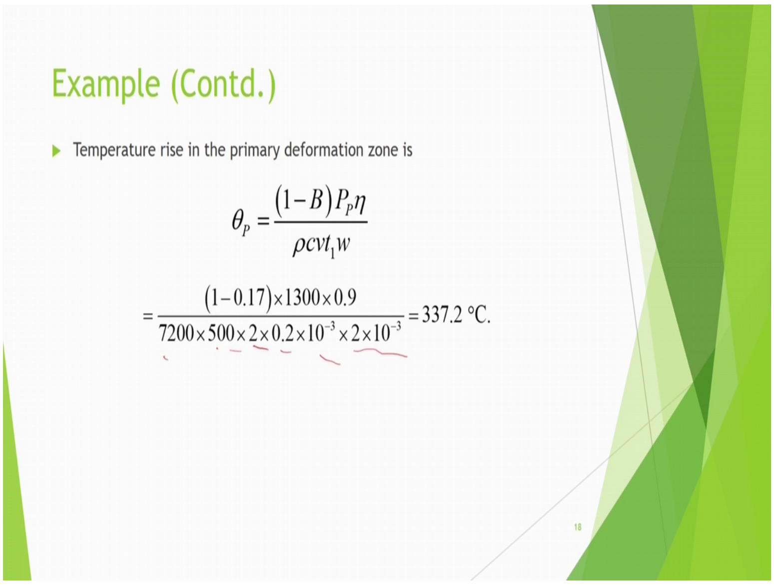

And now temperature rise in the primary deformation zone was already given here.

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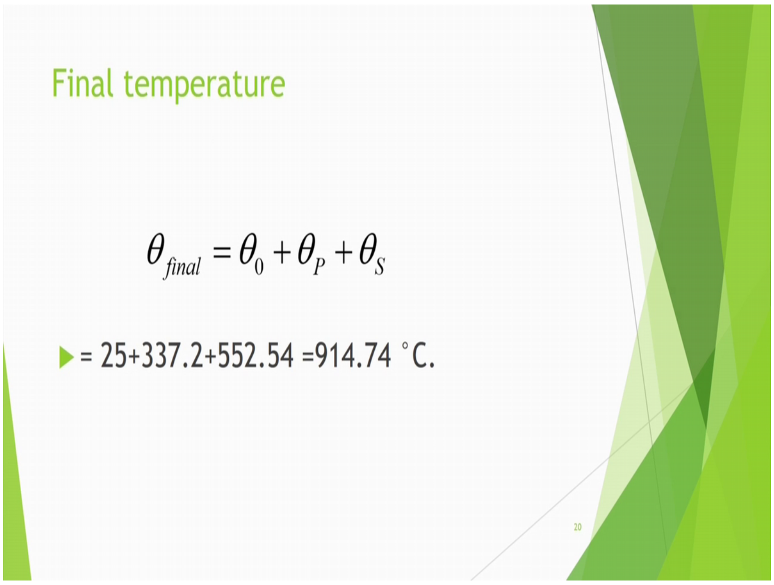

So, we will add them and we find out the final temperature as theta 0 plus theta P plus theta S and that comes out to be 914 degree centigrade.

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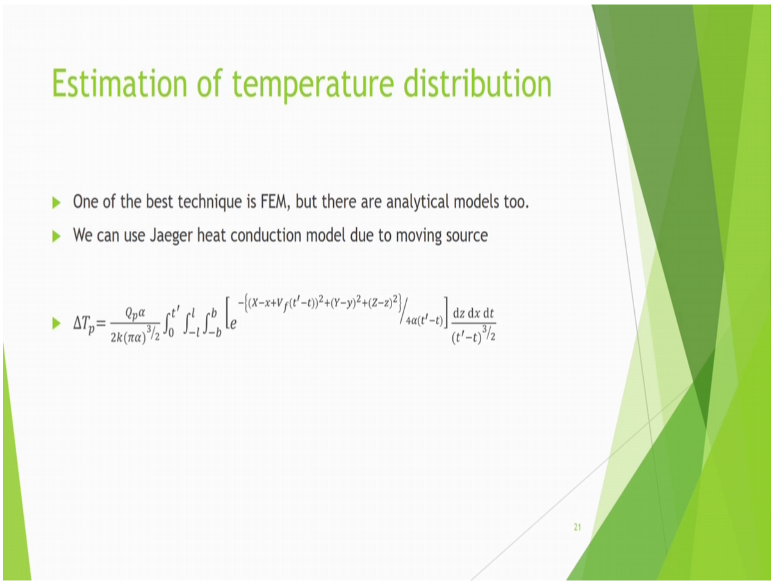

So, this can be the temperature at the rake surface, now this is one simple problem by which we have found out that this is the final temperature. Now estimation of temperature distribution also can be done, but one of the best technique is basically finite element method you have to do finite element modeling basic equations are there. So, as you know that finite element method is a method also is a method of solving the differential equations.

But there are you can use many analytical models we can use Jaegers heat conduction model due to moving source. That source that suppose there is a heat source means suddenly that we you Q p amount of heat and then we have got and this is delta P and this expression we have got Q p into alpha divided by this one 2 k and phi alpha 3 by 2 and if we have got that width of the chip is 2 b. So, minus b to b minus l to l and 0 to t prime and this t is the time here and we have written dz dx dt.

So, that way we can increase integrate and we can find out that what is delta p and as you see that it is exponential type of function. That means, with a distance as the distance from the source increases, then the heat temperature basically reduces and this will be a meter square suppose alpha is having meter square per second yes. So, meter square per second into second, so meter square that is meter square, so non-dimensional, so e to the power e to the power whenever there is a exponential. So, exponential to the power it should be dimensionless quantity, so it is consistent that is what was checking and it is done.

So, this expression is this, so such type of expression can be used for finding out the temperature rise and then you have so am not going into much detail beyond that only thing that you depending on the situations you can integrate and do that type of thing, but most of the time nowadays we use there are finite element package by that we find out.

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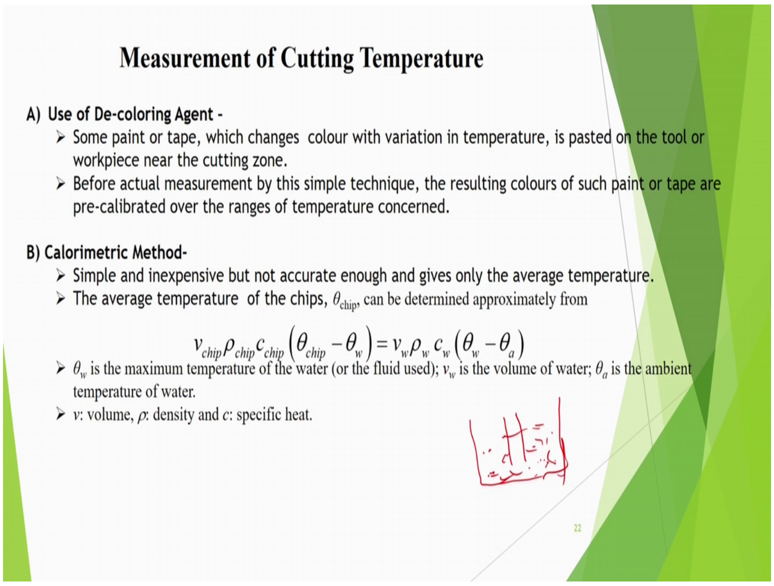

Now am coming to that how you can measure the cutting temperature, so there are various methods to measure the cutting temperature one is can use some de coloring agent there are some paint and tapes which change color with variation in temperature. Suppose color changes then means temperature changes then colour of that tape will also change and that tape can paste on the tool or workpiece near the cutting zone. So, heat is generated and we can see how the colour of the tape is changing by that can estimate or we can put some paint also some paints are there, which will change the colour know

So, before actual measurement by this simple technique the resulting colours of such paint or tape are pre calibrated over the range of temperature concern that means, suppose we know temperature may go up to 600 degree centigrade. So, starting from 25 degree to 600 degree centigrade we first heat and measure it by thermometer or thermocouple mostly thermocouple. And then see that how the colour is changing and that colour change we have made the noted that suppose it becomes yellow then the temperature must be 300, when it becomes red then temperature must be 600 like that we can make a chart type of thing.

And next time when we do the machining then we will be able to know that what must be the temperature we need not put any thermo couple or thermometer because putting those things is very problematic there is lot of hindrance because of the chip and coolant etcetera.

Then another method is calorimetric method it is simple and inexpensive, but it is not accurate enough and it gives only the average temperature. So, the average temperature of the chips can be determined approximately like this we say volume of chip into density of chip. So, becomes mass of chip mass of chip into C C of chip that means, specific heat that means, total heat capacity and multiplied by theta chip minus theta w.

So, theta chip is the means theta chip minus theta w, w is the volume of water and theta w is the maximum temperature of the water. So, water temperature rises how much so that means, theta chip has given this much heat that means, chip has given theta chip minus theta w heat to this one. That means, temperature has been suppose chip temperature was 300 degree centigrade and then after that water has become that temperature of 200 degree centigrade.

Then that means, 100 degree heat is 100 degree temperature difference is there so that means, this much heat is lost. So, that is this one and the waters temperature has risen from suppose 25 degree to 200 so that means rise in the water temperature is equal to rho V, V w volume of the water at rho w density of the water C w is the specific heat of the water. So that means, basically the heat capacity of water into temperature rise so that means, heat gained by water must be equal to the heat lost by chip.

So, that is why this equation is there this is the heat lost by the chip V chip into rho chip into C chip and this one is heat gained by this one. So, this we have obtained this expression so by this everything we can measure. So, theta chip can also be obtained this can be done and means it can be done that means, this is very useful suppose you can have entire calorimetric setup here and here may be drilling suppose this is drill.

So, it is doing cutting and it is surrounded by water so cannot have access to chip easily, but can know the temperature of this so that means, particularly in drilling very advantageous this type of calorimetric technique.

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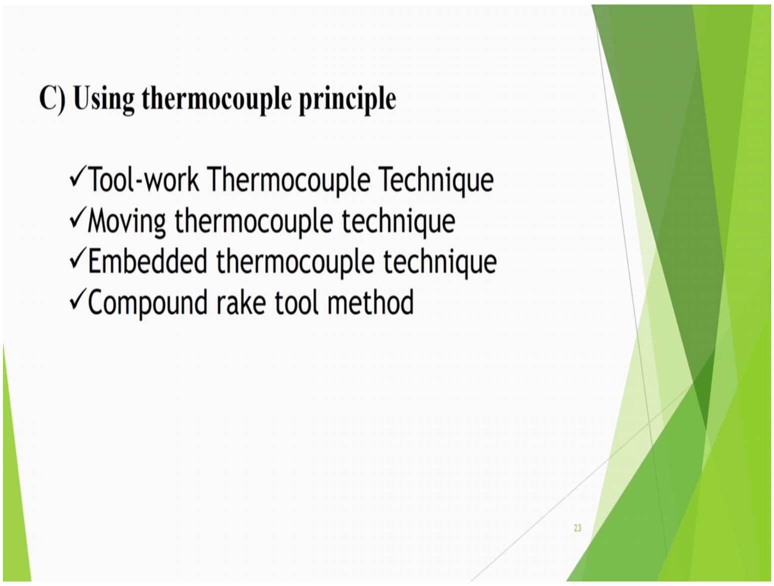

And using thermocouple principle that means, we can put the thermocouple tool and work can make one junction, tool and work thermocouple technique moving thermocouple technique, embedded thermocouple technique. And compound rake tool method these are the various methods for this one measurement by thermocouple.

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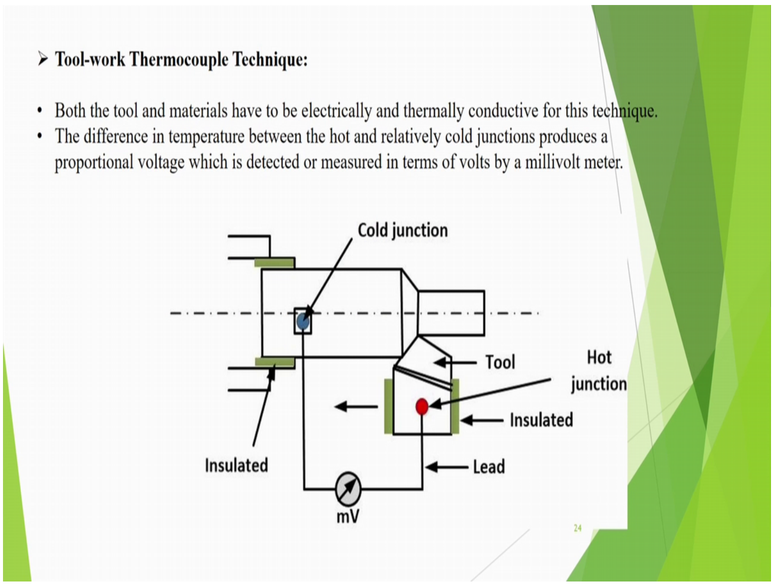

So, one method suppose to tool work thermocouple so tool workpiece is at cold that this place this is this one and at this place cutting tool is there so it is hot junction. So, hot junction and cold junction if we make them, so therefore, there will be thermoelectric effect.

So, depending on the temperature difference here you will see the some voltage it is in miili volt you are measuring that, so here this is lead and by that, but here you have to properly insulate. So, that it there is no short circuiting here this type of thing so it is not so, easy, but you can make many people have done that type of thing both the tool and materials have to be electrically and thermally conductivity for these technique the difference in temperature between the hot and relatively cold junction produces a proportional voltage which is detected or measured in terms of volts by a milli voltmeter.

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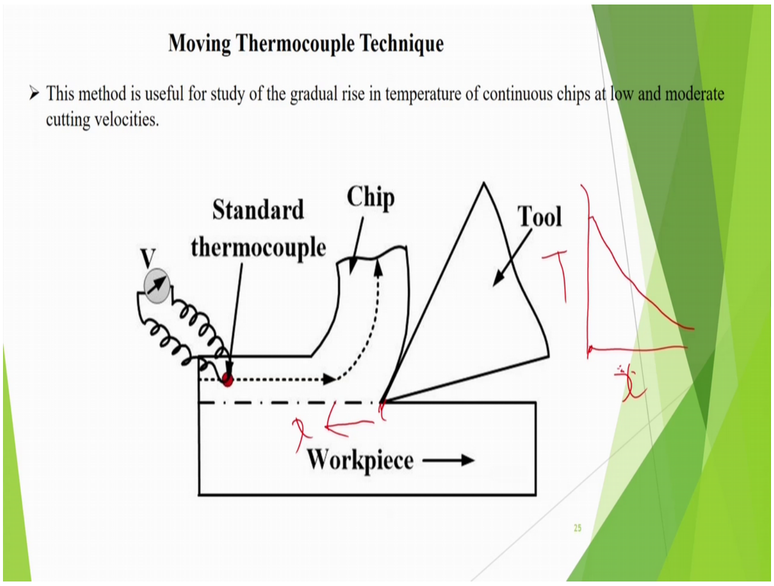

Then there is a moving thermocouple technique here if put there is chip and it is this one. So, it is useful for the study of gradual rise in temperature of continuous chips at low and moderate cutting velocity here the workpiece is moving and it is going near the tool. So, suppose here have put standard thermocoupleam measuring the temperature here, but that thermocouple, but my whole thing is moving also. So, workpiece is moving so that means, my contact point is reaching near to the tool.

And when it is reaching near the tool g then maybe we can see the continuous temperature rise. So, maybe we can plot a this type of graph or so t versus how much is the distance from here. So, this distance from if we plot in a reverse direction this maybe tool point contact here x x 0 means here x is like this then in that case it will be like this.

So that means, we may study that how the temperature is changing gradually then embedded thermocouple technique is also used suppose you are doing a milling operation this is a milling cutter this is a workpiece.

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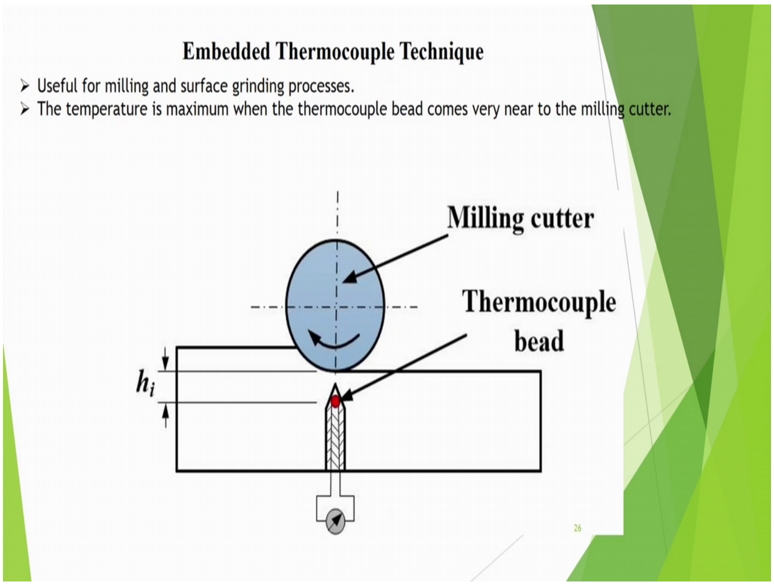

And you can embed thermocouple you can make a very small hole and there is a thermocouple bead. Then just below the surface you can see what is the temperature it is useful for milling and surface grinding processes temperature is maximum when the thermocouple bead comes very near to the milling cutter. Otherwise you can do some extra position and you can make some estimate like that at least qualitatively you can study even if you have to thermocouple here. But still you can find out that when the cutting speed is increasing, then this particular temperature is also increasing although it is not the temperature exactly at that contact ok.

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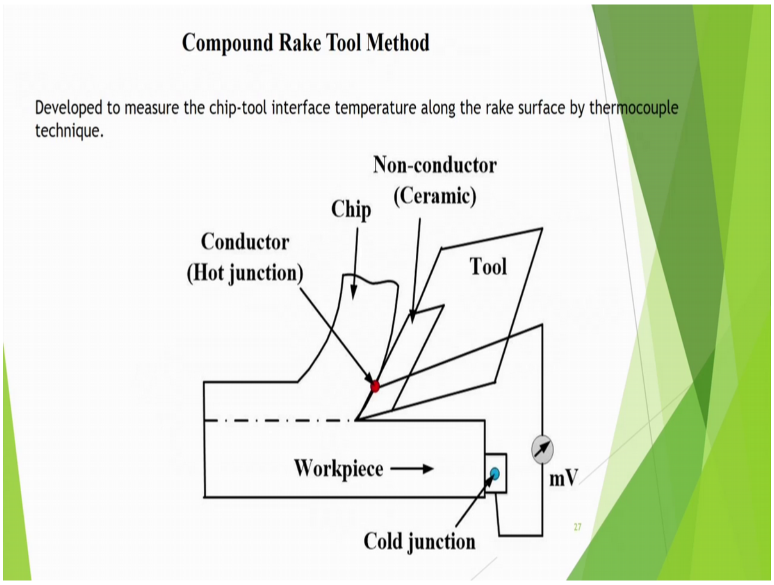

So, in embedded thermocouple technique also have been used then compound rake tool method also has been used. Here you have hot junction at this one tool rake surface you can make the hot junction and the cold junction is here between the workpiece and this is this may be nonconductor ceramic tool, but here you have hot junction here and this is. So, it is developed to measure the chip tool interface temperature along the rake surface by the thermocouple technique.

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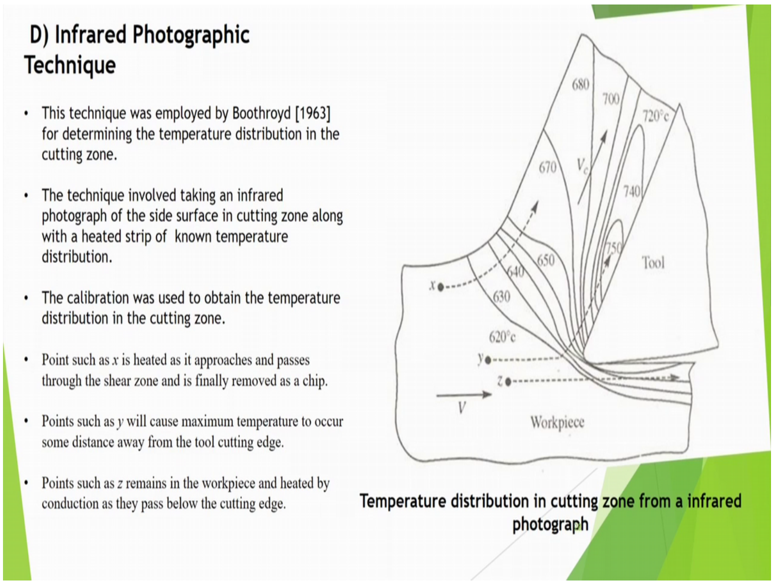

So, it is then infrared photographic technique nowadays we have many infrared cameras this technique was implied by Boothroyd in 1963 for determining the temperature distribution in the cutting zone.

So, the technique involved taking an infrared photograph of the side surface in cutting zone along with a heated strip of known temperature distribution this one. So, we compare that we take a photograph of that thing calibration was used to obtain the temperature distribution in the cutting zone we take a photograph of the whole thing. So, depending on the temperature your intensity of the photograph will change so infrared photograph, so intensity will be dependent on the temperature. Point such as x is heated suppose this point x is heated as it proposes and passes through this shear zone and finally, removed as chip. And point such as y will cause maximum temperature.

So, here you will have maximum temperature say maximum temperature is at the rake surface some distance away from some distance away from the nose, why it is some distance away from the nose because by this time the plastic deformation also has heated the chip and then there is a some sliding. So, friction also has rise the temperature here so further has increased and after that there will be of course, decrease in the temperature. Point such as z remain in the workpiece and heated by conduction as the pass below the cutting edge.

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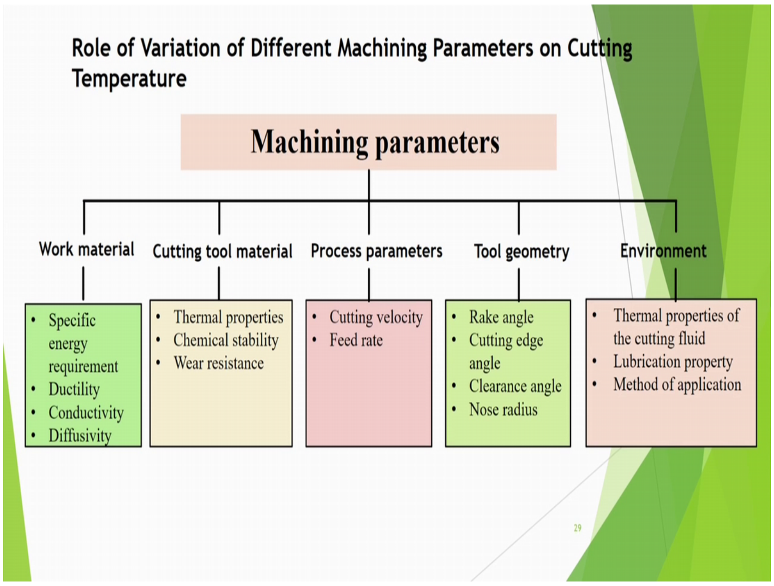

So, that is what the these things are there, now let us discuss role of variation of different machining parameters on cutting temperature. So, machining parameters bulk material that means, bulk material affects what is the specific energy requirement of the material what is ductility? What is conductivity? What is diffusivity? Then cutting tool materials thermal properties chemically stability wear resistance then process parameters cutting velocity feed rate and of course, the depth of cutters also you can add in this.

Toll geometry means rake angle, cutting edge angle, clearance angle, nose radius may be affect environment will affect thermal properties of the cutting fluid and lubrication property method of the application how you are applying the cutting fluid whether you are exactly supplying at that spot and with high pressure or you are just doing flirt cooling or this will affect.

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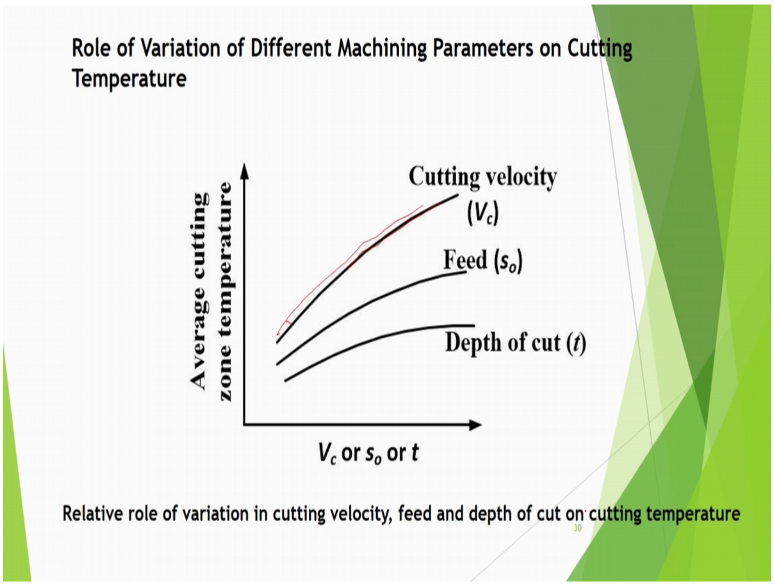

So, let us just discuss few things role of variation of different machining parameters on cutting temperature average cutting zone temperate increases if the cutting velocity is increases. So, cutting velocity has more influence you see that it is increasing like that and with feed also temperature increases with depth of cut also it is increases relative role of variation in cutting velocity feed and depth of cut on cutting temperature has been shown here.

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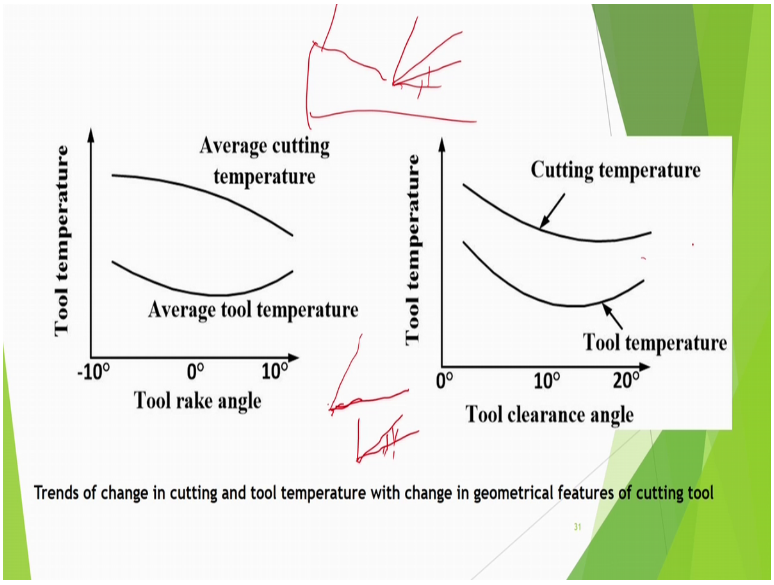

Then average cutting temperature basically in a way it is decreases with this one a geometric feature of this one, so suppose this is tool temperature and this may be the cutting temperature ok. So, cutting temperature may be with increasing the rake angle, cutting temperature will decrease only why because as we told in last time also means simply previous lectures that when the rake angle increases then cutting force decreases cutting force decreases means more less amount of power is required.

So, less amount of power is converted into heat so it is obvious that if the rake angle will increase then your machining will be here and your cutting temperature will be reduced here. But rake angle if it is increases then average cutting temperature is increasing, but if rake angle has increased too much then that volume of the tool reduces. That means, this one suppose this was one tool, but now if it is like this rake angle has increased a lot.

So, this tool has become thinner so that means, this will have tendency to increase the tool temperature. So, that is why we get this type of behavior there are two opposing effect if rake angle increases means less amount of heat generation will be there, but the tool will become thinner and that is why more temperature rise may be there. So, that is why first it decreases and there is one optimum tool rake angle and after that average tool temperature increases.

And similarly the clearance angle if the clearance angle is increases naturally the cutting temperature generally may have a decreasing tendency may decreases, but may decrease.

But then the tool temperature because of the same region toll temperature will must decrease then increase, why because if keep on increasing the clearance angle this is the suppose we have this type of tool ok. So, this is say my tool may be here right and this portion, so if this is increasing then again tool will become thinner and that is why the temperature will increase so tool temperature again increase, so there is a optimum clearance angle.

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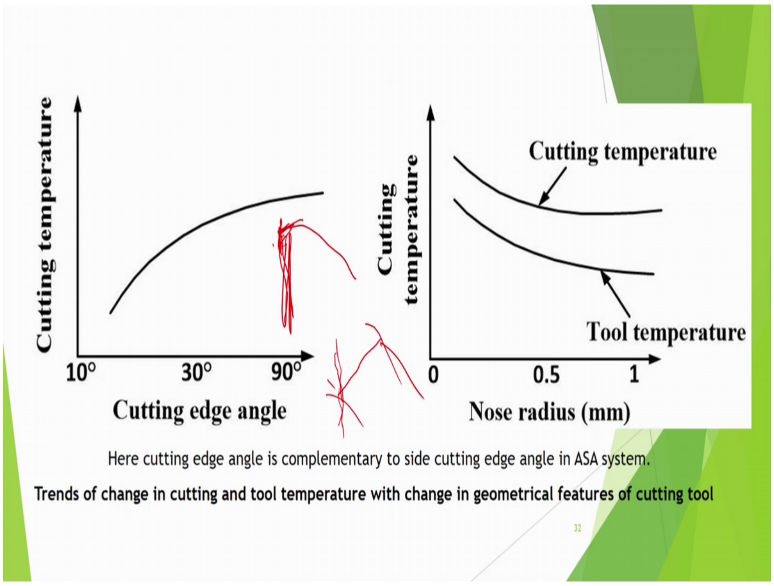

And cutting edge angle if the cutting edge angle is increasing cutting edge angle is complementary to side cutting edge angle in ASA system. That means, am telling that cutting edge angle is increasing that means, side cutting angle is decreasing. If side cutting angle is decreasing then the tool temperature will increase because as we told that suppose you are doing the cutting like this.

Suppose this was the cutting edge this was the cutting edge it was very straight, and then after that you may have suppose this type of thing then the total in oblique type of cutting that edge inclined then you are getting more area. So, heat is distributed, so that is why in this particular case if the in this particular case your temperature will be less actually and here it will be more know.

So, that means, but you remember that cutting edge angle is complementary to side cutting edge angle that means, cutting edge angle is 90 minus side cutting edge angle. So, similarly nose radius if the nose radius increases naturally the cutting temperature may reduce, but sometimes if you know that sometimes if there are other effects it may increase also, but tool temperature will surely will decrease because of the more area ok.

So, nose radius also has got that effect and so this is now so these are the trends with geometric figure.

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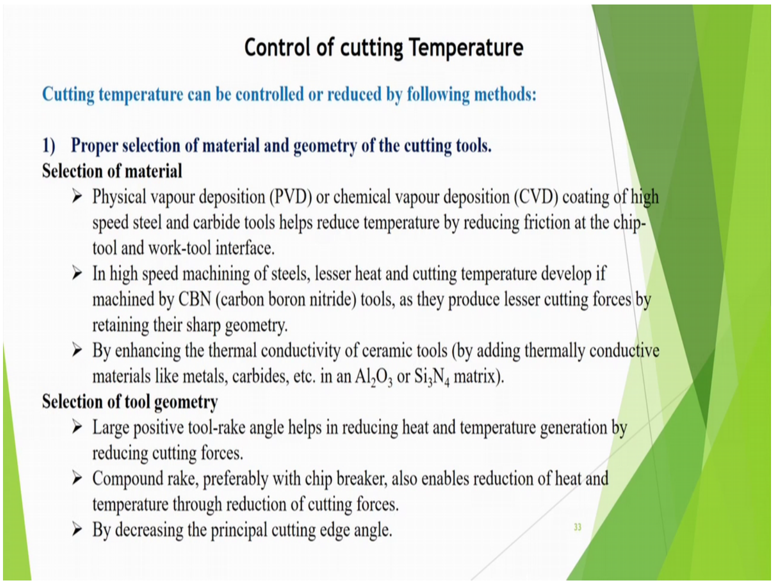

And now cutting temperature can be controlled or reduced by following method now this is proper selection of material and geometry of the cutting tool. Selection of the material is important physical vapour deposition or chemical vapour deposition coating of high speed steel and carbide tools helps to reduce temperature by reducing friction at the chip tool and the work tool interface.

In high speed machining of steels lesser heat and cutting temperature developed if machined by CBN tools as they produce lesser cutting forces by retaining their sharp geometry. By enhancing the thermal conductivity of ceramic tools that is by adding thermally conductive materials like metals carbides etcetera in an Al 2 O 3 or Si 3 N 4 matrix we can enhance thermal conductivity.

Then selection of tool geometry large positive tool rake angle helps in reducing heat and temperature generation by reducing cutting forces, but you know that if you increase it too much then the tool becomes thinner. So, that is also not good and compound rake preferably with chip the colour also enables reduction of heat and temperature through reduction of cutting forces we can have compound rake. That means, in the here that we can have some rake and after that after some distance another rake by decreasing the principle cutting edge angle principle cutting edge angle can also be decreased then also you can or in a way increasing the side cutting edge angle.

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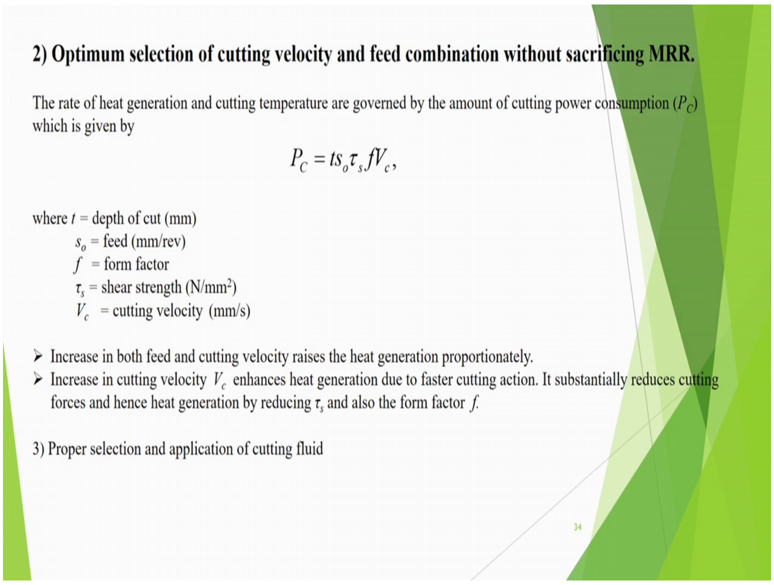

Then optimum selection of cutting velocity and feed combination without sacrificing material removal rate is important rate of heat generation and cutting temperature are governed by the amount of cutting power consumption which is given by P c is equal to t S 0 tau s f times V c f is the form factor. So, increase in both heat and cutting velocity raises the heat generation proportionately increase in cutting velocity enhances heat generation due to faster cutting action, it substantially reduces cutting forces and heat hence heat generation by reducing tau s and also the form factor s.

So that means, velocity has two type of affects that means, on one hand it of course, increases the temperature because heat generation rate increases, but then material also gets soften. So, you have to select that proper way proper selection and application of cutting fluid is also important.

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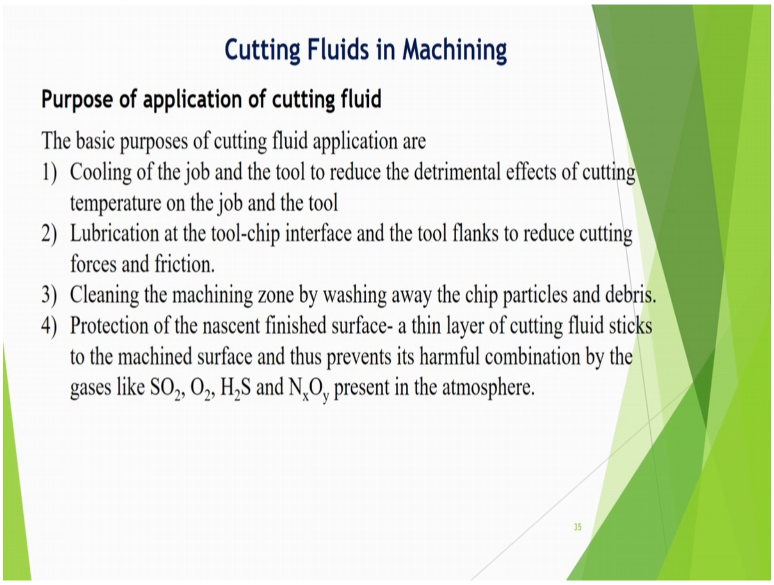

Now, what are the cutting fluids in machining, now basic purpose of cutting fluid applications are cooling of the job and tool to reduce the detrimental effects of cutting temperature on the job and the tool. Lubrication at the tool chip interface and the tool flanks to reduce cutting forces and friction. Cleaning the machining zone by washing away the chip particles and debris and protection of the nascent finished surface a thin layer of cutting fluid is sticks to the machined surface and thus prevents its harmful combination by the gases like SO 2 O 2 etcetera.

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So, these are the essential properties of the cutting fluids, it should have high specific heat thermal conductivity and heat transfer coefficient, it should have good wettability, it should have high lubricity. Wetting and spreading should be there high film boiling point should be there and chemical stability should be there less volatility should be there it should not get oxidized to much non-toxicity these are the various properties of the cutting fluids.

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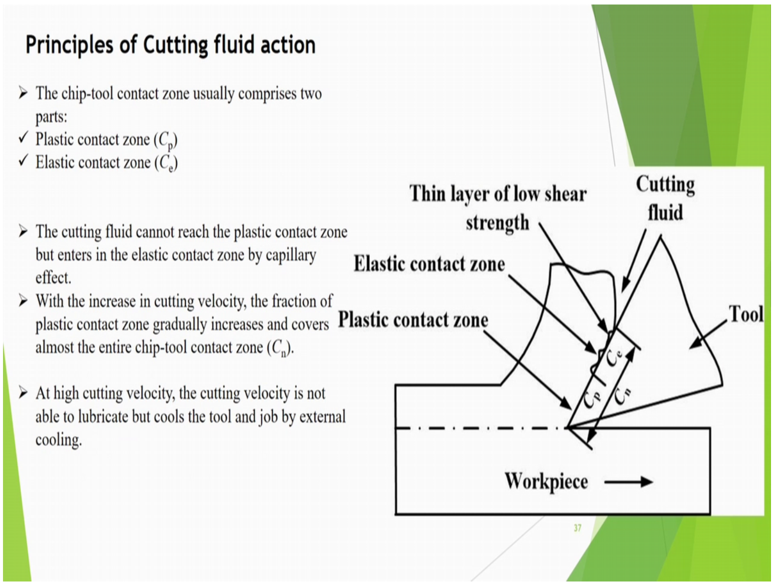

Now, now here we generally when the chip is there, so there is a plastic contact zone where the chip usually sticks and then there is a elastic contact zone whether the fluid can easily enter by the capillary action.

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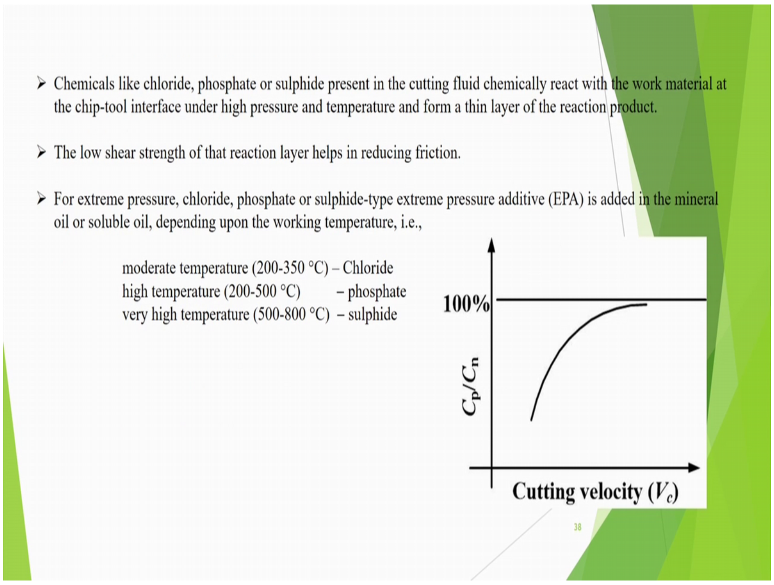

This thing has been there chemicals like Chloride, Phosphate or Sulphide present in the cutting tool chemically react with the work material under high temperature and pressure. Low shear strength of that reaction helps in reducing the friction for extreme pressure Chloride Phosphate or Suphide type extreme pressure additive is added in the mineral oil or soluble oil depending upon the workpiece temperature.

At moderate temperature you can add Chloride then high temperature Phosphate and very high Sulphide. And this is showing that with cutting velocity that effect is shown here that means how much is the ratio that means, you do maximum high pressure additives benefit you actually get at high cutting velocity ok.

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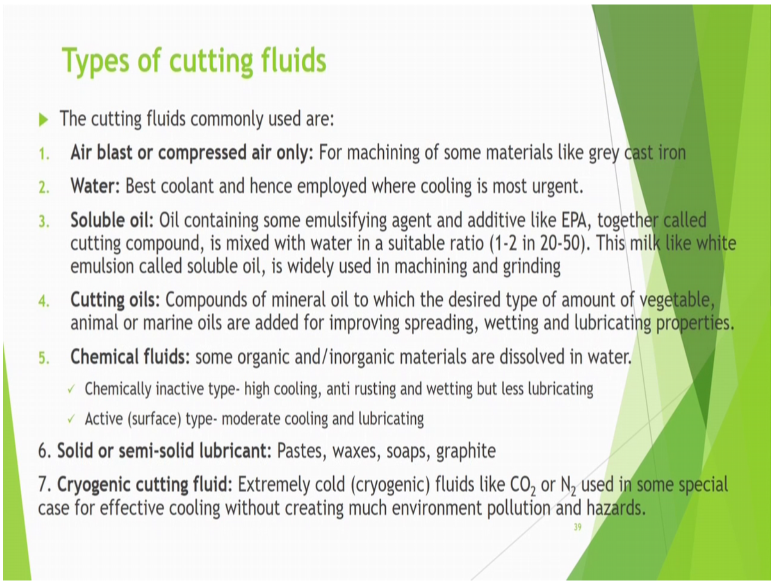

So, that is what this one and these are the type of cutting fluids it can be just simply air blast or compressed air it can be water, it can be soluble oil it can be cutting oil, it can be chemical fluids, and then it can be solid lubricant and it can be cryogenic cutting fluid.

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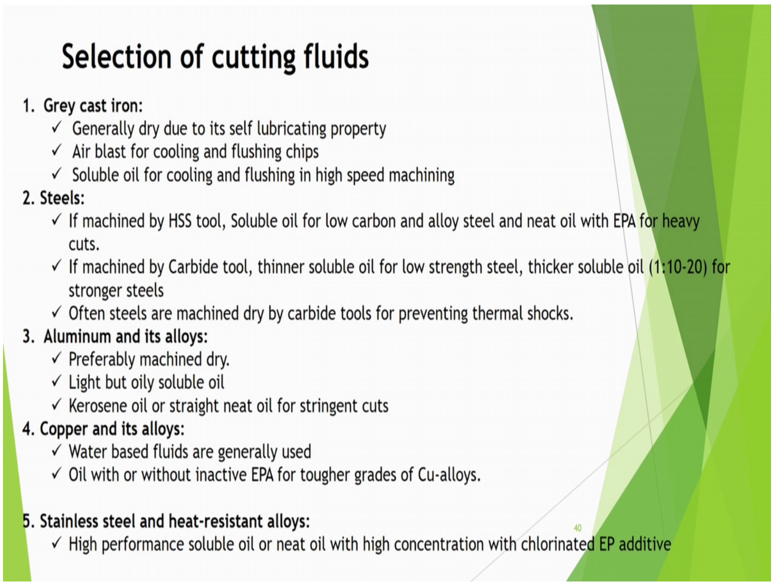

And we can have like for grey cast iron we do not use the coolant usually for a steel we can have a soap solutions also and soluble oil we can have extreme pressure additive. And then we can have for aluminum we can use kerosene oil and for copper also we can have water based fluids and this is for stainless steel also there are some extreme pressure additive most of these coolants are the trade secrets of the suppliers.

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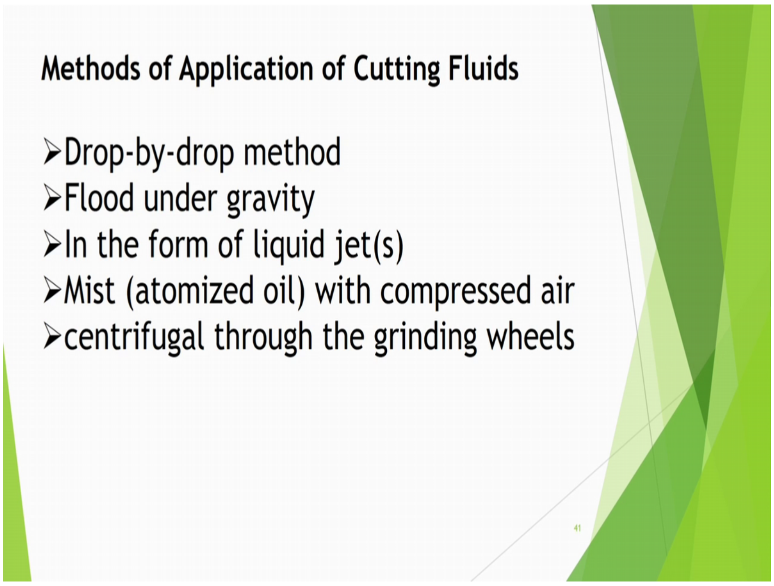

And methods of application can be drop by drop method or it can be flood under gravity it can be in the form of liquid jet. Now what is mist lubrication with compressed air is implied where it is atomized oil is there for efficient cooling, because we do not want to waste too much coolant it is not good for environment also and centrifugal effect also sometimes does the job like in grinding wheels.

So, these are the methods of the sheet of ah means cutting fluid applications. So, these much for today and in the next class we will tell about this one may be little bit we recapitulate these topics and then we will move ahead.