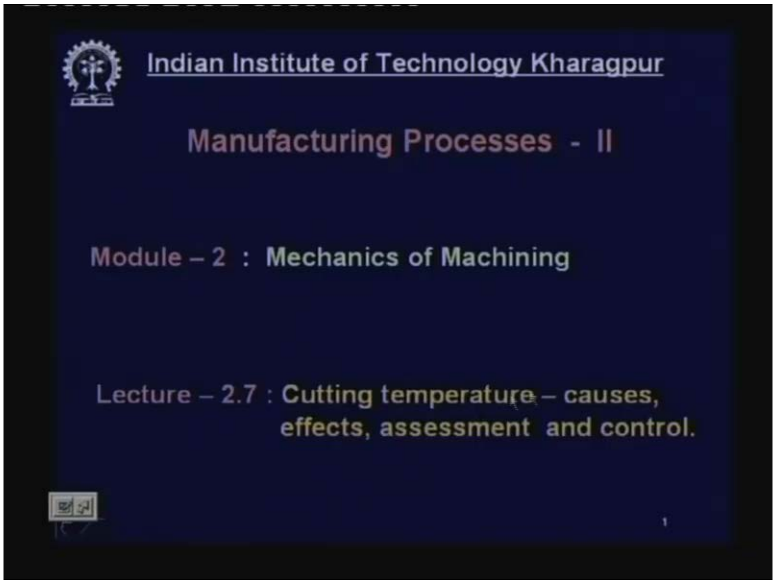
Manufacturing Processes II
Prof. A.B. Chattopadhyay
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture No.11
Cutting Temperature Causes Effects Assessment and Control

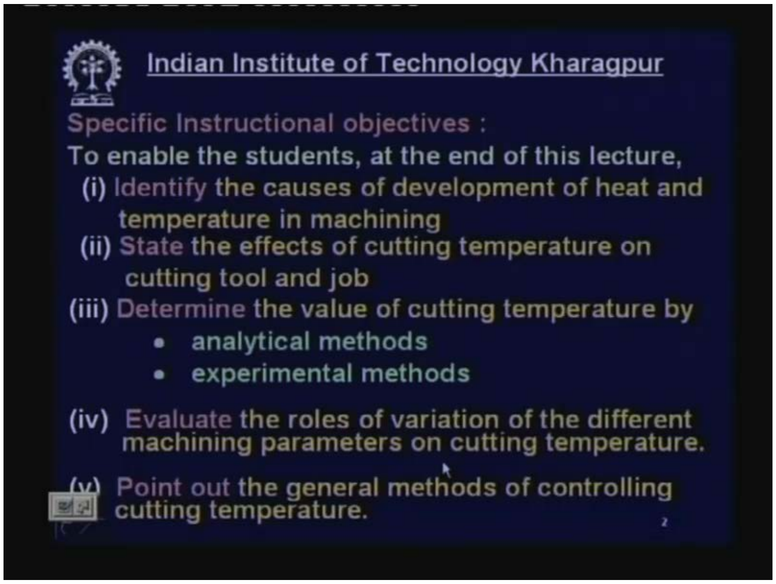
Now you are welcome again to the course Manufacturing Processes – II.

(Refer Slide Time: 01:00)



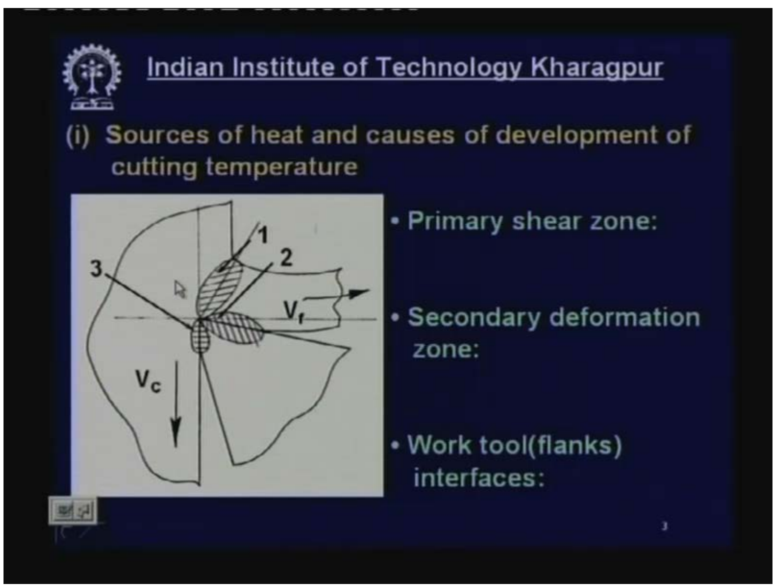
Now we are continuing Module – 2: Mechanics of Machining. Now under this module our lecture today will deal with cutting temperature - sources of heat and temperature, causes of such temperature effects, assessment and control of cutting temperature. Now what are the contents today? The Specific Instructional Objectives:

(Refer Slide Time: 01:28)



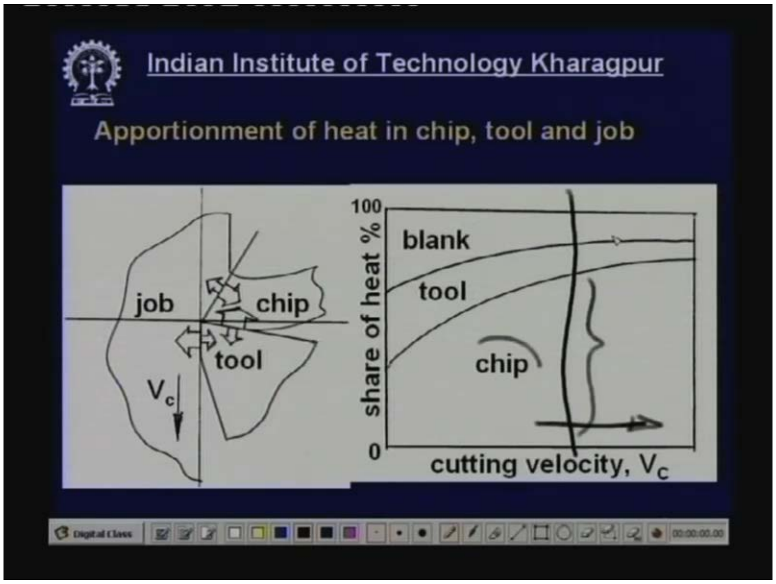
This will enable the students to identify the causes of development of heat and temperature during machining then state the effects of cutting temperature on cutting tool and the work piece the product, then determine the value of cutting temperature by analytical methods as well as experimental methods. Next evaluate the roles of various machining parameters on the cutting temperature because our aim will be to reduce the cutting temperature as far as possible for that we must know what parameters affect cutting temperature and how? And last is point out the general method of controlling that is reducing the cutting temperature.

(Refer Slide Time: 02:23)



Now first let us discuss with the sources of heat and causes of development of cutting temperature during machining. This is the orthogonal sectional view of a cutting process. This is the work material, this is the cutting tool and this is the chip flowing with the velocity V f and the cutting velocity is V c. Now the sources are the first is a primary deformation zone indicated by 1 were the plastic deformation takes place and the chip comes out and separate out from the work piece in the form of chip and flows out. Here the mechanical energy expended partia deformation is converted into heat. Next one is the chip tool interface which is also called secondary deformation zone because of the rubbing and secondary shear lot of heat is further developed in the zone called 2 secondary deformation zone and at the flanks also heat is generated to some extent at the flanks, the tool and work interfaces. There are two interfaces principle flank and auxiliary flank so work tool flanks interfaces. So these are the three sources from were the heat is generated and because of that temperature develops which is shared by the chip tool and job.

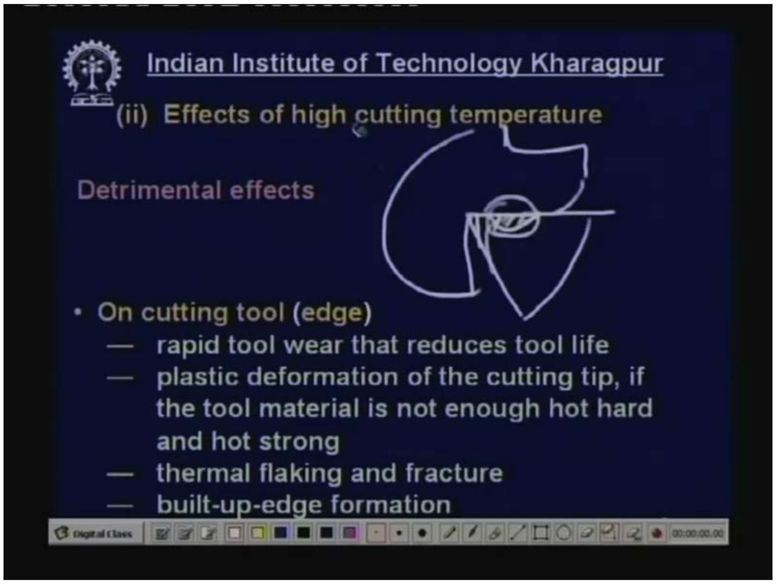
(Refer Slide Time: 03:56)



Now this shows the apportionment of heat in chip, tool and job. When the heat is generated how this shared amongst the chip tool and job? From share zone primary deformation zone, here you can see the major amount of heat goes into the chip and a small amount goes into the job because the chip is flowing at high speed. Now at the secondary deformation zone, that is chip tool interface that is rake surface of the tool major amount of heat that is generated goes into the chip because the chip is generated of ductile material and tool is sorry no not that thermally conductive material. So heat goes into that and cutting tools have got poor thermal conductivity. Further it receives lesser amount of heat and the heat generated at the principle flank and auxiliary flank that is sheared between the tool and the job. Major portion goes into the job which is thermally conductive, more thermally conductive hence the large sink. So it observes more amount of heat.

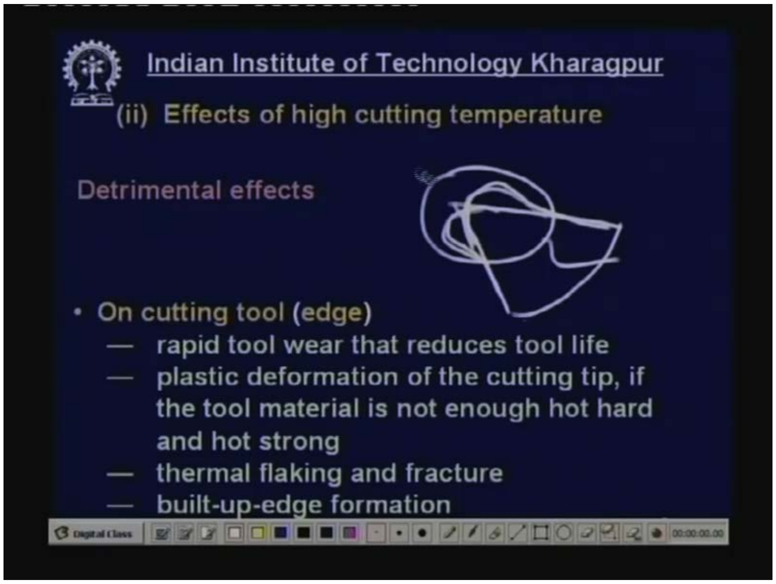
Now this shows that say for example at particular velocity say the particular velocity here this amount of heat say 75 percent goes into the chip this chip and 10 percent around 10 percent goes into the tool and around 15 percent into the job. Now fortunately the major amount of heat goes into the chip which is thrown out whether it is affected or damage by the heat it does not matter because it is not utilize. It is also important to note that with the increasing cutting velocity the chip shares the major amount of heat. So the share of the chip gradually increases with increase in cutting velocity that is when you produce more for more and more productive or high rate major amount of heat goes along with the chip and small amount goes into the tool and a rest amount into the blank. So this is favorable. Next is effect of high cutting temperature:

(Refer Slide Time: 06:12)



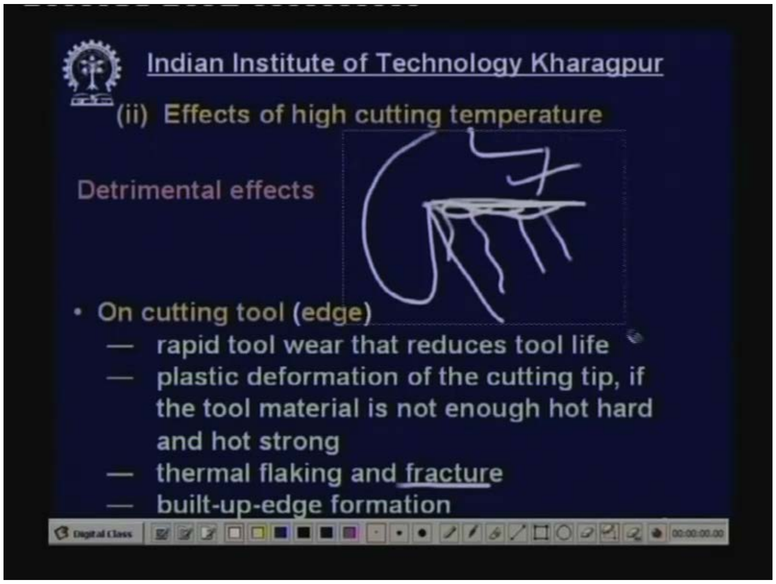
The cutting temperature is usually high may vary from say 500 degree centigrade. It can go up to 1000 degree centigrade, so which is very detrimental. Mostly the effect of the temperature is detrimental and in very few cases it can be favorable. Now what are the detrimental effects? On cutting tool that is cutting edge, so it has got detrimental effects on the cutting tool and work piece. Now first let us study the detrimental effects of the cutting temperature on cutting tool, rapid tool wear that reduces the tool life. Now what is it? say this is the tool and the chip flows over it wear takes place. This is the rake surface were wear takes place, this material goes out and here also the material goes out. Now the rate of wear of this cutting tool increases with the increase in cutting temperature were the cutting temperature high, this wear grows very fast and the tool become blunt in short time. So it reduces tool life. Now next is plastic deformation of the cutting tip, if the tool material this means suppose this is the sharp cutting tool. Due to high cutting temperature in this region, this portion is subject to high stress and high temperature

(Refer Slide Time: 07:27)



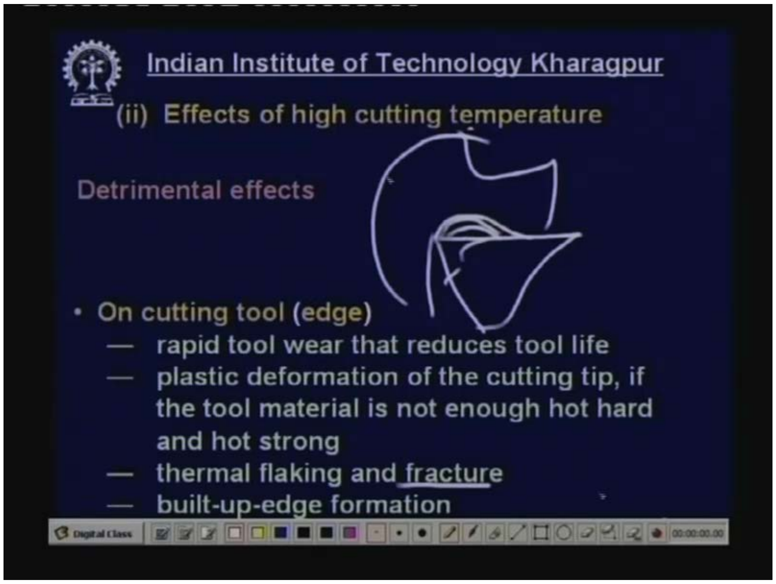
it can undergo plastic deformation like this. It can undergo plastic deformation like this also whatever be the amount or type of plastic deformation, the sharpness of the cutting tool is totally lost and the cutting tool becomes unable to cut and it breaks. Especially if the work material, if the tool material is not enough hot hard and hot strong; what is hot hard? A material may remain hard and a near temperature but it and strong but it has to hold its strength and hardness even at high elevated cutting temperature that is called hot hard and hot strong the material of the cutting tool should be like that, then thermal flaking and fracture now what is it?

(Refer Slide Time: 08:29)



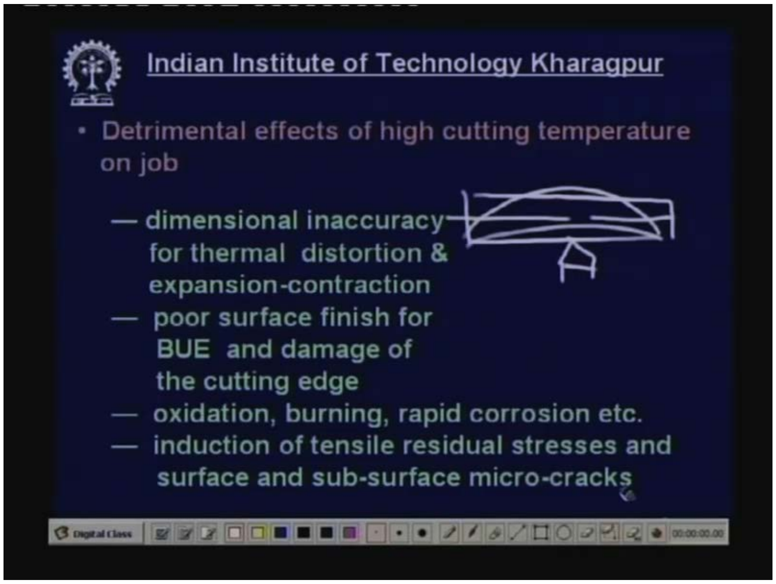
This is the cutting tool and the chip flows over this. Sometime chunk of material gets removed in the form of flaking. So this kind of material gets removed particularly when the chip materials stick strongly on the rake surface, then this kind and some time the fracture can also take place there can be fracture there can be fracture like this thermal fracture because of high thermal gradient this can happen and beside that the built up edge formation.

(Refer Slide Time: 09:06)



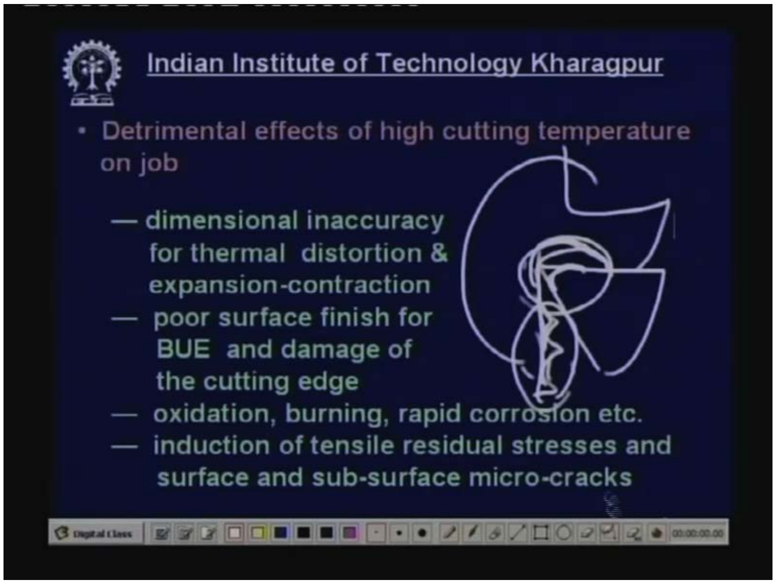
built up edge formation you know at high temperature at the chip tool at the tool the built up is develops because of the built up edge the cutting force increases, power consumption increases, and there can be breakage of the tool. So lots of problems arise. So these are the detrimental effects of high cutting temperature on cutting tool. Now let us go to the next.

(Refer Slide Time: 09:36)



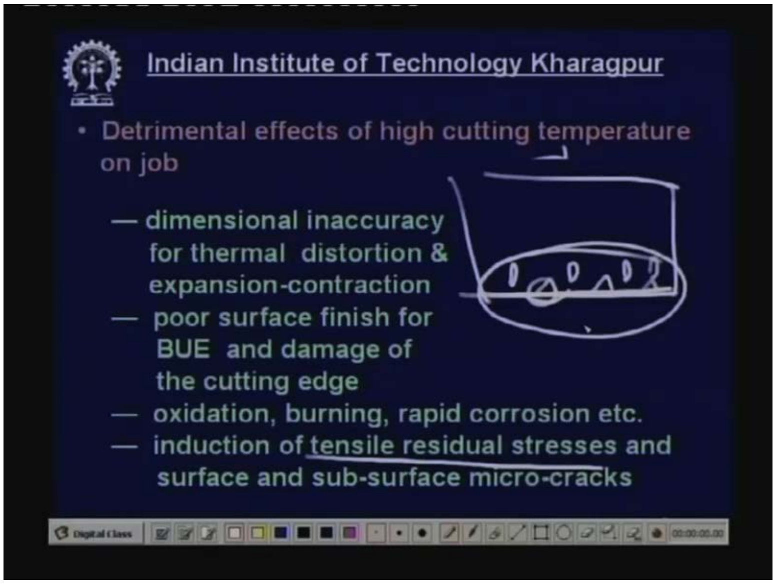
Detrimental effects of high cutting temperature on job: So what about the detrimental effects on the product. Let us examine dimensional inaccuracy for thermal distortion and expansion contraction. Now when a job is machined, suppose you are machining a rod say turning, if you allow continue sitting of the job, then this can undergo some distortion thermal distortion and that will result dimensional inaccuracy. Beside that beside that when we machine say when the cutting temperature is high, then we give a definite depth of cut but after cooling the dimension will come down and the accuracy will be further lost due to contraction. Poor surface finish for built up edge. Now poor surface finish means because of built up edge and damage of the cutting edge.

(Refer Slide Time: 10:39)



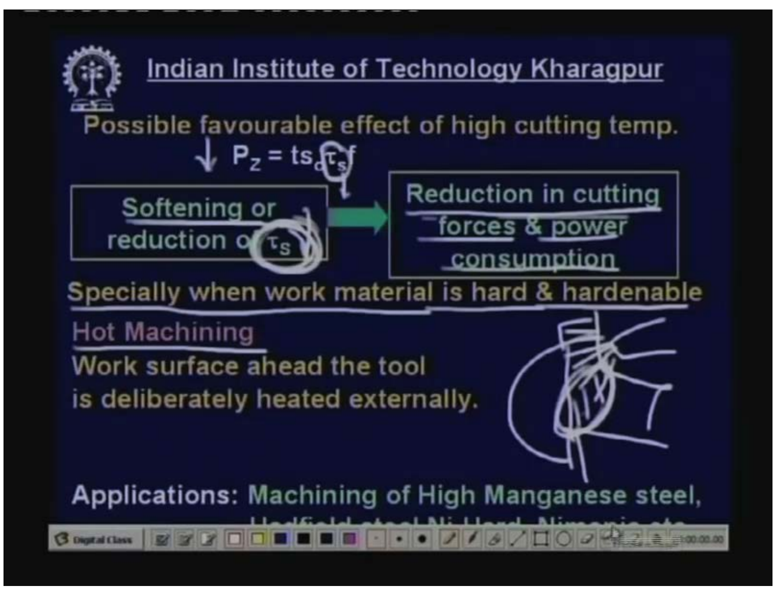
Now what is it? Suppose this is the tool and this is the material flowing and built up edge is developing. Now when this built up edge grows further, it over flows and comes into the finish side and then it forms some roughness on the surface. So this over flown part of the built up edge remain stuck on the finish surface and this causes this causes roughness of the surface. Sometime this can also cause the damage of the cutting edge. The cutting edge can be totally damaged because of this built up edge. So this is a harmful effect on the work piece and if this cutting tool gets damaged the job will also be damaged. What else it can do the high cutting temperature on the work piece oxidation, burning, rapid corrosion, etcetera oxidation burning rapid corrosion these are all you know spoil the surface integrity of the product. Induction of tensile residual stresses and surface and subsurface micro cracks. What happens due to high temperature at the cutting zone at the cutting point some residual stress develops and you know that the residual stress that is induced by heat or temperature that is tensile in nature and tensile kind of residual stress is very harmful.

(Refer Slide Time: 12:08)



Beside that it produces suppose this is the machine surface on the machine surface there will be certain cracks develop like this. So small cracks will develop on the surface and even sometime if is smeared off the crack remains inside. This is called subsurface cracks whether the outside cracks or subsurface cracks on a machine rod suppose the machine rod is the machine surface these are equally detrimental that reduces the dynamic property and the static strength of the material. So these are all detrimental effects. Is there any favorable effect on this?

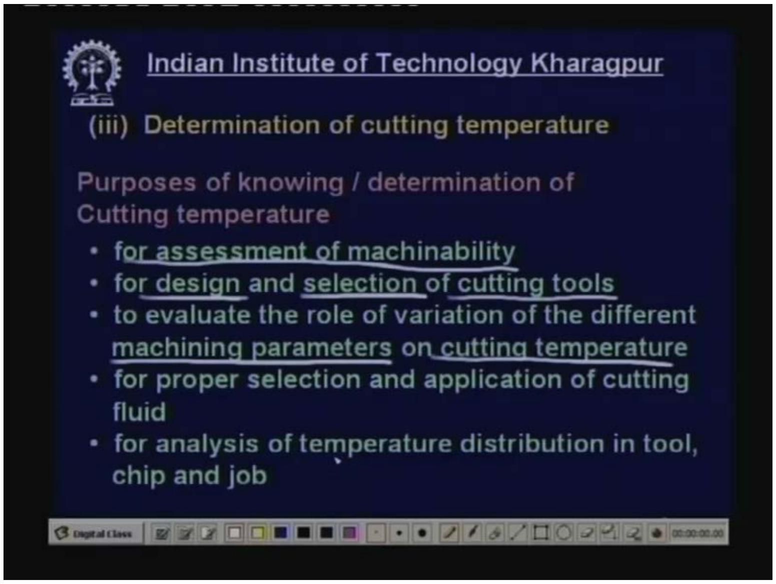
(Refer Slide Time: 12:53)



very rare favorable effect of high cutting temperature is very rare. Anyway the possible favorable effect of high cutting temperature may be here you see that we know the cutting force P z main cutting force P z depends upon the depth of cut feed the shear strength of the work material under the cutting condition and form factor. Now this tau s the dynamic yield shear strength of the work material that gets reduced because of high temperature the work material becomes soft and softening means reduction of the shear strength. If the shear strength is reduced, then the cutting force will come down reduction in cutting forces and because of that the power consumption specific energy consumption all will decrease. This is a very rare favorable case now it can happen especially when the work materials is very hard and strong that is tau s is very high, very difficult to machine for that and hardenable becomes harder along with the growth of machining. Because of this reason, this you know the possibility of reduction of tau s and resulting reduction of P z.

This possibility is often exploited in terms of what is called hot machining. What is hot machining? In hot machining, so this is the tool and this is the work chip coming out. Here the work material is deliberately heated from outside by flame or by friction or by say induction by eddy current. There are various methods; as a result, the work material when it reaches the shear zone that the temperature raises, because of that there is some inherent cutting temperature because of shear deformation. Now you are adding further heat, so temperature will rise further because of that, this tau s will decrease and that will help reduction in the cutting force and power consumption that is enable machining etcetera. Now what are the applications? Machining of that kind of material which is very hard and becomes more hard during machining like manganese steel, high manganese steel, hat trick steel, pneumonic, Inconel and so on. So this is hot machining is often very useful but does not give very good surface finish or accuracy but rough machining can be easily conducted by hot machining and this is favored preferred for such kind of material.

(Refer Slide Time. 15:35)



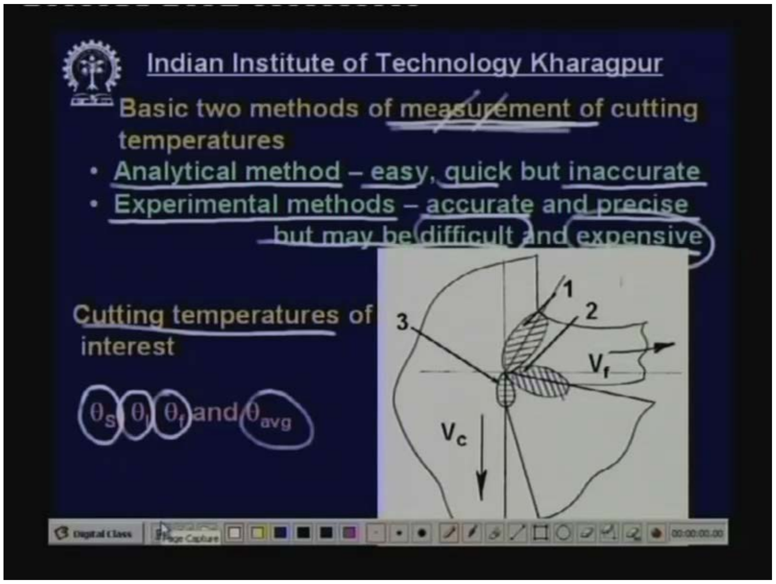
Now the determination of cutting temperature: How will you determine the magnitude of cutting temperature and its distribution over the tool, chip and so on? Before that, why should we measure? Why we should determine the cutting temperature? What is the use of it? Who will be benefited? Let us examine purposes of knowing or determining cutting temperature for assessment of for assessment of machinability of any work material or tool work combination. Now you know the machinability means ease of machining which is judged by cutting force, cutting temperature, tool life and so on that is cutting temperature. Lesser the cutting temperature we call the machinability is good. So whether machinability is good or bad, for that we have to measure the temperature know the temperature. So this is called for assessment of machinability study.

For design and selection of cutting tools, first let me tell about the selection, in the cutting temperature appears to be very high because of the work material hardness, strength and the cutting condition velocity etcetera then, we should take such a cutting tool material which can withstand high cutting temperature that is, we should take say carbide cutting inserts instead of high speed steel beside that the size and shape of the cutting tool that is design should also be taken care of for this cutting temperature to be reduced. Now after design and selection, we should measure the temperature and decide with the design is appropriate or not. So before design, we must know the temperature and accordingly should design and after design we should measure the temperature again whether design is appropriate or not.

Similarly selection of the cutting tool: Next to evaluate the role of variation of the different machining parameters now, we want to reduce the cutting temperatures. Now this cannot be done directly. This depends upon all the machining parameters and their values. What are the machining parameters, the process parameters, cutting velocity feed and depth of curve tool parameters material and tool geometry environmental parameters the cutting fluid etcetera. So we have to study that what are the roles of this parameters on cutting temperature. For that, by varying these parameters, we must know either analytically or determine the cutting temperature. Next for proper selection and application of cutting fluid, if you find that the cutting temperature is going to be very high, then cutting fluid has to be applied if the temperature is very high then appropriate cutting fluid has to be selected and employed.

So that the cutting temperature high cutting temperature can be taken care of so that it does not damage the tool and job. It is also necessary to measure the temperature often for analysis of temperature distribution in tool chip and job. For study of the deform distribution of temperature in the chip, in the tool, in the job, it is necessary for design of the tool, for analysis of the tool failure and all these things, for that we must know initially what are the temperature at the different zones like primary deformation zone and secondary deformation zone at the flanks what are the temperature? Based on that the temperature within the chip tool job have to be evaluated by say computation methods like fam or bound elimination boundary eliminatory method and all these things.

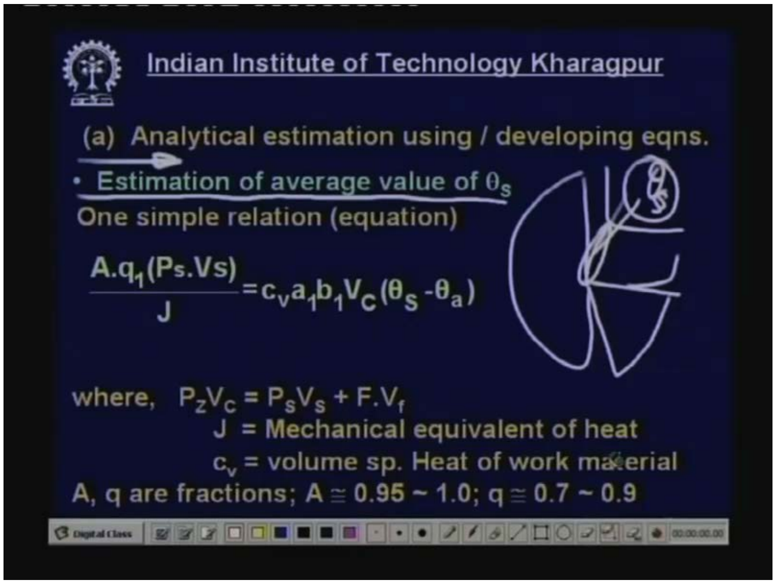
(Refer Slide Time: 19:13)



Next let us find the basic two methods on measurement of cutting temperature. This is not measurement actually this has this will be determination. Basic two methods of determination of cutting temperature not measurement determination. There are two methods basically; one is analytical method by using equations if available. If not available, can be developed and this will enable determination. This process is very easy, quick, but inaccurate and not very precise. It gives generally average values and though it can be done easily, quickly but it is not accurate. So not reliable, but if you want very accurate measurement and distribution over the surfaces and locations then experimental method has to be employed.

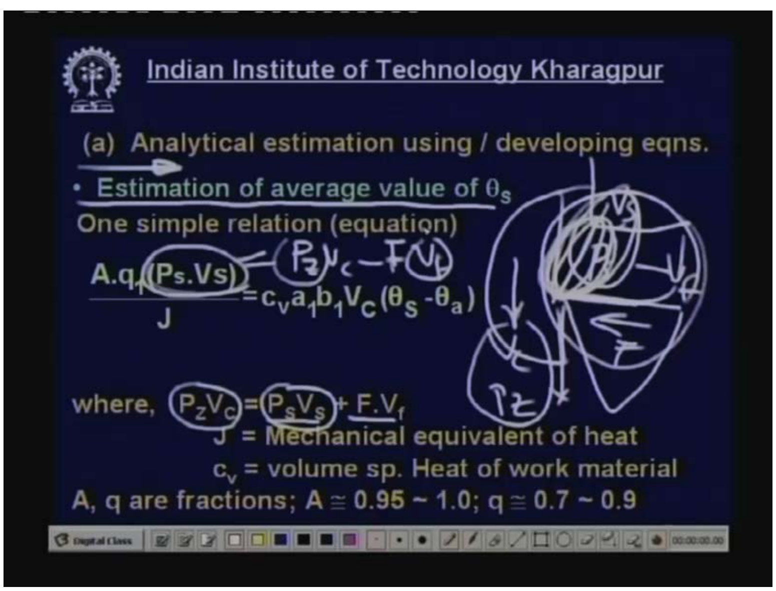
This accurate measurement are definitely accurate, more precise and give detail but may be difficult and expensive because you have to use instruments, stop machining, do some work and equipment and expert people have to do work so it may be difficult as well as it may be expensive also but this will give accuracy and precision of measurement. Now when you talk about measurement or determination of cutting temperature cutting temperature what we talk? Which temperature we are interested of? These are the average shear zone temperature; this is the shears on temperature. In the shears on temperature, what is the average temperature in this region that is theta s then this is another major heat source were at the chip tool interface there will be heat generation temperature and average of that is theta i. At the flank, at the principle flank suppose theta f and some time over all average temperature theta average. So these are the temperatures which are we are interested for various purposes.

(Refer Slide Time: 21:25)



Analytical estimation using or developing equations using or developing equations. Yes now, there are various methods here it is interesting should know that there are different method various methods available in the books and journals and lot of people have done research earlier and develop lot of equations of varying accuracy level and reliability. But here, we have got limited scope to discuss all of them. So let us take one say estimation of average value of shear zone temperature. What is shear zone temperature? This is the tool chip is flowing and this is the shear zone, what is the average temperature here? That is theta phi, sorry theta s that is what we are going to estimate first. Now this will be done by using this equation. So what is this equation and were from it comes?

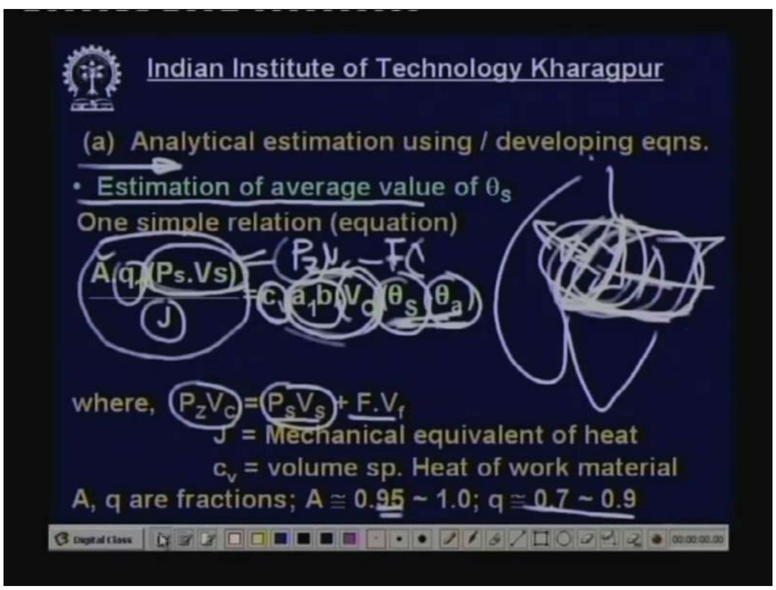
(Refer Slide Time: 22:29)



Here you see that, this is the tool flowing job and the velocity is here cutting velocity V c, the force main force is P z, so P z into V c that is P z into V c that is the amount of energy we are putting in for conducting machining work that is utilized for causing shear that is shear plane area multiplied by the shear area by the stress in the force and this force P is multiplied by the velocity in this direction, shear velocity V s. So this P z into V c should overcome or provide this amount of energy and also to overcome the friction if and the velocity V f. So these two things have to be provided by V c into P z. So P z V c is comprised of two parts, it has to provide this shear action and overcome friction at the chip tool interface. From this one, what is our interest is shear zone at this moment. So what is this energy? This energy is equal to P z V c, P z V c minus F V f.

So this P s V s is the source of heat. Now suppose this is the energy mechanical energy. Here at the shear zone Ps Vs and this is equal to P z V c minus F into V f. We know P z, we know V c, and we know friction four by dynamometer and the chip velocity from the chip reduction coefficient. So P s V s is known now, whatever heat is generated here. So whatever mechanical energy expended here, a major part of that a major part of that goes into heat say fraction A what is fraction A? Fraction A means amount of energy that is converted into heat so this is A. So 95 percent around 95 percent of the mechanical energy shear energy will be converted into heat.

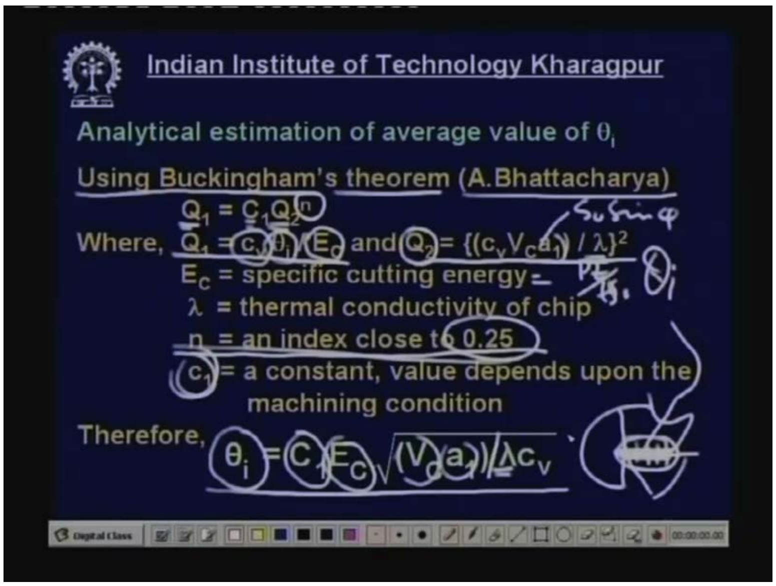
(Refer Slide Time: 25:05)



After that, after that the heat that is generated in the shear zone that will be shared. A major portion goes into the tool chip and a small amount goes into the job. Now this apportionment suppose heat is generated at this zone and then its fraction say q. q is the fraction may be 70 to 90 percent will go into the chip and 10 to 20 percent go into the job. Now the chip the chip which is coming out, the chip receives from the shear deformation this amount of mechanical energy multiplied by A and q 1. So A into this one is the heat energy and q 1 is the fraction that goes into the chip and one minus q one goes into the tool. So this is the heat generated that divided by J is the mechanical equivalent of A. So this is the amount of heat carried by, produced by and carried absorbed by the chip due to shear deformation alone.

Now in one minute or per unit time how much heat is contained by the chip in one minute if it comes out continuously that is the cross section of the chip A1 V 1 velocity of the so this is the amount volume of the chip flow rate of the chip that flows out and this is the temperature average temperature at this region and this is ambient temperature and C v is the volume specific here. So flow rate volume specific heat multiplied by the difference in temperature. Just a minute sorry sorry, now here what you find? This is the amount of energy received by the chip per unit time and this is the amount of heat contained by the chip per unit time. So now balancing these two, we get the equation say A is known. Say as 0.95 q one is say 0.8 P s V s are known J is known C v is the property of the chip material A 1 B 1 are known. This shear energy and theta A is the mean temperature known. So you have to determine theta s from this expression. Now this is another analytical estimation of average value of the chip tool interface temperature I remind

(Refer Slide Time: 28:06)

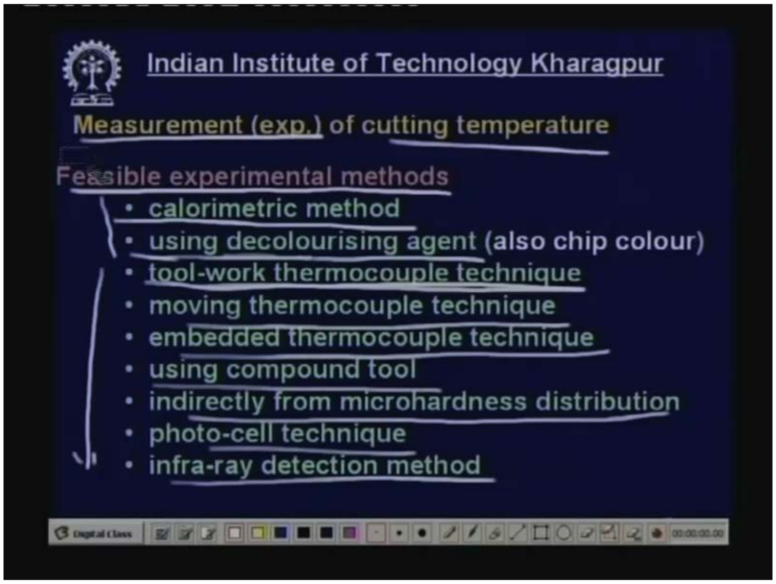


you that this is the tool and this is the rake surface were the temperature is theta i. This has to be determined the average value of theta i. How? 1. There are many methods very beautiful methods are available in different books including A Bhattacharya's book machining theory and principle. Now using the Buckingham's, the starting point is using Buckingham's theorem which states that there are two dimensionless quantity Q 1and Q 2 two dimensionless parameters and they are connected by a constant C1 and Q to the power Q 2 to the power n were Q 1 represents the volume specific heat of the chip material theta i is the average temperature at the shear zone sorry at the chip tool interface and E c is the specific energy consumption that is equal to cutting force P z divided by unit chip area chip cross section area and Q 2 this is given by this expression.

This value specific heat multiplied by the cutting velocity, process parameter multiplied by the uncut chip thickness A1 which is equal to you know s 4 sine phi that is p and phi is the principle cutting edge angle and lambda is the thermal conductivity whole square. Now as it said E c is specific cutting energy which can be determined from the cutting force divided by the chip cross section area chip flow tso lambda, thermal conductivity of chip n an index close to this have been observed studied experimentally and found that is very close to 0.25. c 1 is a constant which depends upon the machining condition that is the cutting fluid application, friction, some time tool geometry and so on.

Now combining these three equations what we get? Taking n is equal to this n is equal to say point two five and then combining Q 1 Q 2, we get an expression like this a similar expression theta is equal to c 1 is a constant like this and E c the specific energy consumed by the material which depends upon the cutting force etcetera and then root over cutting velocity feed and thermal conductivity divided by thermal conductivity and these value specific heat. So if all these are known, we can determine theta i approximately and this is average value not at the point by point only average value over the surface. Remember the temperatures at different points on the rake surface are different.

(Refer Slide Time: 31:06)

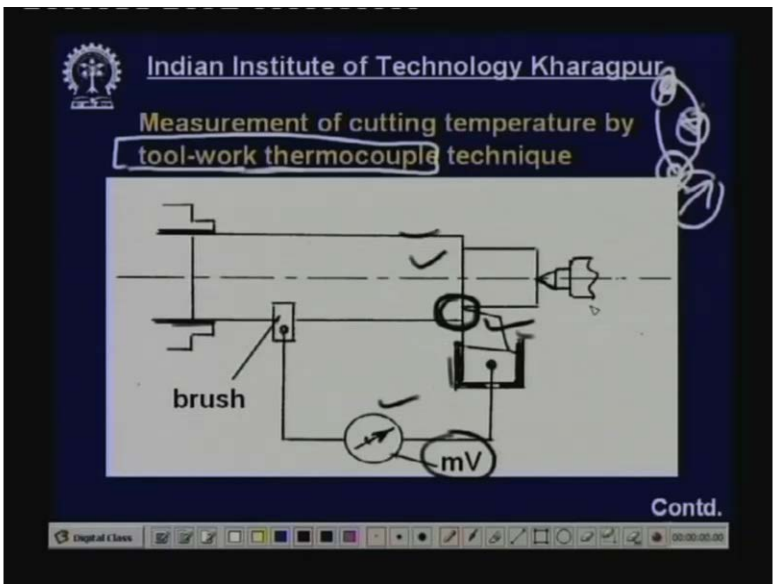


So this, what we have discussed those are analytical estimation. Now we shall see how the measurement is possible? Measurement experimental experimental measurement or experimental determination of cutting temperature: Now there are many methods which can be applied. Some of the method is feasible, some of them are not that feasible, some methods are very accurate, some methods are not accurate and so on. However some feasible experimental methods which are normally you know used by the people who are interested in measurement of cutting temperature, they use these things. See calorimetric method calorimetric method is very simple, quick method but definitely neither accurate nor reliable. It gives very average value and for operations like drilling and so on, the heat that is developed is contained in the water or the fluid and from by balancing we get the average temperature.

Second method this is also a crude method, but better than calorimetric using decolorizing agent that means there are certain paints and chocks which when pasted or painted on the hot surface depending upon the temperature of the hot surface the colour changes. Say it coloured depending upon the temperature of the cutting tool or the job, the colour of the chock that is pasted or marked or the paint that is marked on the tool or the job will keep on changing and if you know in advance that what is the correlation between the colour and the temperature? you can determine the level, at least the level of the temperature not exactly from the range of the colour approximately. Now example also chip colour. Now for materials like steel, from the colour of the chip colour of the chip produce the temperature of machining that was develop can be estimated can be apprehended.

For example if the colour of the chip is bright like steel, then temperature is definitely less than 500 centigrade if it is plain yellow then 600, if it is say orange colour 700, if it is brown 750, if it is you know say chocolate colour 7 to 75, if it is black then it will be 800, if it is blue then above 800 say 825 and it can be grey colour that is above 95 approximately. So from the colour of the chip of materials like steel, the cutting temperature can be estimated. These are not very reliable. These two are not very reliable, but what is reliable? These are very reliable say tool work thermocouple technique. This is a very simple method, very accurate. but it does not give the detail but average value then moving thermocouple technique, embedded thermocouple technique, using compound tool indirectly from microhardness distribution photo cell technique and infra ray method. So so many methods are there which can be used. Now we shall discuss one by one those which are important.

(Refer Slide Time: 34:23)

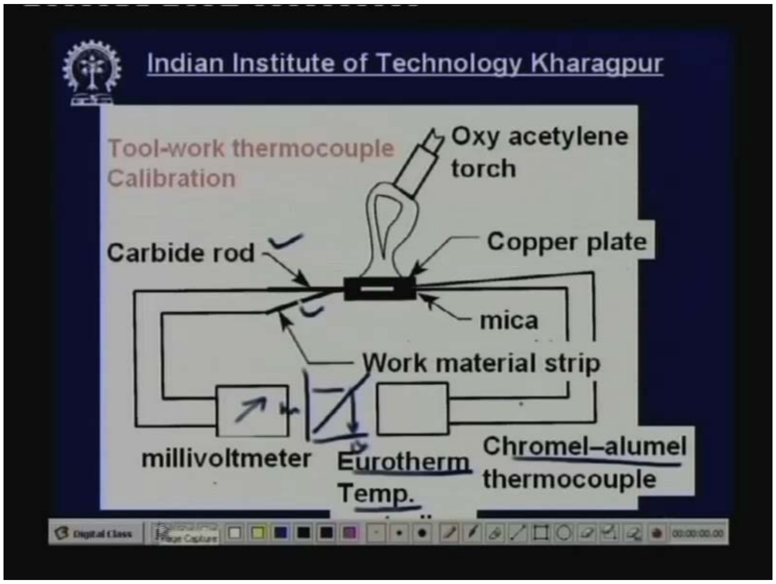


See tool work thermocouple technique: In tool work thermocouple technique, here you see tool work thermocouple technique. The tool and the work will function as the two conductors of the tool leads of the thermocouple. You know in thermocouple, there is pair of materials conductive thermally, electrically, conductive material say copper and constantan, then chrome alumel are different types of materials. The principle is, when these two metals are joined and the junctions are kept at different temperature high and low, because of the difference in temperature at the two ends, some current will flow and that will be measured by a millivolt meter. For example, say this is one conductor, this is another say copper, this is constantan, this is a hot junction and this is cold junction.

So this current will flow. Now if you put a say mini volt meter, this will give a reading and this millivolt will be proportional to the current and the current will be proportional to the difference in temperature between the hot and cold junction. So this is the basic principle. So now this is also this tool and work comprise this tool-work thermocouple technique. The work material the work material is a conductive material, the tool is a conductive material, say high speed steel or carbide, tungsten carbide or this is mild steel and this is the hot junction. The cutting zone that found the hot junction. this one.

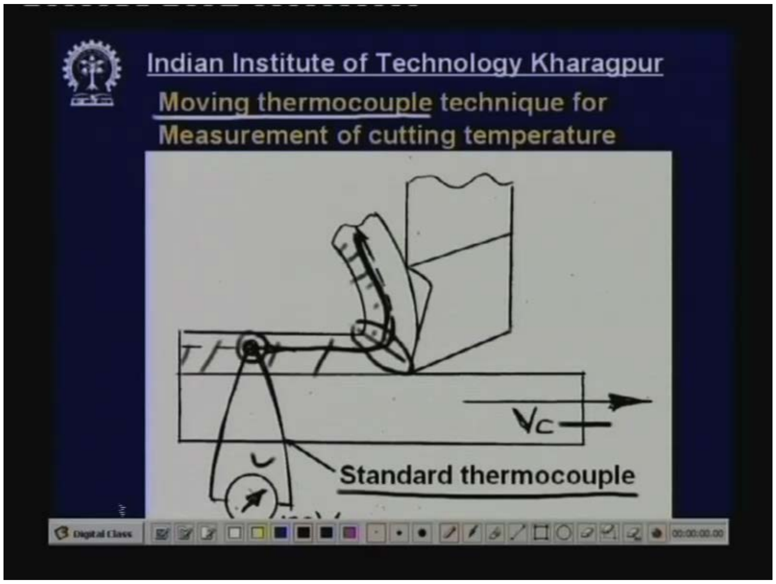
So the current will flow like this in between, but the job will be mounted in the chuck on insulator. The tool will be mounted on the tool pole by insulator; so that the circuit is complete this circuit is complete. Now the current will flow along this circuit. This is one tool material high speed steel is mild steel, another material and the hot junction. So current will flow and that recorded in the millivolt meter and this millivolt recorded will be proportional to the temperature that will develop here, that is maximum temperature that will develop here. Now this relation between millivolt and this temperature should be developed in advance by calibration. So if it is 40 millivolt what is the temperature? Now this has to be calibrated, for these two different materials in advance. How it is done?

(Refer Slide Time: 36:51)



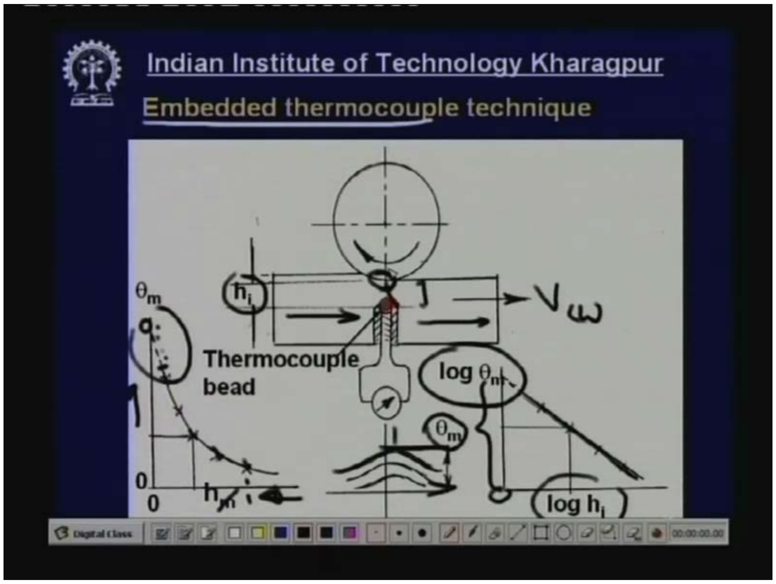
Here this is the carbide. Suppose the work material is mild steel, work material is mild steel this is the mild steel and this is carbide this is carbide this is mild steel. So this is the junction and this junction is fitted on a hot plate say the copper plate is there. On the copper plate, so when this will be heated? This junction will also be heated and these other cold end and this is a millivolt meter here, we put a millivoltmeter so when this will be heated so millivolt will be generated. Now what is the temperature here? How shall we know? On the other side, we shall put another thermocouple, standard thermocouple say chrome alumel thermocouple and here whenever the same temperature will develop that will be recorded in the eurotherm and from here we can get the temperature. So what we get from here on this side? We get millivolt on this side, we get temperature and this is calibration curve. So during use, we form any millivolt we can determine what is the cutting temperature that is called calibration. So this is a calibration technique which is a must before use of this thermocouple technique. Now another simple technique is moving thermocouple technique.

(Refer Slide Time: 38:09)



Moving thermocouple technique what is it? Suppose we are conducting shaping or experiment and this is a work material moving in this direction with a cutting velocity V c and this is the cutting tool chip flows in this direction. Here a standard thermocouple say chrome alumel on nickel chrome is embedded here or bridged here and this is connected to a millivoltmeter. Now when this job will proceed, this layer which is going to be removed is passing through this path and it first reaches the shear zone, then it goes along the chip. So when this one is far away from this one, this will know the temperature is an ambient. So this will not show much reading when this will come close to the shear zone and passes the shear zone heat will develop temperature will rise that we indicated here and the millivoltmeter will record and when this will pass through this, so we get temperature at different point of the path. So this can be continuously located and recorded. This is called moving thermocouple technique.

(Refer Slide Time: 39:24)

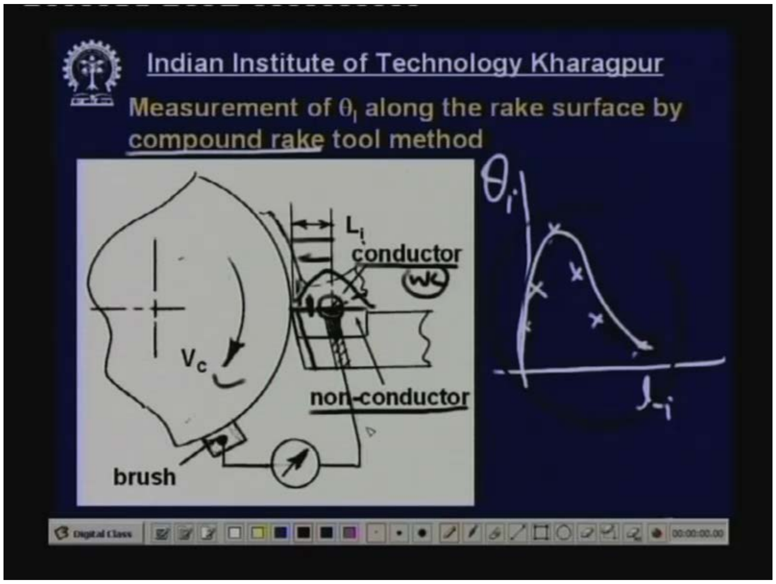


Next is embedded thermocouple technique; Embedded thermocouple technique. Now here, this is applied for cases were the upper surface is not available for any measurement directly. Suppose this is grinding or milling cutter or may be a grinding wheel and finishing the upper surface. Now we are interested to know the temperature in this region at the grinding zone. How this can be done? First of all, a small hole is made here like this, small hole. Through the hole, a standard thermocouple standard thermocouple bit is fitted here. So this will be closed in contact with the job but there is a gap between here is the gap.

Now when you conduct the machining work say V c, then what will happen? This is V w, then this will travel in this direction and this is the direction of travel and this is the height h I, suppose this is a particular h i, now this one this hole was somewhere here. Now gradually, it will move come close to this grinding zone and then pass out. So gradually the temperature will rise in this bit because when it will be close to the cutting zone were heat is generated and then it will gradually decrease. So, this temperature recorded here will gradually rise and it will be nearest when close to this one and then gradually it go down but it is not exactly at the same point this maximum temperature will when this bead is somewhere here slightly offset because of the time lag of heat flow. Anyway, so first you take one pass at a particular height h i and note down what is the maximum temperature observed theta m, then you take another pass when you keep on taking number of passes, this depth of the material gradually decreases.

This is h i not h m, h i this will gradually decrease. When this will decrease, this value of theta m will keep on rising. This will keep on rising. So you measure like this at different values of h i but you cannot go to the surface. So you can go up to say this this much then to get the surface you extrapolate. Just by extrapolation here, you get the temperature here but extrapolation may be difficult in case of say return hyperbola. If you plot in log log log log scale, then you get a straight line and you can extrapolate to get the temperature when h i is very close to zero, very close to zero that is you are taking the measurement maximum temperature at the grinding zone this is a technique very successful technique useful technique in grinding, milling similar operations. Another technique say compound rake tool.

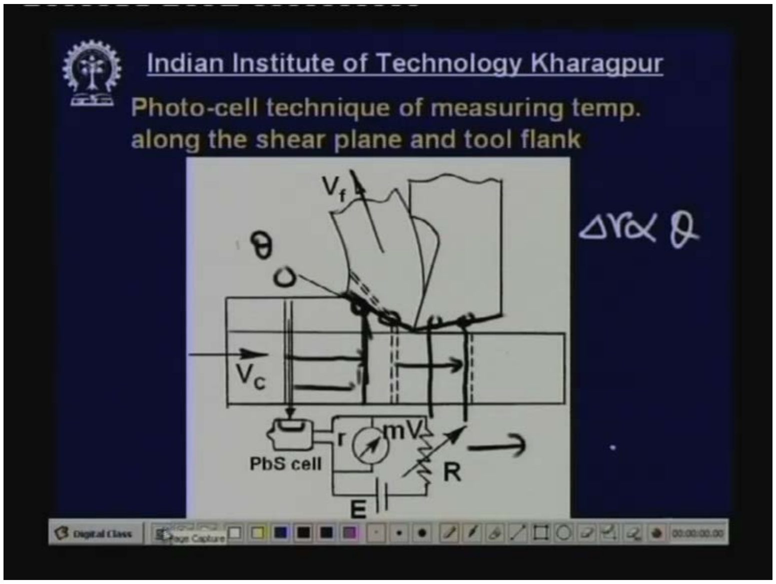
(Refer Slide Time: 42:22)



This is compound rake tool, this is the cutting tool. This cutting tool is made of a nonconducting material suppose ceramic, we take ceramic is a nonconductor but it has got a small slit and a hole, this slit is filled up with another tool piece that is made of conducting material say carbide tungsten carbide. So this cutting tool is manufactured by ceramic tool with a small strip of tungsten carbide which is thermally conductive at a distance say l distance this much. So what will happen? See this is li this is li this distance and you measure the temperature, the tool-work thermocouple technique. This is the hot junction, this is the hot junction at this point and this is the brass. This is the tool sorry tool and job tool were thermocouple technique.

So you are measuring the temperature there. So temperature is suppose here this is temperature i temperature. Now you know after taking this reading, you just grind this portion you grind this portion remove it. So this value of l will change, it will decrease you measure temperature again. So this will rise and this will fall again, that means you get the temperature along the rake surface. Along the rake surface, we are getting the temperature profile by this technique. So it is gradually going high and then gradually decreasing. So temperature at the centre somewhere here it will be maximum here. So the temperature distribution along the rake surface can be well measured by this technique.

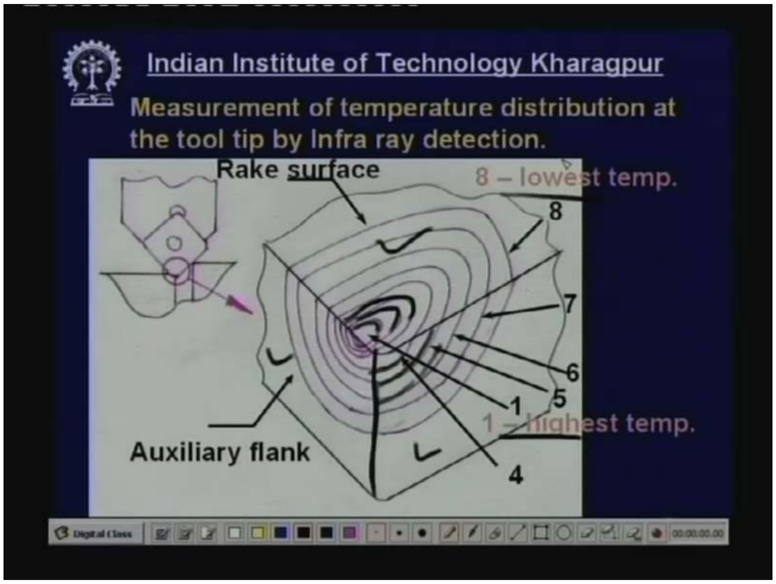
(Refer Slide Time: 44:31)



Next is photo cell technique. What is photo cell technique? This is a photo cell. Basically, this is a lead sulphide cell were if light sorry if heat radiation radiated heat impinges on this sensitive portion of this lead surface cell somewhere here, suppose this is the sensitivity portion, then it's electrical resistance r will change and these change electrical resistances say delta r is delta r is proportional to the temperature of this source from were heat is radiated and coming and impinging on the surface say temperature theta this temperature. Now in this process, a hole is made but so long the hole is away from the shear zone and this region there is nothing from were heat is coming.

So there were no changes in this resistance r. There were no change in resistance but when this will move towards in this direction and coming to this position then say here even here this hole will be deflected and from this region heat will be radiated and received by the photo cell. By this time, this will come to this region whole thing is moving in this direction. So you are getting temperature here. You are getting temperature here thus you can get the temperature all along the shear zone. After that, this whole moves beyond that, so you get the temperature from this region, temperature from this region. So heat will be radiated from that flank and you measure that. So you can get the temperature distribution along the shear plane as well as along the flank surface. So this is the nice, reliable but simple technique or measurement.

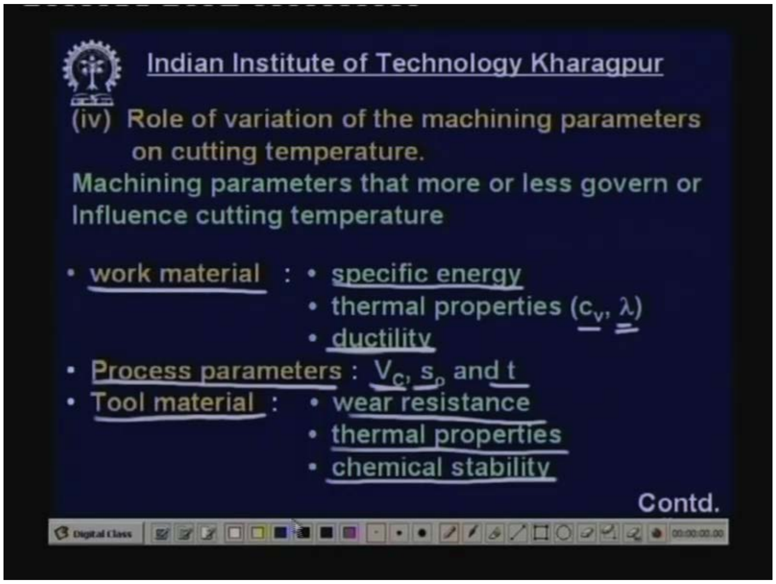
(Refer Slide Time: 46:30)



Next is measurement of very modern method, advanced technology, very expensive also a measurement of temperature distribution at the tool tip by infra ray detection. Infra ray detection is a camera, were this camera is sensitive to temperature. Depending upon the temperature, some signal will be created in terms of voltage or something and that it by image processing that will be stored in a computer and then displayed in this screen. For example, say this is the cutting tool which has got three surfaces. This is the rake surface, this is the this is the you should draw a line of demarcation then this is auxiliary flank and this is principle flank. Now, if you can make the principle flank exposed to the camera, then the camera can detect the temperature profile like this.

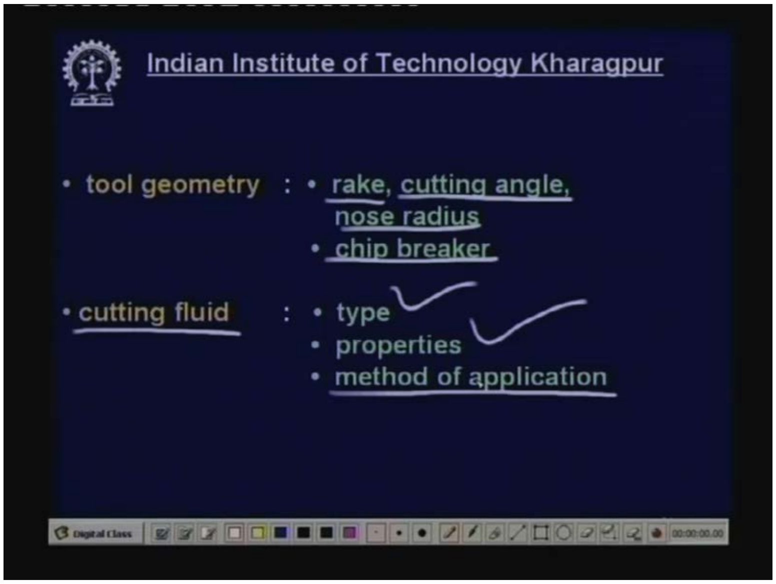
This is isotherms and on the rake surface also there will be some isotherms. For example, say this is number maximum temperature will be here in this region on the rake surface near the tip. So this one were the temperature is highest, and the outer periphery the temperature is a lowest. So, the temperature will vary and this is the isotherms. Entire spectrum of the temperature can be easily and effectively determined and displayed by this infra ray technique with the help of a computer.

(Refer Slide Time: 48:02)



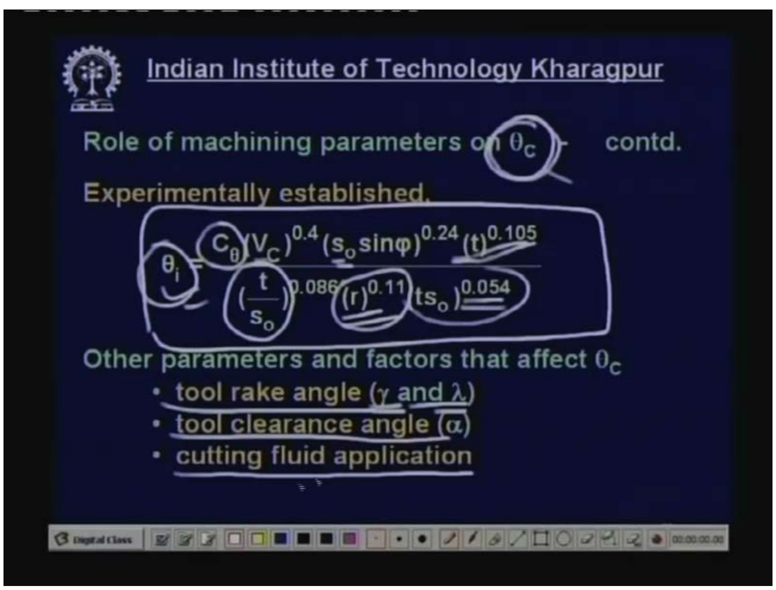
Now let us see the role of variation of the machining parameters. As I told you that temperature have to be reduced and that depends upon the process parameters. How do they influence the cutting temperature? We should know so that we can control the parameters to reduce the temperature. Now what are the machining parameters? There are different machining parameters. What are those? Work material; what are their specific energy requirement by the material, that is specifically the strength of the material or hardness, thermal properties value specific heat and thermal conductivity, ductility of the work material; if it is more ductile, more heat will be generated because of intimate contact between the chip and the tool, then process parameters. Most important cutting velocity, feed and depth of cut, then tool material, wear resistance. If the tool material wear resistant, then temperature will be less because of less friction thermal properties the thermal conductivity and resistivity, chemical stability if it is chemically stable, then less amount of heat will be generated and transferred to the tool and heat will go towards the chip.

(Refer Slide Time: 49:30)



Then tool geometry: Tool geometrical parameters, rake angle, cutting angle, nose radius and chip breaker if applied and cutting fluid very important. What type of cutting fluid you are applying, and then what are the properties of the cutting fluid that is cooling property, lubricating property viscosity, weighting property and so on and method of application of the cutting fluid. How do you apply? drop by drop by flood or jet or as missed or from the direction from top, from bottom. from side and so on. So all these things play vital role.

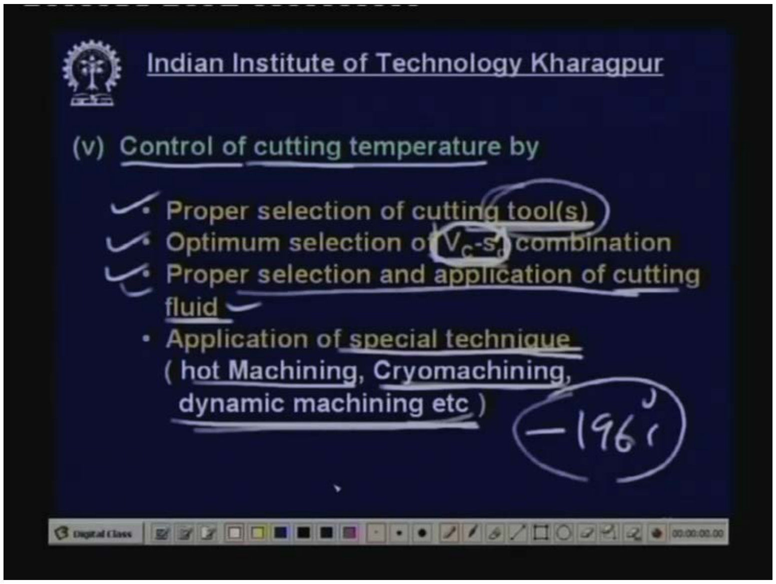
(Refer Slide Time: 50:03)



Role of now the role of machining parameters on the cutting temperature: The general average cutting temperature this is average or overall average cutting temperature denote by theta c. Basically this is very close to the maximum temperature at the chip-tool interface. Lot of experiments have been carried out, lot of analysis have been done and ultimately an expression like this have been arrived. At a very beautiful equation which depicts the role of various parameters on the cutting temperature. What are those? c theta a constant property of the work material, strength of the work material, cutting velocity to the power 0.4, feed to the power 0.24 and depth of cut 0.105.

So from this equation you find, that the variation of velocity plays the most important role on theta i because its index is 0.4. Next feed only 0.24 and depth of cut has got minimum effect on temperature because index is 0.105 interesting to note that, this ratio depth of cut verses feed also plays an important role significant role on the cutting temperature. Nose radius that influence the cutting temperature and the product also but to lesser extent. But there are parameters also which affect cutting temperature. Those are tool rake angle and inclination angle because inclination angle affects rake angle and rake angle affects cutting force cutting force governs energy. From energy, heat is generated so temperature. Tool clearance angle if the clearance angle is not there adequately or reasonably, then there will be rubbing action at the work tool interfaces and then there will be lot of heat generation and cutting fluid application. So the proper application of the cutting fluid that influences substantially if not remarkably.

(Refer Slide Time: 52:13)

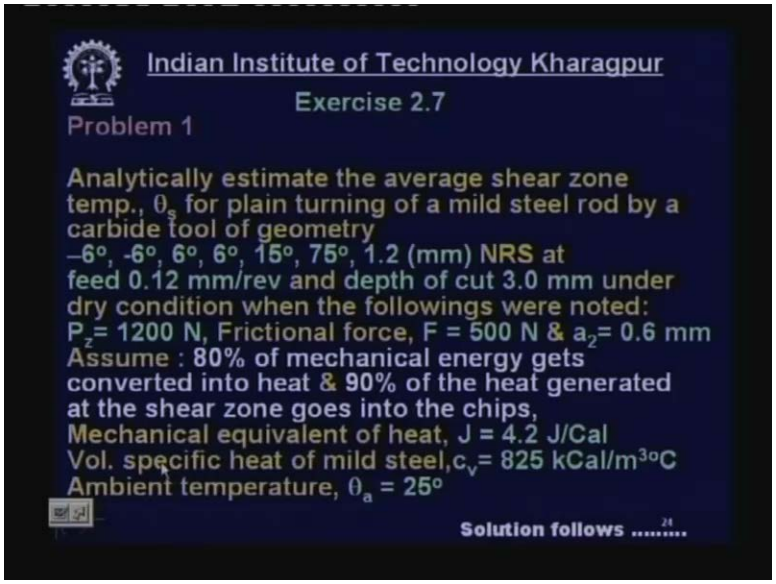


Now the control of cutting temperature: How do you control the cutting temperature? So today we shall just point out what are the methods and these things should be discussed in detail in the next lecture. Now anyway, what are the basic approaches of control of cutting temperature? Now first of all, we should understand what you mean by cutting temperature control control of cutting temperature reduction reduction of cutting temperature as far as possible because it is as such detrimental. How? By proper selection of cutting tools. Now, if you want to reduce the cutting temperature we should take such cutting tool which produces lesser friction at the chip to interface and heat like say instead of uncoated carbide if you take coated carbide tool then less heat will be generated. If you take ceramic tool high polished, then less temperature will be generated. If you use cbn cutting tool, less heat will be generated and temperature. Beside that even if the heat is generated to reduce the temperature of the tool and overall the tool material should be conductive, thermally conductive. Then the temperature will decrease to some extent. Next is optimum selection of velocity and feed. In the previous case, we observe that variation of cutting velocity causes more effect or rises the rises the temperature more significantly then increase in feed.

Suppose if we maintain increase the velocity sorry decrease the velocity by 50 percent and increase the feed by 100 percent, then the productivity will remain same. The product will remain same, but we can reduce the velocity and increase the feed then temperature will come down. Of course, the other kind of problems like surface toughness may arise then proper selection and application of cutting fluid which was already been mentioned for when their temperature is the detrimental then we should apply cutting fluid proper application has to be in use. Now if the temperature is very high then more effective cutting fluid like oil or compound oil extreme pressure id type of oil has to be used which may be expensive but we have to use it then application in spite of that if the temperature is not reduced then we may have to apply special techniques. Is that already been mentioned at beginning of this lecture is a technique like hot machining which softens the work material as well as the machining force decreases the energy requirement, decreases heat generation, decreases overall temperature may decrease because of this hot machining.

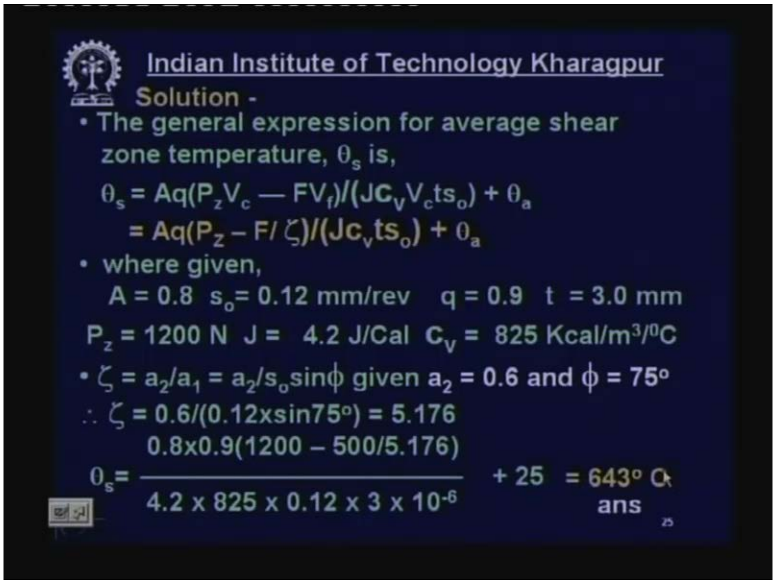
Cryo machining, if we apply see will cryogen like liquid nitrogen at temperature minus 196 degree Celsius, then the heat will be observed by this taken away by this cryogen and temperature will come down. Then dynamic machining by dynamic machining which was discussed earlier the cutting force can be reduced by the reducing friction and so on by more effective cooling and temperature will come down. So these are the basic methods of controlling cutting temperature. Now friend for your practice there is an exercise.

(Refer Slide Time: 55:29)



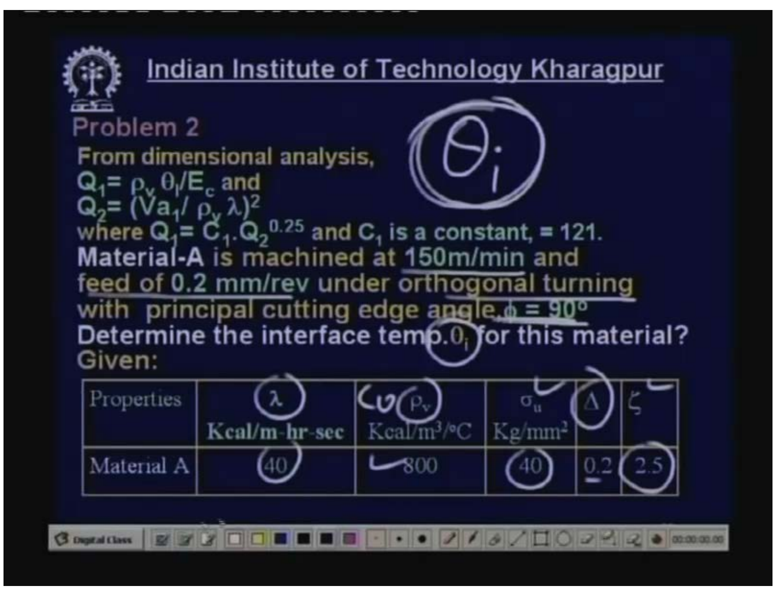
Say 2.7 there are two problems given for your for your practice. Now problem number 1.What is there you can easily solve it the problem one state this is for

(Refer Slide Time: 55:50)



J is given J is now C v known and all these things sure you will get the value of theta is putting all these values into this equation 643 degree centigrade for this the answer. Now this is another problem.

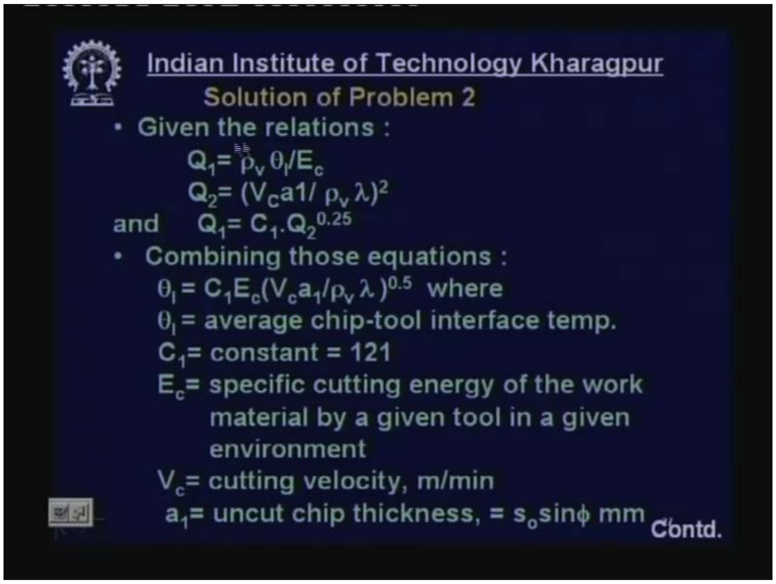
(Refer Slide Time: 56:04)



This is for the determination of theta i here determine theta i that is average shear zone temperature. You can use the Buckingham formula from dimension analysis Q1 is given by this expression, Q 2 by this where Q 1 is equal to C 1 Q 2 to the power n, where n is equal to 0.25

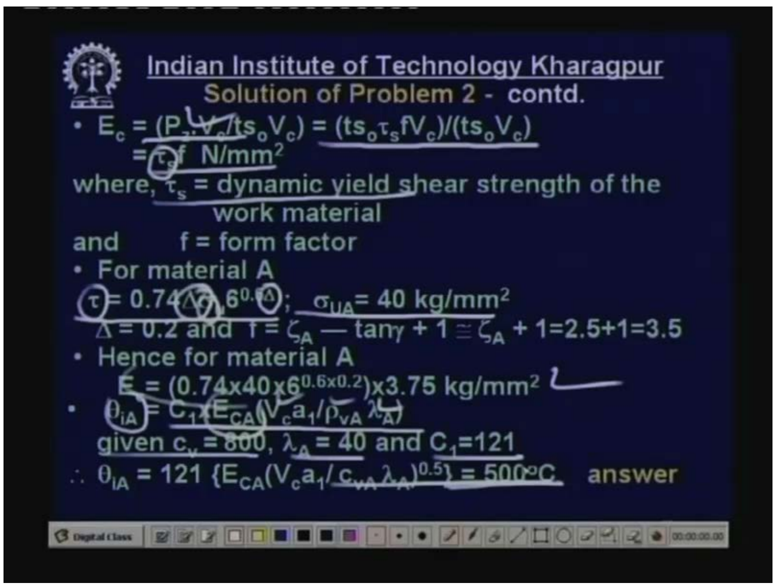
and C 1 is a constant. Suppose it is given a value 121 and there is a material say A is a machine at such a speed and feed this much under orthogonal turning and this angle is 90 degree. Determine the interface temperature theta i for the following condition. lambda is given, rho this is Cv is given and the ultimate tensile strength 40 kg per meter square given this is percentage elongation 0.2 and zeta 2.5. So these are the values which are given. With the help of these values you have to determine theta i this equation.

(Refer Slide Time: 57:11)



So given solution. Now we are going into the solution.

(Refer Slide Time: 57:15)



So E c the specific energy, P z V c by tso the Vc is equal to this much. This is you get 500 degree centigrade, so this is the answer. So this is how you can solve many problems and you have to practice time to time. So this ends today.

Thank you very much.