Mechanics of Machining
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Lecture - 13
Tool Wear and Tool Life and Tool Life Equations

Welcome to the course of Mechanics of Machining. Today, I am going to discuss about Tool Wear and Tool Life; this is the 13th lecture in this course. What is tool wear and tool life?

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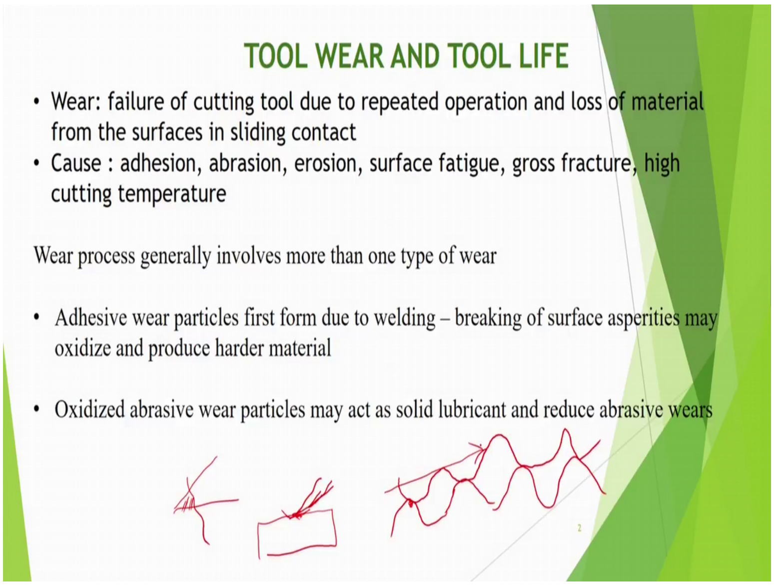

First let us discuss about the wear, wear is the failure of cutting tool due to repeated operation and loss of material from the surfaces in sliding contact. Tool is in contact with the workpiece even the chips are sliding on the rake surface of the tool. So, gradually there is loss of material that is called wear.

Wear can be caused by various reasons adhesion that actually suppose the chip is flowing on the surface. It may addle to the surface, there may be due to adhesion and after that adhesion is a type of small welding and then after that it is removed. So, it takes some material away. Suppose, there is one surface asperity is there, some this surface is not smooth, there are asperities; it may be like this, another surface is also having this type of asperities suppose they come in contact like this. So, momently there is a welding and then after that, this when this separate due to force. Because, this there is a relative motion then it takes away some fragments that is basically adhesion.

Abrasion is actually caused by suppose, you have some soft material and on that top of it there is a some hard particle or hard material that abrates it; that means, because of it something like it ploughs whole material that is called abrasion. If you see the dictionary, erosion will be mentioned as one synonym of abrasion, but there is some difference there is a fine difference and that may differ from book to book also, but generally in erosion there may be some fluid material in that it may get eluded.

Suppose there is a rock and in that water is flowing. So, we say that water is eluding that but if there is a solid material, we say it is abrading that. These type of fine differences are there, but otherwise you can say people generally say abrasion and erosion combine, then, surface fatigue is there because surfaces are on contact, tool is in contact with the workpiece, there are contact forces. So, suppose tool is making contact here after that it will go away it will separate. So, this surface of the tool gets oscillating stress because suppose when this tool is actually taking large cut depth then in that case large amount of forces come on the tool, but then once it has removed that material then the force comes down also.

So, there is alternating or fluctuating force is there and because of that you will get fatigue. Then there can be gross fracture, suppose, load is force is more, then the strength of the material then tool can separate that suppose this type of tool is there, may be it can fracture like this. This portion can totally go away then of course, high cutting temperature high cutting temperature takes place that is why that tool will become soft. It will lose its hardness hot hardness and that is how that you can get this type of wear.

So, wear process generally involves more than one type of wear, one is adhesive wear particles. First form due to welding as I have told adhesive wear is very common and then they these bonds they get broken breaking of surface asperities may oxidize and produce harder material; that means, they gets broken and they get exposed and there can be oxidation and that oxidation those oxides can be actually much harder that type of thing can be there and oxidized abrasive wear particles may act as solid lubricants. Sometimes oxidized lubricants they may be brittle also and they may reduce abrasive wear also; so that means, wear is very complicated phenomena. We cannot say definitely that what will be its effect. Usually we try to make a assessment based on some experiments; so, next.

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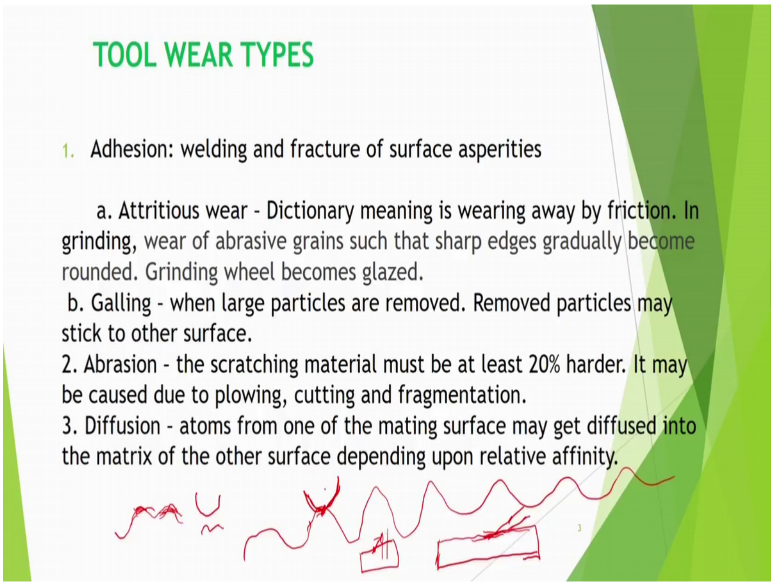

So, suppose discuss one by one I am going to discuss. Suppose, we discuss adhesion in the cutting tool, three type of wears are very common; adhesion, abrasion and diffusion. Now, let us discuss how the adhesion wear takes place in the cutting tool. Adhesion in you can say in one word, it is basically welding and fracture of surface asperities surface is not smooth. If you see under the microscope, it may be having this type of undulations. It is not smooth, other surface is also not smooth and when the peaks of both the surfaces contact with high amount of pressure and temperature is also there..

Then, there may be at micro level there may be welding and then after that because that welded joint is not very strong it separates also. So, it causes the fracture of its surface asperities. Suppose this surface is there another surface as come in contact here they will weld here, but they will separate. So, they will in the process of separation, some material will be removed may be some material has got removed from both sides, from this material as well as from this material.

Adhesion wear may be called attritious wear, usually this we used in grinding. In grinding, we use term attritious wear, dictionary meaning is wearing away by friction. In grinding, wear of abrasive grains such that sharp edges gradually become rounded that is called attritious. It is basically you know rubbing of that and grinding due to which we say grinding wheel becomes glazed. It looks a shining type of thing and you say that this is basically some glazing type of thing occurs. So, you will see that because these glazes are faces will become rounded and you can identify by naked eye that the grinding wheel has become glazed.

Then there is a galling, when large particles are removed that is called galling. Removed particles may stick to other surface. Second type of wear is abrasion; the scratching materials must be at least 20 percent harder. Abrasion is due to scratching. Suppose I am having some type of suppose this is wax and on which I am moving a knife. So, this knife is actually abrading the material. So, here that what happens that the scratching material must be at least 20 percent harder then, it may be caused due to ploughing, cutting and fragmentation. There is a ploughing type of phenomena; it cuts also and the chips gets fragmented means, when it is cutting then there will be fragmentation.

Then diffusion; atoms from one of the mating surface may get diffused into the matrix of the other surface depending upon relative affinity. There can be diffusion, suppose, some work material is containing carbon, it is possible that this carbon may diffuse into the tool material or vice versa. Sometimes tool is at very high temperature from the tool that some material may diffuse into the other workpiece. So, atoms from one of the mating surface may get diffused into the matrix of the other surface depending upon relative affinity that is called diffusion wear.

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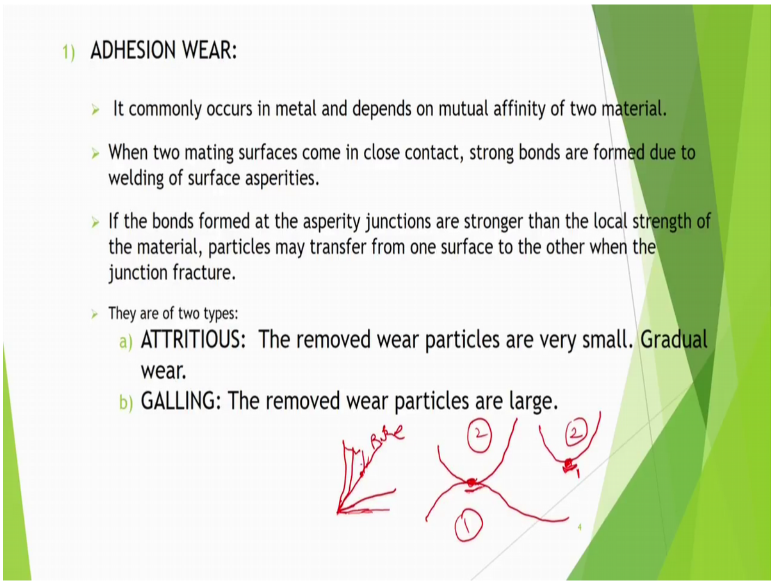

So in this case, adhesion wear is very common on the flank surface of the tool. You have flank face and rake face. Suppose I am making one tool in orthogonal cutting and it is cutting like that chip is flowing here on that; so this surface is called rake surface. As you know, rake surface is that surface on which the chip is flowing and another surface is called flank surface side, which is generally in touch with workpiece; that means, it may rub against the workpiece. So, there are 2 surfaces; this type of adhesion wear is more common in the flank face of this one.

So, when 2 mating surfaces come in close contact strong bonds are formed due to welding of surface asperities. If the bonds formed at the asperity, junctions are stronger than the local strength of the materials then particle may transfer from one surface to the other when the junction fractures. So, this one, suppose I have got this thing and if I have made a bond here, another material is this is material number 1 this may be 2 here. The bond has formed, this bond is very strong, but you applied more force because surface 2 has to move.

So, it will move, but since bond is very strong and below the bond this material is not that much strong. So, what it may do that some portion of this material it may fragment from here. And some portion of material 1 can be removed means bond will also go; so that means, you may have I am showing exaggerated, you may have this situation that this 2 component has come here, this is the bond and this surface has moved this type of material of 1 also has moved with that. So, it is really small portion of material 1.

If the there are 2 types of wear adhesion wear attritious; that means, removed wear particles are very small it is a gradual wear and in galling the removed wear particles are large.

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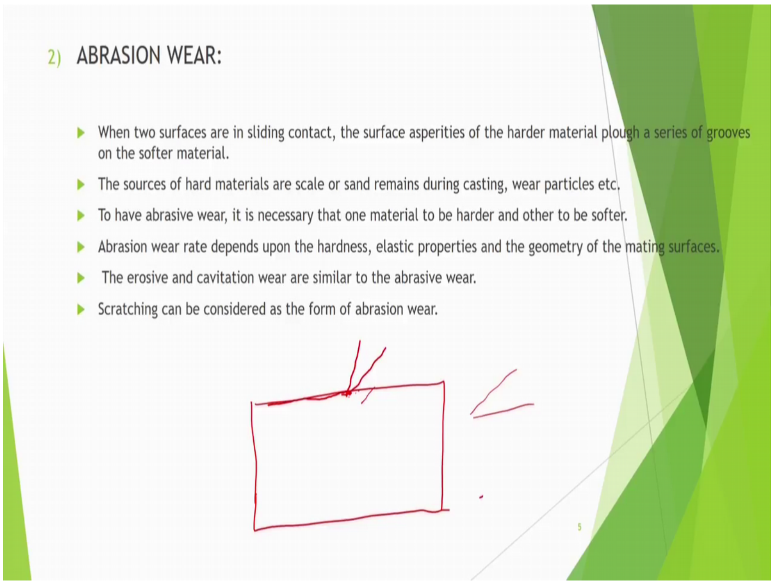

Then about abrasion, when 2 surfaces are in sliding contact the surface asperities of the harder material plough a series of grooves on the softer material. So that means, basically this is a soft material on that a hard material is moving like this and this is abrading; it is like this, like this, like this. So, this is making a groove if you see the if I make the top view you may observe this type of groove type of thing here.

So, the source of hard materials are scale or sand remaining during casting because we are concerned about tool wear. So, what I am telling that surface of the tool may get abraded. Who will do that? Why you say tool is very hard? Tool is harder than the work material, but then also the work material may have some constituents which will be very hard. For example, in a casting there may be some sent particles. These sent particles which were produced during casting they may abrade the tool and there may be wear particles also. They may also abrade to have abrasive wear, it is necessary that one material is harder than the and the other is softer.

So, what may happen, that may be very high temperature can rise it. When high temperature reaches, then the tool becomes soft, relatively soft and suppose you have this sand parties or anything or even the material is also suppose harder material and its temperature may not reduce that much. In fact, tool temperature may reduce more then that particular portion can be removed; that means, workpiece may contain some constituents which may be harder than the tool, at that particular temperature and it can remove this one.

So, abrasion wear rate depends on the hardness, elastic properties and the geometry of the mating surfaces. The erosive and cavitation wear are similar to the abrasive wear. Just like abrasion, in abrasion what we mean that suppose, it is one best example is there suppose you have butter and with the knife you are moving, you are moving the slice of that. So, you are basically ploughing, I am having this material and on that I am ploughing, I am rubbing, I am moving.

Let me make correct type of figure, here, I can let me just erase these like this. See even here I may be doing some abrasion when I am moving. So, here what may happen? I have some suppose soft material and this is a tool type of thing I am just it is abrading, it is moving. It takes some cut means it plunges little bit and it is hard and it is removing so it is removing the material like this.

So, that is called abrasion, but sometimes suppose the some water fluid is moving or some chemical is moving. So, this particle may get dissolved that is generally, we call erosive wear and cavitation wear is what? You know that, cavitation sometimes occurs. Particularly, this is very common not here, but suppose in turbines, etcetera that you have some water turbine and suppose at some location, the partial pressure becomes very low. So, that water may vaporize and again, it may condense and it can condense and it can drop with a force that phenomena is called cavitation.

So, cavitation is also similar and it erodes that you know that I can have say jet of some vapor or something. So, this cavitation is also similar to that scratching can be considered as the form of abrasion wear. Suppose, we scratch we have scratcher surface scratcher is there. So, in that there is a scratcher is there that like I am doing scratching here. So, this is also a form of abrasion wear..

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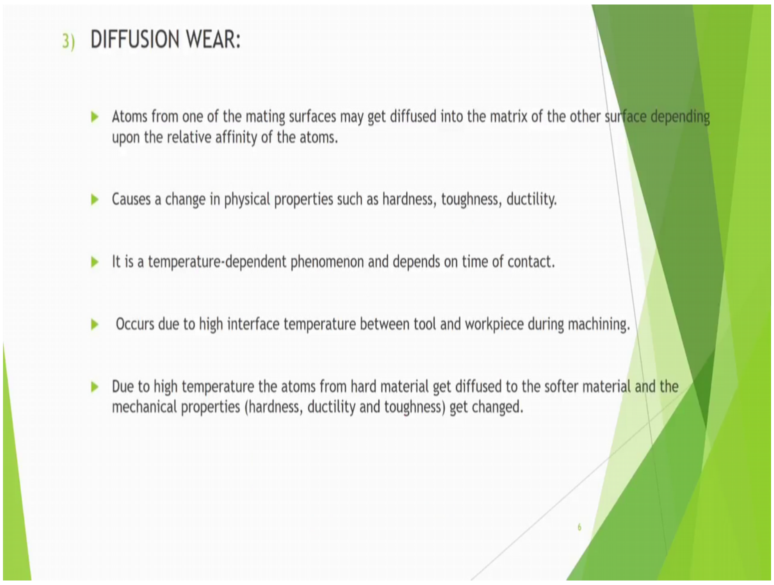

So, these wears are also they are and then diffusion wear that is more common on the rake surface not on the flank surface. Because, rake surface temperature is very high we have discussed in the previous class that, you get lot of temperate on the rake surface. At some distance away from the tool cutting edge; that means, from nose of the tool.

So, in diffusion wear atoms from one of the mating surfaces may get diffused into the matrix of the other surface. Depending on the relative affinity of the atoms, it causes change in physical properties such as hardness, toughness, ductility, diffusion is a time and temperature dependent phenomena, it depends on the time of contact more there is a contact more will be the diffusion, diffusion is a process which is dependent on the time and also it is dependent on temperature. Diffusion is basically a type of chemical process when one constituent will enter into the other because of the concentration difference.

So, it is accelerated usually by temperature at high temperature more material will diffuse. So, it occurs due to high interface temperature between tool and the workpiece during machining due to high temperature the atoms from hard material get diffused to the softer material. And the mechanical properties hardness ductility and toughness get changed.

So, they get diffused to the so what happens, that tool is suppose very hot hard, but it is hard and from there it may get diffused into the workpiece. And therefore, tool may become weak that type of thing may happen.

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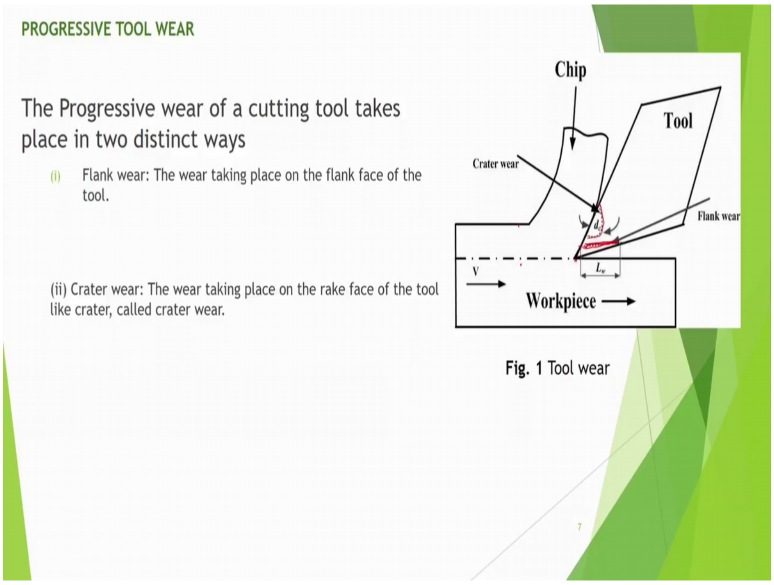

Now, so progressive tool wear what do we mean by progressive tool wear; that means, wear is increasing with time. So, I have made a schematic diagram here this is the workpiece and this is a cutting tool and this is doing cutting suppose workpiece is coming in this direction. So, material is removed in the form of the chips as you can see that the chip is rubbing against the rake surface and maximum temperature may be somewhere here on this surface in this one. So, 2 type of wears are very common one is the flank wear on the flank surface. This material some wear may take place and therefore, this is the wear and may be this much material gets removed ultimately this portion comes.

So, flank wear will affect the dimension because, as you can see that suppose this portion has come in contact and. Therefore, that what happens that instead of this much surface now this one is there. So, it is basically effectively that distance from this one has increased suppose here you are getting this type of surface, but suppose this material has been removed. So, now, the tools location is land this one. So, this nose basically has shifted from here to here because that much. So, new geometry is this because the bottom portion has worn out so; that means, effectively now earlier the depth of cut was from here to here now the depth of cut is from only here to here.

So; that means, you basically get dimension. So, dimension is stability is effected by means of flank wear and this is this much material has been removed from here to here and this portion has come in contact. Now, so this is called wear land L w is the wear land on the other hand crater wear takes place on the rake surface here you get a crater type of thing; that means, a pit type of thing like this type of pit some material. So, crater wear occurs here crater wear will not affect the dimensional stability because crater is on this surface, but dimensional accuracies effected by this one, but crater may change effective rake angle and how and it generally makes the tool very big.

Suppose this much crater, crater has been created you see that here this much material is only left. So, the tool has become very weak. So, flank wear is the wear taking place on the flank face of the tool and crater wear is the wear taking place on the rake face of the tool like crater or pit this is called crater wear.

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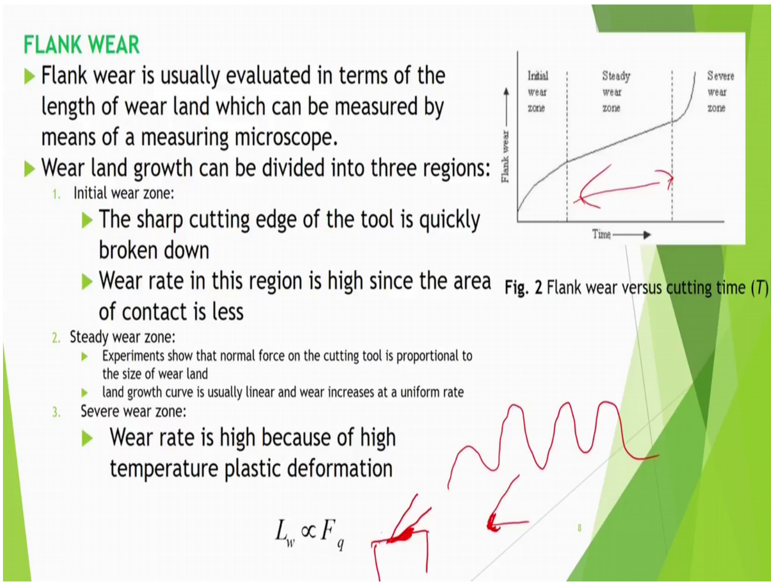

Flank wear is usually evaluated in terms of the length of the wear land which can be measured by means of a measuring microscope. We can see it on a tool makers microscope so this is flank wear land from here to here. If you say material has been removed and wear and growth can be divided into 3 regions. We can make time versus flank wear to initially the wear is very rapid. Why because on the surface there may be already some asperities which are actually very high may be 1 or 2 and in a regular way. So, what will happen that they will get warm soon, but once they have become worn then more or less you get relatively flat structure. So, now, the wear will be small. So, initially there is some (Refer Slide Time: 22:55) period in which the wear rate is very fast then there will be steady wear zone which is for a longer duration. And after some time the tool will become very weak and then there will be severe wear zone that will be very rapidly causing tool to fail.

So, initial wear zone; that means, sharp cutting edge of the tool is quickly broken down suppose tool is there it is having very sharp cutting edge. In beginning then it will produce large amount of stress also because these stress are force divided by area. So, that sharp cutting edge will experience lot of stress and it will be getting broken or fractured or it will deform here. Then what happens that remain suppose this much small portion gets. So, it automatically will become rounded type of thing and contact area will increase. So, now, further wear will reduce.

So, in the beginning sharp cutting edge of the tool is quickly broken and wear rating this region is high. Since, the area of contact is less that is the initial tool wear zone this figure is not to the scale. Actually, this region may be very small and this region can be very bigger actually middle region then we have got steady wear zone in that experiment show that normal force on the cutting tool is proportional to the size of wear land. So, it is generally proportional to the normal force and land growth curve is usually be linear and wear increases that uniform rate then we have got severe wear zone; that means, wear rate is high because of high temperature plastic deformation.

When lot of wear has taken place more wear has taken place more area is in contact. Suppose, even the tool was very nicely doing its job in the beginning and it was having something like this type of shape. Not much portion was in contact, but after some time when the material has worn then, there will be more contact just like suppose you have got suppose some tyre. It is a brand new tyre it will be having contact at point and then after that suppose tyre gets worn out then it will be more surfaces will be in coming in contact and therefore, this temperature will increase further and high temperature. You will be getting and then the wear rate will be very rapid in this case.

So, finally, that wear rate is very high and generally it is seen that the wear land is proportional to F q particularly in steady wear zone. So, F q is may be the force normal force coming on the tool

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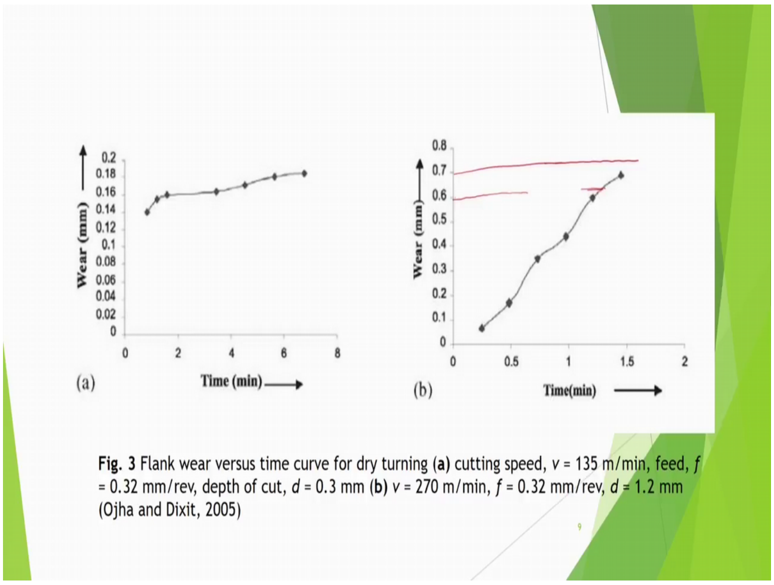

We did some experiments actually with time and wear we are measuring the wear up to now, we have taken one condition in which cutting speed was 135 meter per minute. These were called wipe tools feed was point 3 2 mm per evolution depth of cut was point three mm and we got this type of curve c we have got very small here the wear is very rapid, but then more or less. It is steady wear rate is not very high and we did only up to this, we got a wear of about less than 0.18 or something, but here the second case you have velocity cutting speed of 270 meter per minute, speed of 0.32 meter per evolution and depth of cut was 1.2.

So, more severe condition so here the wear rate was very high very rapid and you are having that here you see up to that, about I think more than 0.6 or something like 0.6 up to 0.6 or 0.7. That you just see no if you draw may be 0.6 is up to here. Only and this may be 0.7. So, between 0.6 to 0.7 somewhere that much wear has taken place and naturally the tool is considered to be fail many people take this as a criteria that this much amount of wear land as tool rate if the wear land is beyond that then naturally it has to be tool has to be changed.

So, I just showed these 2 figures to illustrate that how the cutting conditions affect the flank wear.

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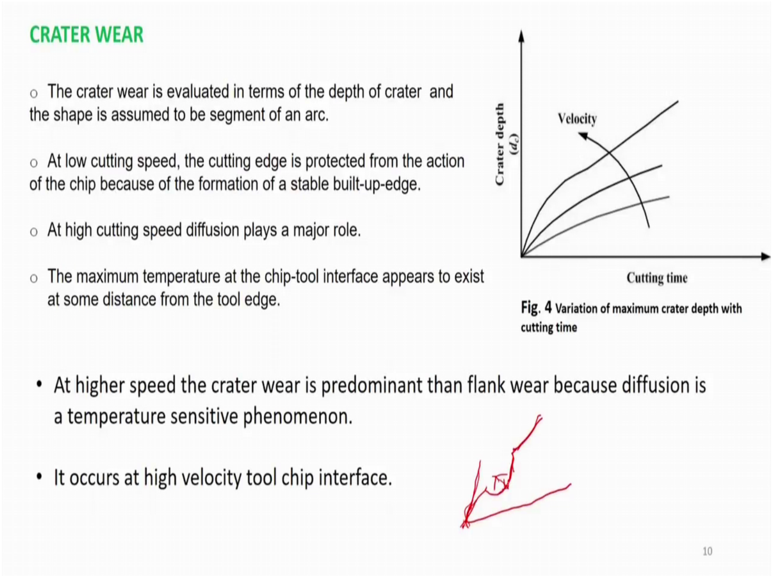

Now, what about crater wear? Carter wear is evaluated in terms of the depth of crater and the shape is assumed to be segment of an arc; that means, basically it is usually will occur on the rake surface of the tool. Suppose, this is the tool this is nose and this is rake surface and here I get crater type of thing I plot a crater this much; that means, this is we you have got a crater let me erase that upper proton yes up to this; that means, now the tool has become like this we got a we got a crater type of thing just like we get a pit in the road. Pothole type of thing we get that type of crater we will be getting and it is evaluated in terms of the depth of crater;.

That means, we say how much is the depth of the crater from here to here and the shape is assumed to be circular at low cutting speed the cutting is protected from the action of the chip because of the formation of a stable built up edge at low cutting edge speed already there is built up edge.

So, chip will slide on the top of the built up edge and there may not be contact of the chip with the rake surface. So, we do not get crater, but at high cutting speed diffusion plays a major role why because the at high cutting speed temperature also becomes high. Because, more power is there that gets in converted into heat. So, maximum temperature at the chip tool interface appears to exist at some distance from the tool edge not at the tool edge maximum temperature is not here rather it is here why it is here because already some heating was done because of the plastic work then on top of that chip is sliding and the chip is sliding. So, its temperature is again increasing. So, it may be somewhere here maximum temperature that is why maximum amount of crater wear is here.

At higher speed the crater wear is predominant than flank wear because diffusion is a temperature sensitive phenomena it occurs at high velocity tool chip interface. So, generally it will occur on this one now having talked about the flank wear and crater wear.

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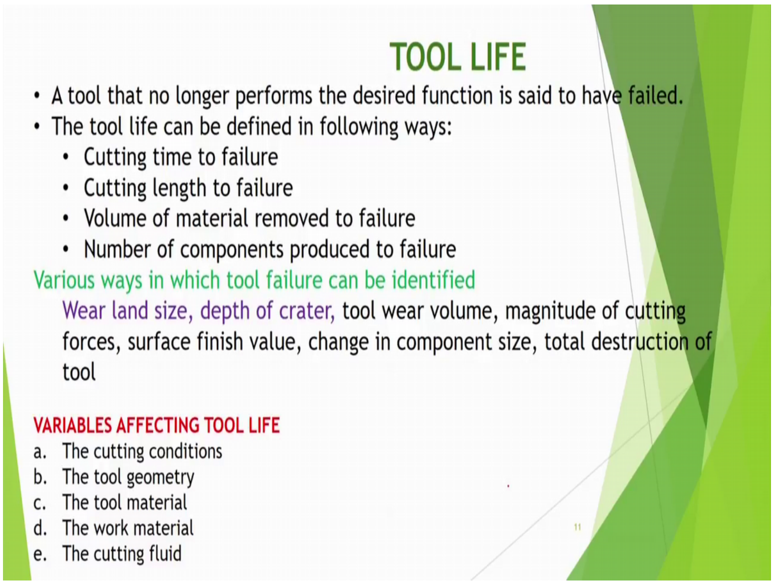

Which are the 2 common wear in which of course, as I told dimensional stability or dimensional accuracies affected by flank wear and rake angle is affected by top rake angle? By crater wear even side rake angle also will be affected by crater wear.

So, tool life we should discuss now a tool life is what a tool that no longer performs the desired function is said to have failed; that means, we say tool life failed tool life can be defined in many ways. One is cutting time to failure like after 5 minutes of machining. My tool failed then we say that tool life is 5 minutes cutting length to failure that how much meter it has moved so; that means, cutting length or volume of material removed to failure; that means, before failing. How much volume it has removed and the number of components produced to failure. We can do like that if there are similar type of components we can say this tool made about hundred components other tool made 150.

So, one tools life is 100 piece others is 150 piece, but cutting time to failure is most common tool life. Various ways in which tool failure can be identify; first we have some criteria about wear land size. Say for example, we say HSS tool is there and we say if the wear land is more than 0.4 mm. Then we will say tool has failed and we will change the tool. So, wear land size is there, depth of crater can be there, some criteria tool wear volume we can measure, magnitude of cutting forces; that means, we can also say tool life like this that if the cutting forces will increase then we will say the tool life is means is 1; when the tool life will be over the forces will increase to a large extent.

Then, surface finish value suppose we are not now getting the good surface finish. In the beginning, surface finish was good, but now the surface finish has become poor then also this one change in component size the suppose lot of flank wear is there you are doing the same type of setting, but now you see that your component is of slightly increased size; that means, some wear has taken place and total destruction of the tool sometime catastrophic failure can also be there; that means, tool can be tool can get broken variables effecting tool life are cutting conditions what is the feed depth of cut and cutting speed tool geometry is one feature then tool material and then the work material and whether we are using cutting fluid or not because cutting fluid does some lubrication so may be the tool life is improper.

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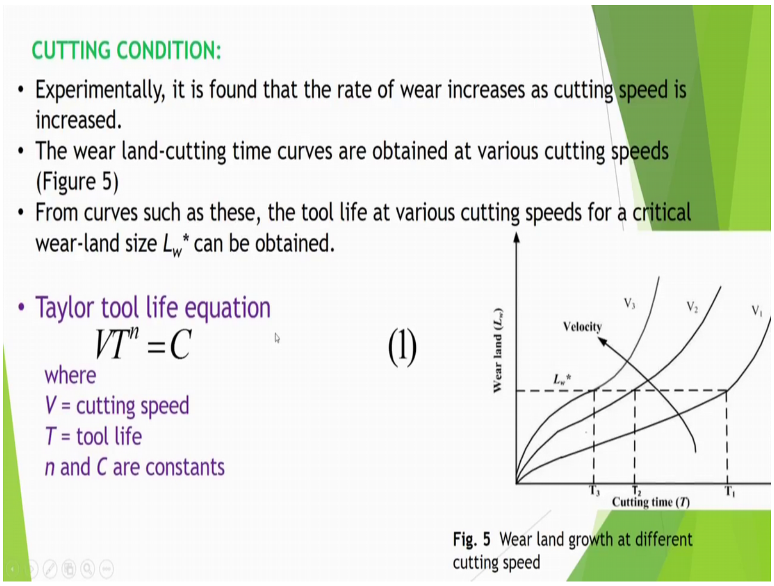

Cutting condition means experimentally it is found at the rate of wear increases as cutting speed is increased. The wear land-cutting time curves are obtained at various cutting speeds. Suppose this is the at V 1 is less cutting speed, V2 is more, V3 is the highest cutting speed in this figure. And this is the wear land and this is cutting time. So, we are seen that here at low cutting speed, first you are having some initial wear period. Then steady wear period and then high wear period rapid wear period, but this wear is nevertheless less. If the cutting speed is increasing, then the wear is increasing. And similarly if the cutting speed has increased further then wear rate has increased further and overall life has reduced.

From such curves, we obtain 2 life at various cutting speeds for a critical wear land size L w can be obtained. I may have some criteria. So, my critical wear may be L w star, when L w star wear will take place I stop my machining operation and change the tool. So, you see that L w line was cutting this curve here at this point. So, at V1 the tool life is T1, at V2 the tool life is T2 and at V3 the tool life is T3. Taylor did these type of experiments basically, in the something last decades of this one 19th century; that means, before something like 1900 and he has done lot of experiments F W Taylor. And he machined several materials and got lot of data and that he has in fact, he has tons of material I think he machined.

So, he gave and this a study he conducted for about decade and then he obtained this type of Taylor tool life equation that is V T to the power n is equal to C, where V is cutting speed, T is tool life, n and C are constants. So, V is cutting speed, T is tool life and n and C are constant which depend on the tool and workpiece combination; this is called Taylors tool life equation.

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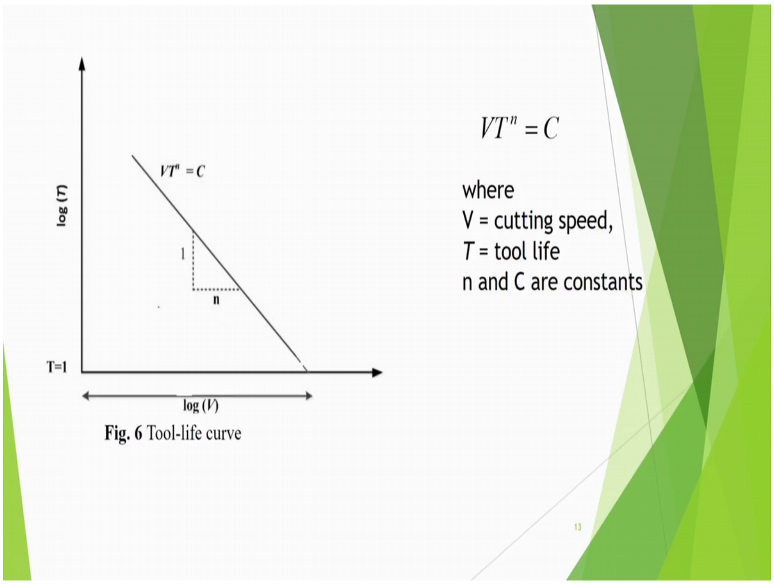

I can plot it on log plot I take plot here log v and log n, then I am getting a linear type of curve and the slope of this one is basically 1 by n; means tan theta is equal to basically minus 1 by n.

So, this we can find out if we can conduct plot of experiment we can plot this type of curve then we can find out exponents also. So, this equation one can use.

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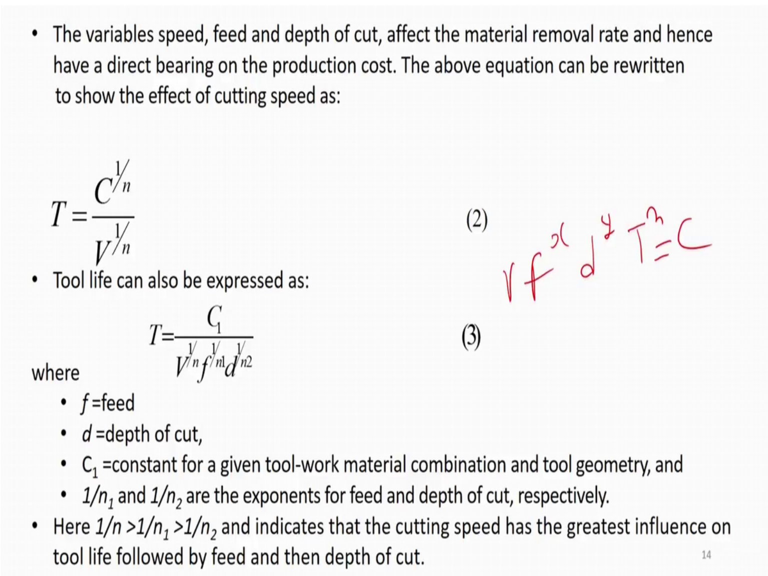

The variables speed and depth of cut affect the material removal rate and hence have direct bearing on the production cost. The above equation can be rewritten to show the effect of cutting speed as tool T is equal to C1 to the power n divided by V 1 by n. So, you can see that if n is very small then, we will have more effect much more effect on that one, but suppose n is very large then it may not have that much effect.

So, tool life can also be expressed as T is equal to C 1, V 1 by n 1 f 1 by n 1 and d1 by n 1 or sometimes we say V and may be f to the power something x and d to the power y and t to the power n is equal to constant; this type of thing, no matter in what way you express. Here, it has been expressed in this way T is equal to C 1 by this one, but or you can express in this way, but this is called Taylors extended tool life equation. It is showing the effect of f and d also. If f increase then also tool life decreases if d increases then also T2 life decreases, but effect of these speed is more; that means, in this expression 1 by n is much more than 1 by n 1 and it is much more than 1 by n 2. So, it indicates that the cutting speed has greatest influence on tool life followed by speed and then depth of cut. So, therefore, what you should do? That you should try to take as much depth as possible and then you can have more speed also, but try to have the cutting speed somewhat small.

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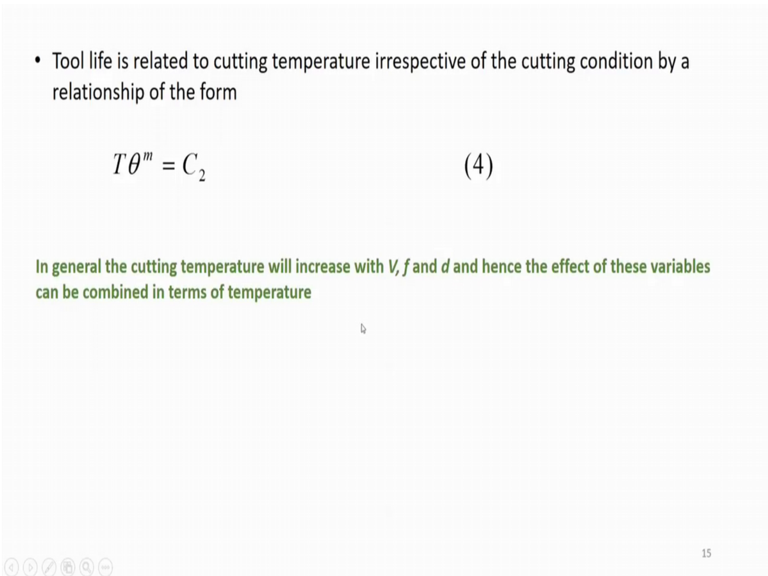

Now, tool life is related to cutting temperature irrespective of the cutting condition. Means whatever effect is there, cutting speed effect or speeds effect ultimately generates some temperature and we can also like this type of equation. That T theta m to the power m is equal to C 2. In general, the cutting temperature will increase with V, f and d and hence the effect of these variables can be combined in terms of temperature.

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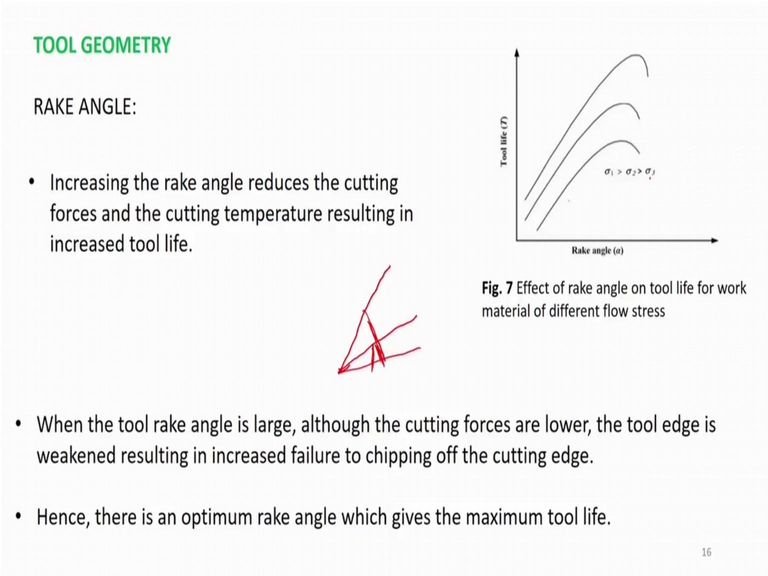

Now, let us see that what is the effect of the tool geometry rake angle, what is the effect of the rake angle? If we increase the rake angle, then the cutting force reduces and the cutting temperature also reduce because of that. So, it results in increase tool life, but when the tool rake angle is very large although the cutting forces are lower. The tool edge is weakened resulting in increased failure to chipping of the cutting edge. So, that is why that if the rake angle in the suppose, there is tool like this its rake angle is this if I increase the rake angle; that means, this surface really has come here then in that case you see the tool has become week. Earlier, this much thickness was there here now this thickness is this much only.

So, that is why tool edge will be weakened and it will result in increased failure chipping of the cutting edge. Hence, there is optimum, there is an optimum rake angle which gives the maximum tool life. So, that is why you are seen that the tool life is first increasing with rake angle and then it is starts decreasing. So, there is an optimum tool angle.

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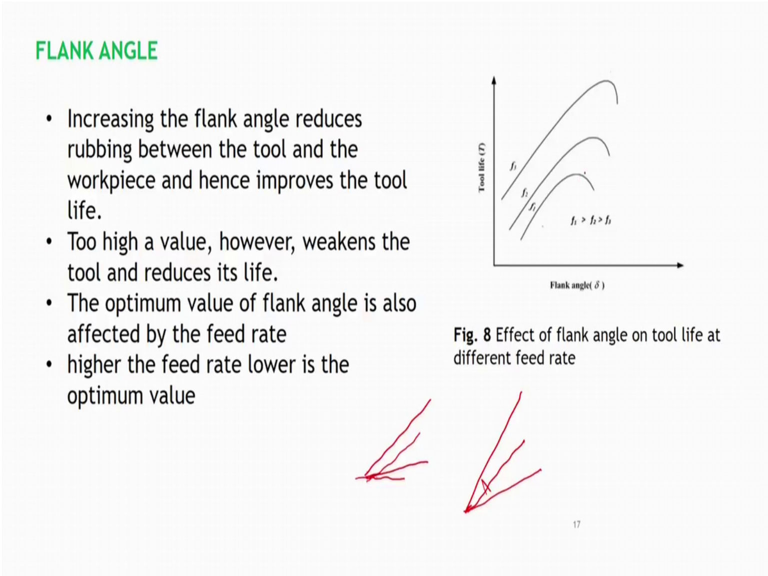

Rake angle same thing happens about flank angle or clearance angle. Here, that cutting tool is there and this is the flank surface this is the surface which is machined there is some gap between machine surface and this.

Now, if I have it very less then there will be rubbing between the workpiece and tool there may be some even if we set it to like there is a clearance here, but because of the heating there will be expansion. So, this portion will stop touching the tool here these type of. So, therefore, you have to have sufficient gap so there may be rubbing between the tool and the workpiece and hence if you increase the flank angle.

Then, it will reduce the rubbing between the tool and the workpiece and hence it will improve the tool, but life, but again if you increase the flank angle too much, again tool gets weakened. Because, suppose I am showing that suppose this is like this. Now you want to increase this one flank angle, then you may make a tool like this, but this tool is thinner.

So, optimum value of flank angle is also affected by the feed rate higher the feed rate lower is the optimum value. So, here it is this one here the optimum flank angle here is this, but if the here f 1 is more much more and this is less. So, that is what it is happening; f1, f2, f3, f 1 is the highest. So, you are having optimum flank angle is less.

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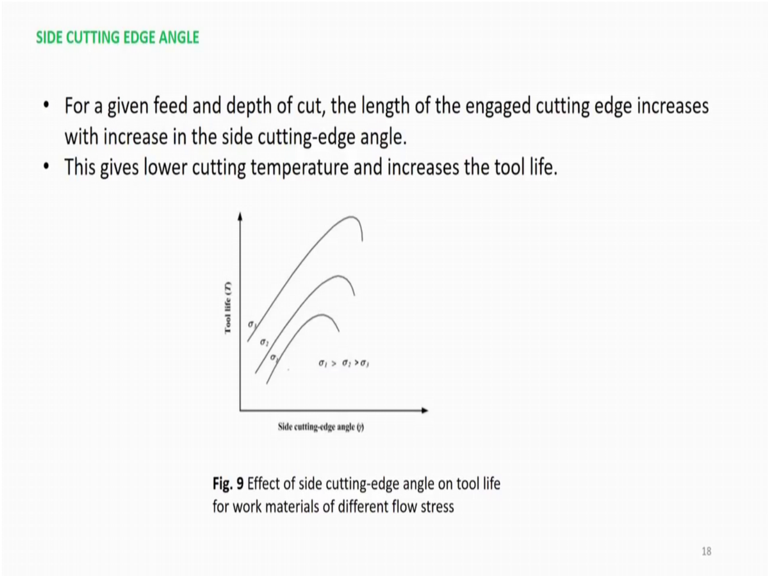

Side cutting edge angle for a given feed and depth of cut the length of the increase engaged cutting edge increases with increase in the side cutting edge angle. This gives lower cutting temperature and hence increases the tool life. So, side cutting edge is also having this type of behavior.

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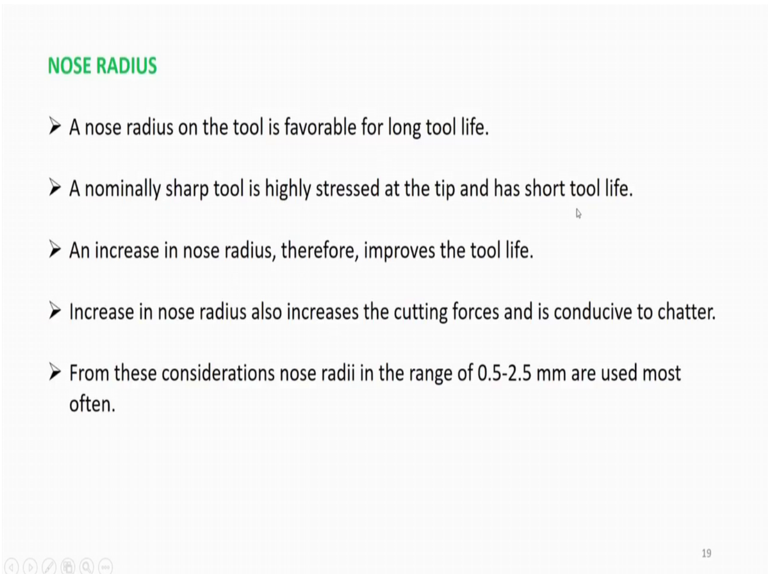

And nose radius nose radius on the tool is favorable for long tool life suppose nominally sharp tool is highly stressed at the tip and has sharp tool life increase in nose radius. Improve the tool life increase in nose radius also increases the cutting forces and is conducive to chatter. So, therefore, you have to have here also some optimum nose radius and that is generally kept between 0.5 to 2.5 mm these type of we keep.

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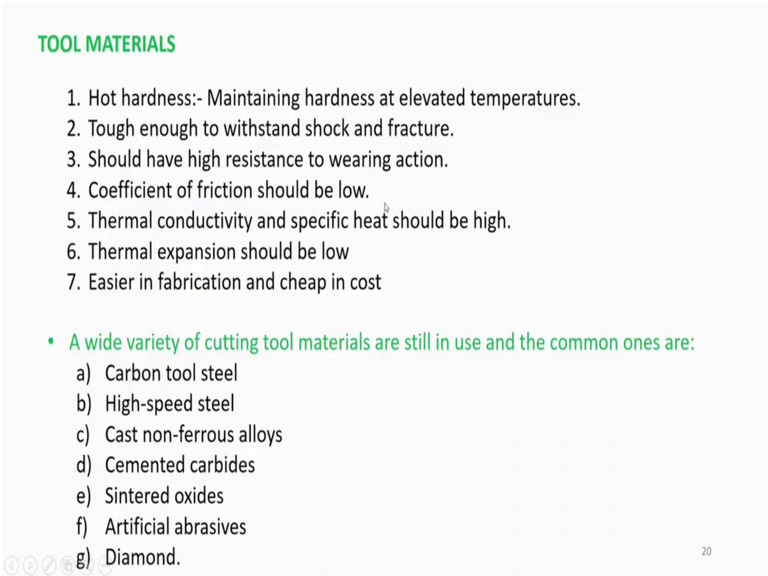

Now, what are the properties of the tool materials, very important is the hot hardness; that means, it should retain its hardness at high temperature, then it should be tough; that means, it should be able to withstand shock and fracture it should have high resistance to wearing action. It should have coefficient of friction should be low its thermal conductivity and specific heat should be high thermal expansion should be low it should be easy to fabricate and cheap in cost.

Wide variety of cutting tool materials are still use and common ones are carbon tool steel basically high carbon tool steel. Then high speed steel then cost non ferrous alloys then cemented carbide sintered oxide and artificial abrasives we can have diamond also.

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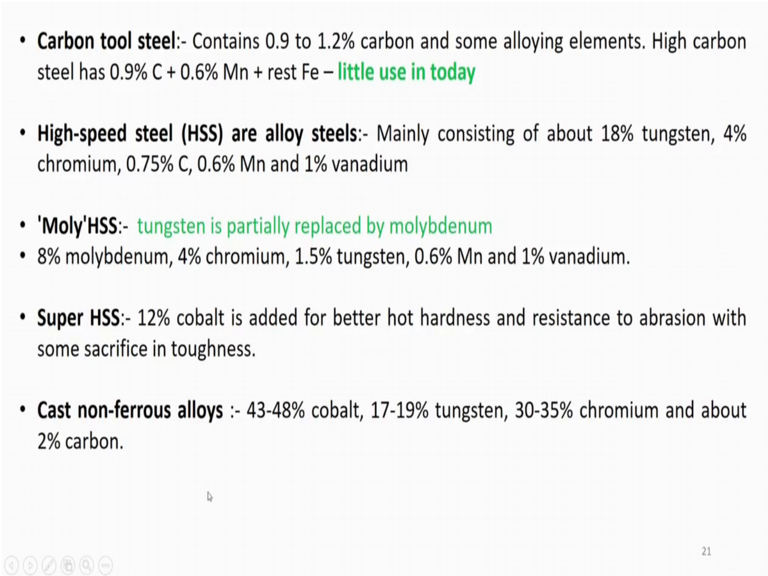

Carbon tool steels will contain generally, carbon in the range of 0.9 to 1.2 percent and some alloying element. It may have manganese and this one small amount of sulphur is also there, but not much used in industry nowadays. High speed steel usually they contain suppose 18 percent tungsten, 4 percent chromium and 1 percent vanadium. This type of steel is called 18 41 and there is some carbon and manganese also there.

Molybdenum HSS is basically tungsten is replaced by molybdenum. So, we have 8 percent molybdenum, 4 percent chromium, 1.5 percent tungsten, 0.6 percent Mn and 1 percent vanadium. Super HSS; Super High Speed steel 12 percent cobalt is added to better hot hardness and resistance to abrasion with some sacrifice and toughness. Cast non ferrous alloy can be 43 to 48 percent carbon, 17 to 19 percent tungsten, 30 to 35 percent chromium and about 2 percent carbon.

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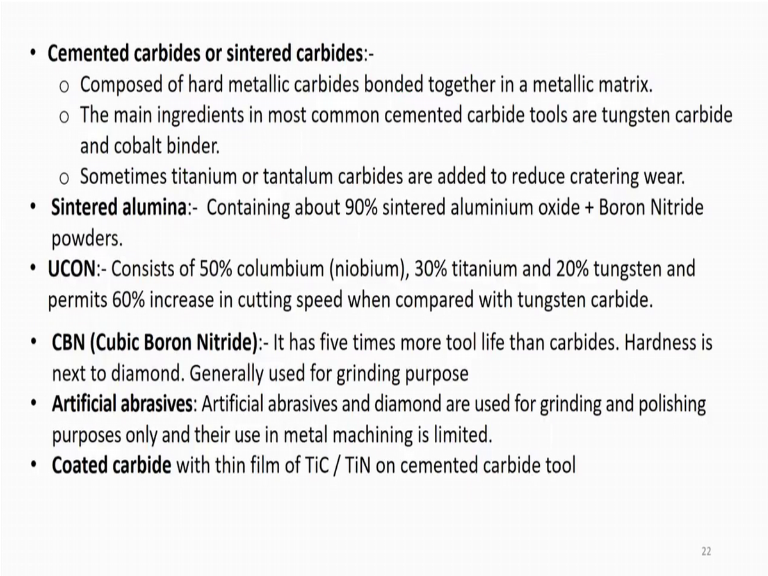

Cemented carbides or sintered carbides are very much in use they are composed of hard metallic carbides like tungsten carbides bonded together in a metallic matrix. Main ingredients in most common cemented carbide tools are tungsten carbide and cobalt binder. Sometimes titanium or tantalum carbides are added to reduce crater wear sintered alumina containing about 90 percent sintered alumina oxide plus boron nitride power union carbide developed some UCON. It consists of 50 percent columbium thirty percent titanium and twenty percent tungsten and permits 60 percent increase in cutting speed.

Cubic boron nitride expensive tool, but it has five times more tool life than carbides hardness is next to diamond. Generally, used for grinding purpose artificial abrasives and diamonds are used then coated carbide are there in which we put a thin film of tic or titanium nitride on cemented carbide tool.

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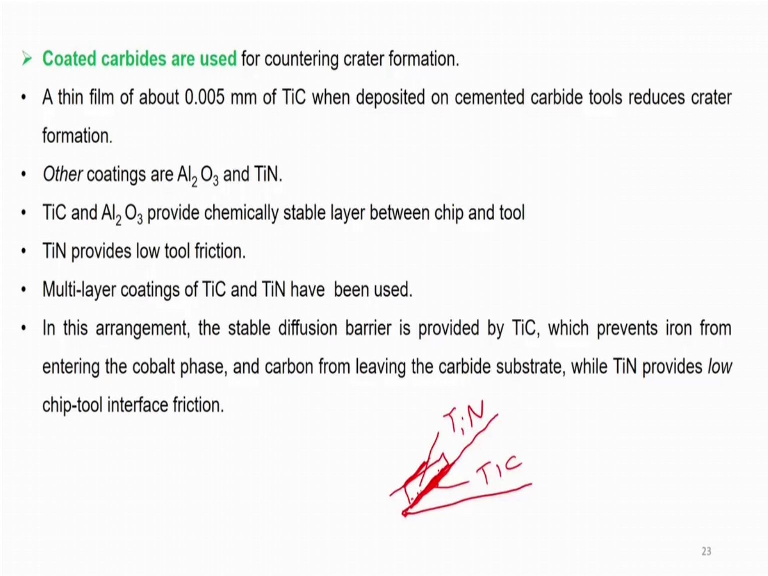

So, coated carbides are used for countering crater formation a thin film of about 0.005 mm; that means, 5 micron of tic when deposited on cemented carbide tools reduces crater formation. Other coatings are Al2O3 and tin tic and Al2O3 provide chemically stable layer between chip and tool. Tin provides low tool friction multi-layer coatings of tic and tin have been used in this arrangement the stable diffusion barrier is provided by tic and then tin provides low chip tool interface friction.

So, what happens that suppose the coating I will do like this, that here suppose this is my tool this is the rake surface. So, here first I will coat tic and on top of that I will coat this one will be this is not up to the scale, but I am just showing tin. So, tin portion will come in contact with the chip. Whereas, tic portion is in contact with this side. So, this is what this type of thing you can do and.

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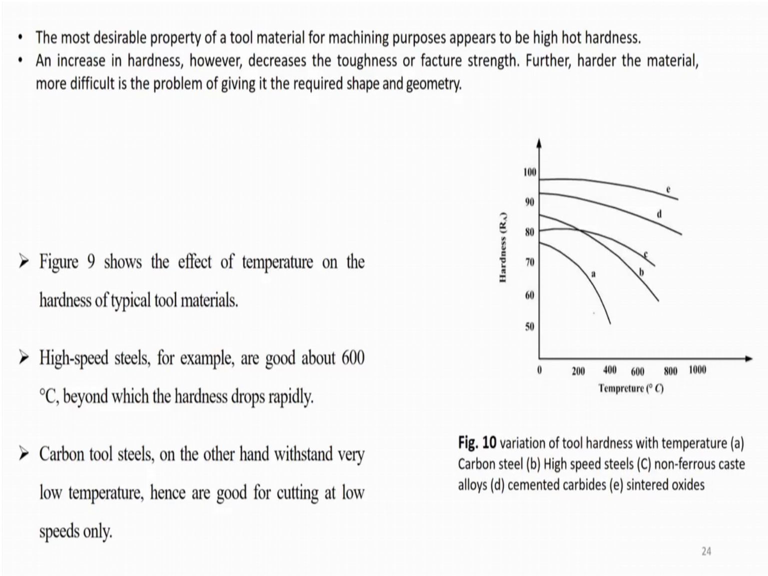

The most desirable property of a tool material for machining purpose appears to be high hot hardness.

An increase in hardness decreases the toughness and we see the graph that with temperature the hardness is decreasing. So, high speed steel or good about 600 degree centigrade up to that. So, these type of for various type of tool materials these graphs have been plotted

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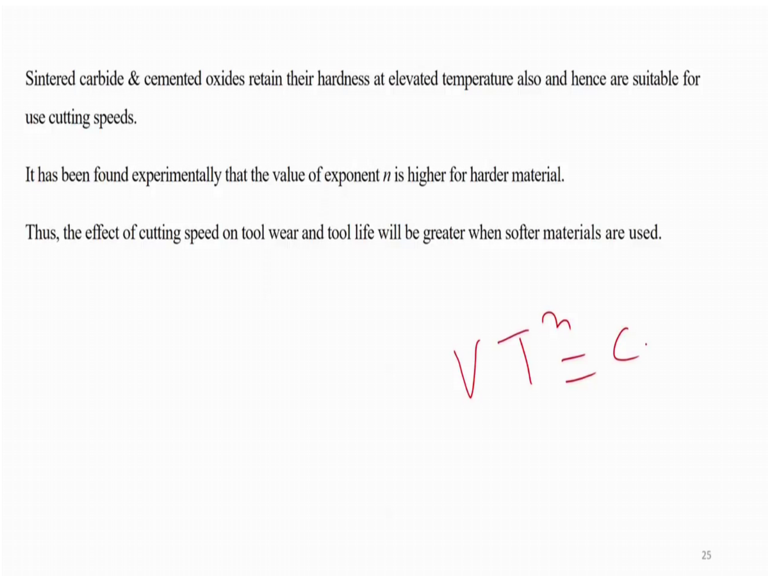

And then it has been found experimentally that the value of exponent n in Taylor's tool life equation is higher for harder tool material; that means, VT n is equal to constant and this one.

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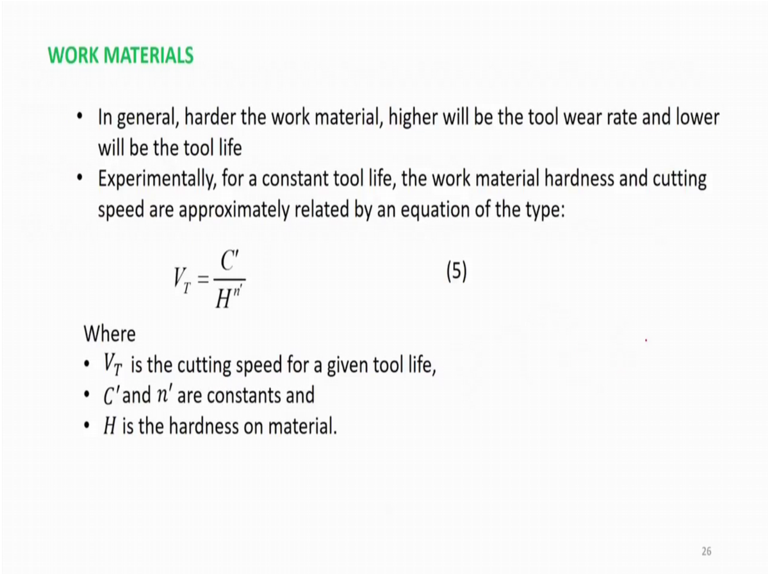

And then generally that hardness of the material also effects the tool wear; that means, corresponding cutting speed for a given tool life will reduce of the hardness is more.

So, we can have such this type of some equation approximate equation.

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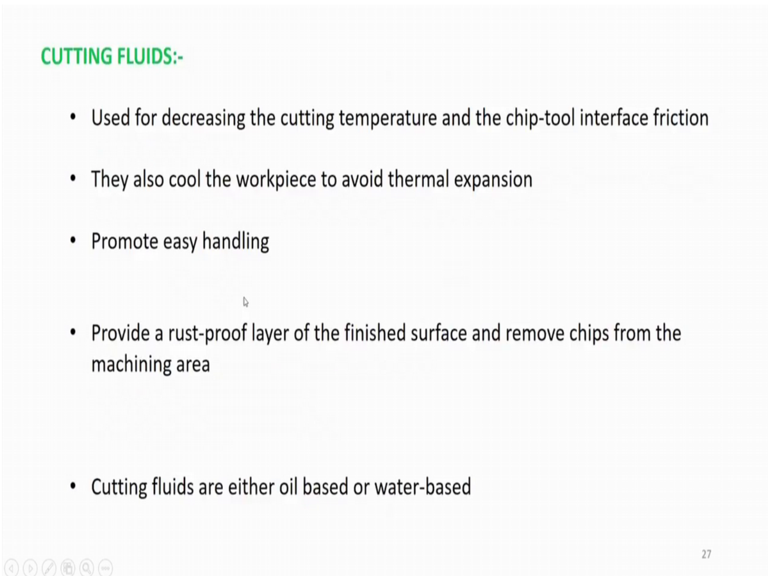

Cutting fluids are used for decreasing the cutting temperature and the chip tool interface friction. They also cool the workpiece to avoid thermal expansion and they promote easy handling they provide a rust proof layer of the finished surface. And remove chips from the machining area cutting fluids are either oil based or they are water based.

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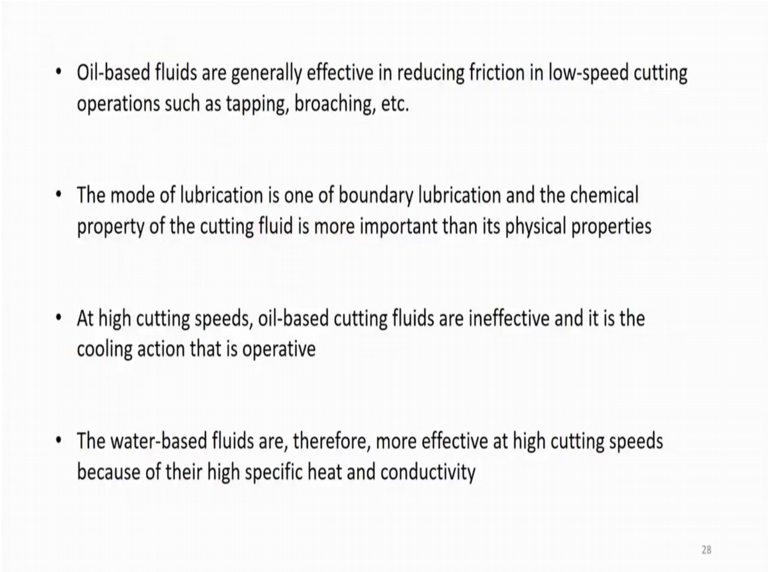

Oil based fluids are generally effective in reducing friction in low speed cutting operation such as tapping and broaching etcetera. Now, mode of lubrication is one of boundary lubrication and the chemical property of the cutting fluid is more important than physical properties at high cutting speed oil based cutting fluids are ineffective and it is the cooling action. That is operative water based fluids are therefore, no effective at high cutting speed because of their high specific heat and conductivity because they have to quickly dissipate heat.

Now, let us see that how we determine tool life equation 1 way is that you conduct large amount of experiments at different.

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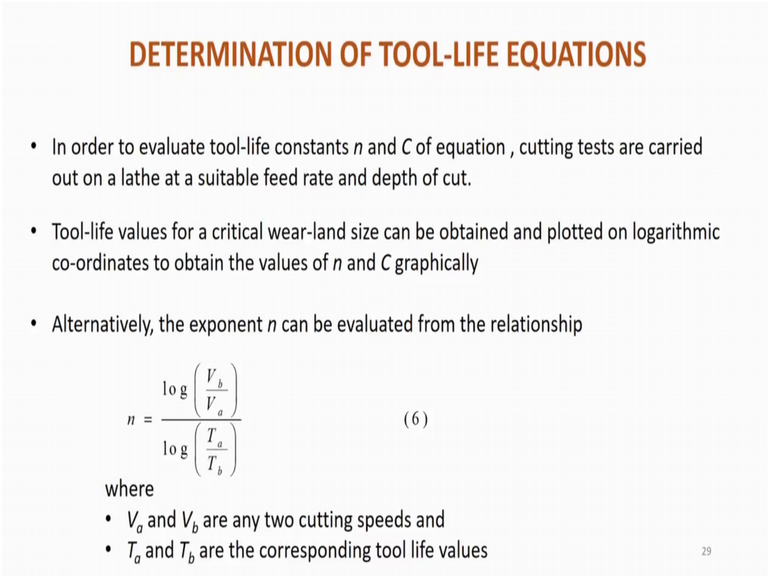

Temperature different cutting speed and then you can get you can plot, but what happens in order to evaluate tool life constants n and C of equation cutting tests are carried out, but you cannot effort to waste lot of material in conducting the test. So, some efficient ways has to be found out tool life for a critical wear land size can be obtained and plotted on logarithmic coordinate to obtain the values of n and C graphically and exponent can be evaluated. From this relationship also, n is equal to log V b by V a log T b T a by T b. Where, V a and V b are any 2 cutting speed and T a and T b are corresponding tool life values.

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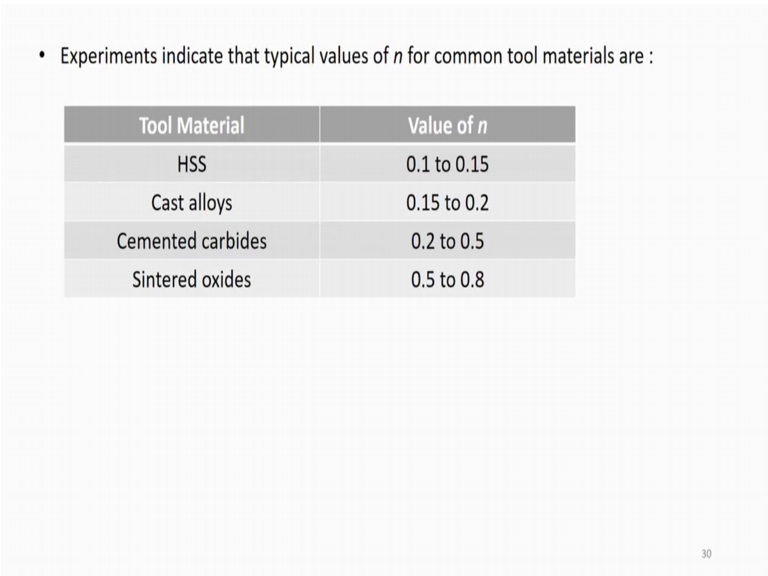

We can do that and experiments have indicated for HSS we got 0.1 to 0.15 cast alloys n was 0.15 to 0.2 cemented carbide. It was 0.2 to 0.5 sintered oxides was 0.5 to 0.8.

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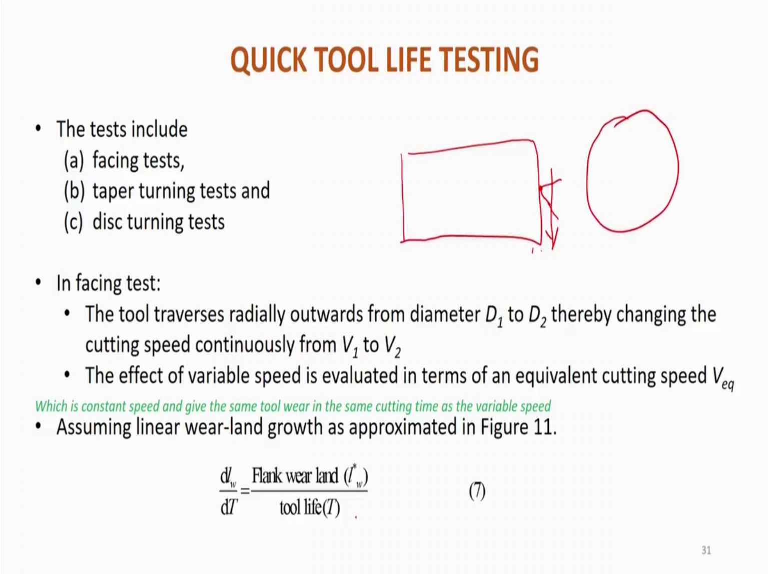

Now, quick tool estimation methods are like that one method is based by based on facing test, other is taper turning test. And the third is the disc turning test in facing test what we do tool traverses radially outward from diameter D1 to D2. There by changing the cutting speed continuously from V1 to V2. So, cutting speed is continuously changing it is not a constant speed I will put a tool here and the tool will start moving like this. So, it will do facing you know facing operation.

If I show the other view it is a circle and this face will be machined. So, effect of variable speed is evaluated in terms of equivalent cutting speed which is constant speed and give the same tool wear in the same cutting time as the variable speed you assume there is linear wear land growth because steady wear zone you have seen that wear land is proportional to time. So, we say d l w by d T is equal to flank wear land l star w by tool life this equation is there you can use.

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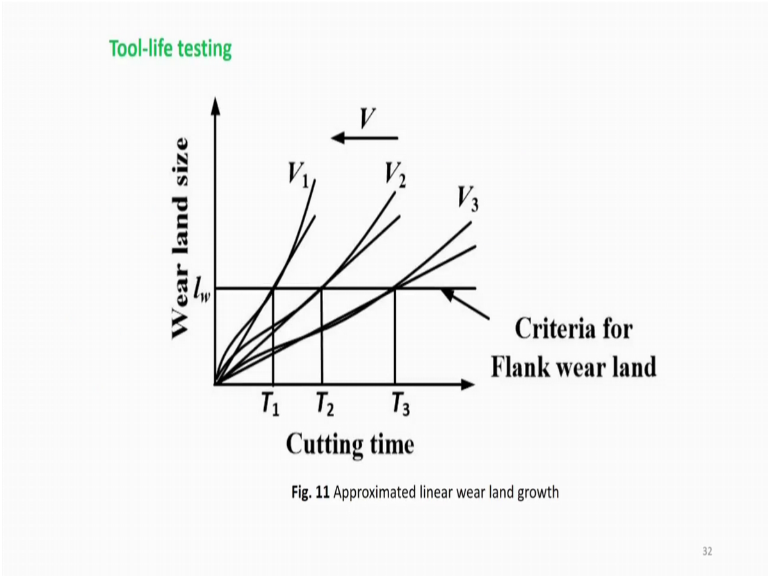

And then we have we conduct tool life testing like this wear land size l w and criteria for flank wear land and this is what you see that it is linear.

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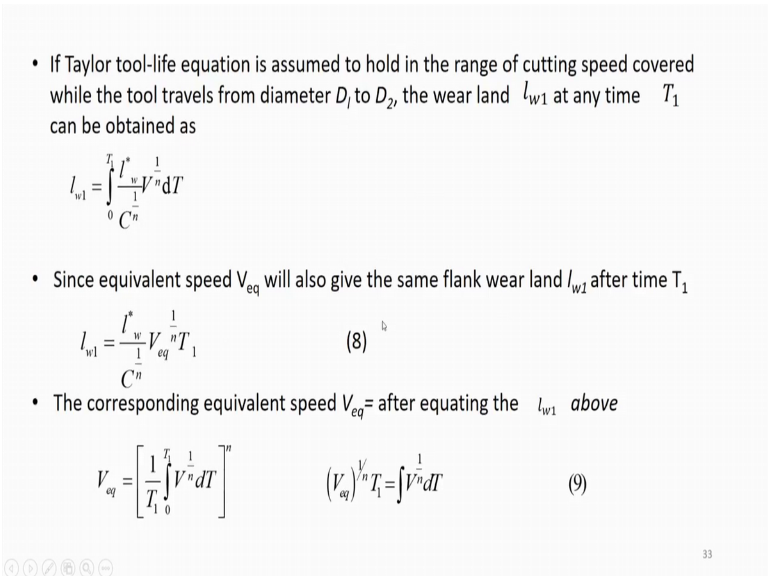

So, here if Taylor tool life equation is assumed to hold in the range of cutting speed covered while the tool travels from diameter D 1 to D 2, D 2 is more than D 1, the wear land l w 1 at any time T 1 can be obtained by this formula; l w 1 0 to T1 and we have l w C n V n dT. Since, equivalent speed V eq will also give the same flank wear land after time T1 then we get this type of relation, l w 1 is actually this. So, if we make the correspondence between these 2 we get, V equivalent is equal to 1 by T1 0 to T1 V to the power 1 by n dT to the power n and we are getting this type of relation.

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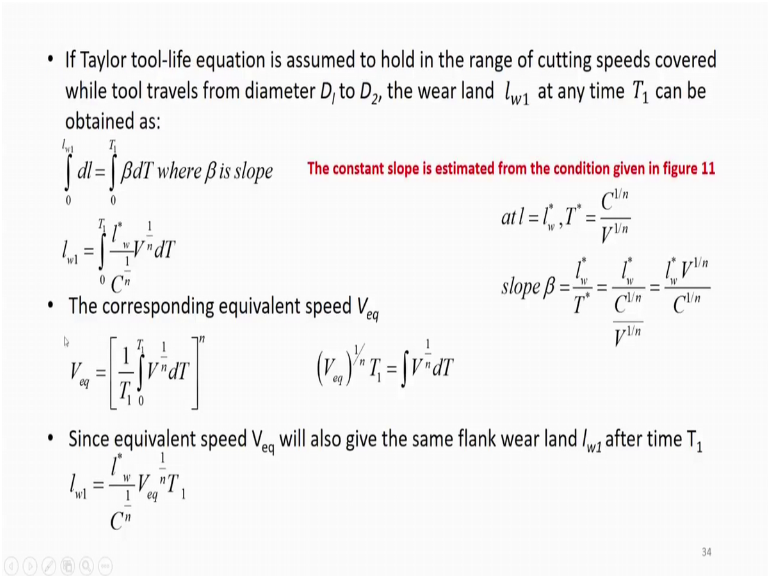

If Taylor tool life equation is assumed to hold in the range of cutting speeds covered while tool traverse from diameter D1 to D2, the wear land l w 1 at any time can be obtained like that 0 to l w 1 1 T l is equal to 0 to T1 beta dT, where, the beta is the slope and the constant slope is estimated from this. So, we get l w 1 is equal to this one and at l is equal to 2 l w star, T star is equal to this much and slope beta l star w by T star that can be written as l star w star by Taylors tool life equation VT n equal to constant. So, T star can be written like this and you get this equation. So, corresponding equivalent speed comes out to be this one. Since equivalent speed will also give the same flank wear land l w 1 after time T 1, so, we get l w 1 is equal to this much..

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- In facing tests the cutting speed varies with diameter and time as

$V = 2\pi RN = 2\pi N(fNT + R_l)$

Where
N = spindle speed,
f = feed per revolution and
T = cutting time to reach radius R

- From equations (9), the equivalent speed V_{eq} in facing from radius R_1 to R_2 in time T_1 can be obtained as

$$V_{eq} = \left[\frac{1}{T_1}\int_0^{T_1} V^{\frac{1}{n}} dT\right]^n = 2\pi N\left[\frac{1}{T_1}\int_0^{T_1} (fNT + R_1)^{1/n} dT\right]^n = \pi N\left[\frac{n}{n+1}\left(\frac{D_2^{\frac{1+n}{n}} - D_1^{\frac{1+n}{n}}}{D_2 - D_1}\right)\right]^n \quad (10)$$

$$T_1 = \frac{R_2 - R_1}{fN} = \frac{D_2 - D_1}{2fN} \quad (11)$$

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And then if you equate in facing test the cutting speed varies with diameter and time as this one V is equal to 2 pi RN; R is the radius and 2 pi N and this is fNT plus R1, f is feed per revolution and this one.

So, here equivalent speed in facing from radius R1 to R2 in time T can be obtained by putting these values and integrating then you will get equivalent speed and you get T1 is equal to this much R2 minus R1 D2 minus D1 by this one. So, you can obtain this one.

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- For a given D_1 and D_2, $V_{eq} \infty N$ and the effect of cutting speed on tool life can be obtained by varying N
- The fraction of tool life X consumed in time T_1 when tool moves from D_1 to D_2 is

$$X = \frac{1}{C^{1/n}} V_{eq}^{1/n} T_1$$

$$X = \left(\frac{\pi N}{C}\right)^{1/n}\left[\frac{n}{n+1}\left(\frac{D_2^{\frac{1+n}{n}} - D_1^{\frac{1+n}{n}}}{2fN}\right)\right] \quad (12)$$

$$l_{w1} = \frac{l_w^*}{C^{\frac{1}{n}}} V_{eq}^{\frac{1}{n}} T_1$$

$$i.e.\ \frac{l_{w1}}{l_w^*} = \frac{1}{C^{\frac{1}{n}}} V_{eq}^{\frac{1}{n}} T_1$$

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For a given D1 and D2, V equivalent is proportional to N and the effect of cutting speed on tool life can be obtained by varying N. So, fraction of tool life consumed in time T1, when tool move from D1 to D2 is X is equal to this much and X is equal to pi N by C and this one. You can substitute these values equivalent speed, l w 1 is equal to this much, this is also is given here.

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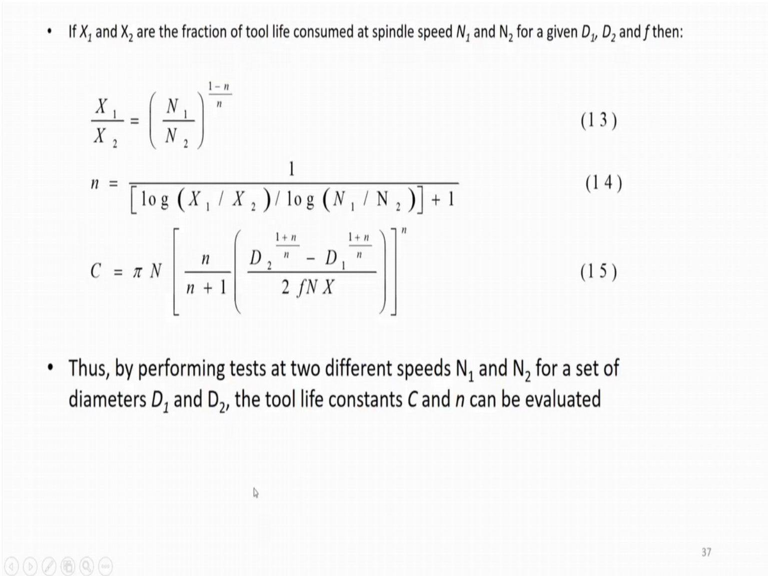

If X1 and X2 are the fractions of tool life consumed at spindle speed N1 and N2 for a given D1 D2 and f, then X1 by X2 is equal to this much.

So, if we put these things ultimately we can get n is equal to in this form and C is equal to this much. So, performing test at 2 different speeds N1 and N2 and diameter D1 and D2 we can obtain C and N.

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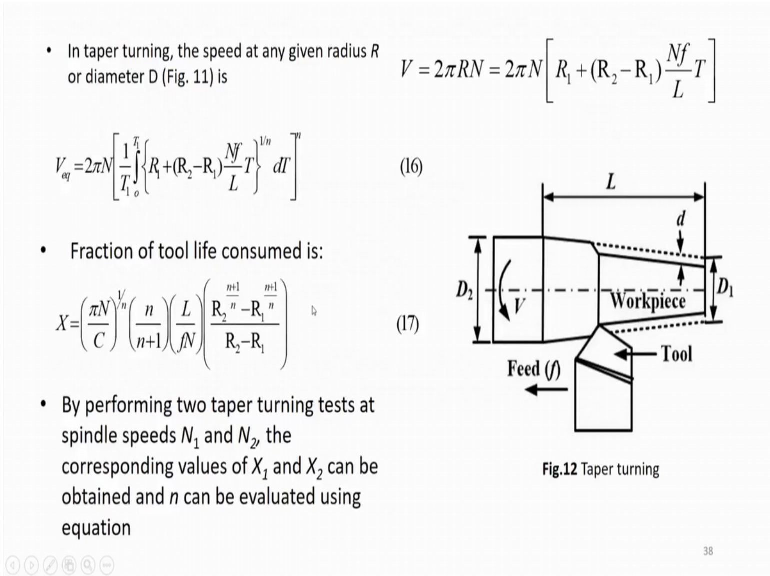

In the same way, we can do taper turning also. In taper turning the tool is experiencing the variable speed because change of diameter. In this case, the equivalent speed expression becomes this and fraction of tool life consumed comes out to be like this. There is some algebra which I am skipping here. Now by performing 2 taper turning tests at spindle speeds N1 and N2, the corresponding values of X1 X2 can be obtained and again you can obtain and N can be evaluated using that type of equation.

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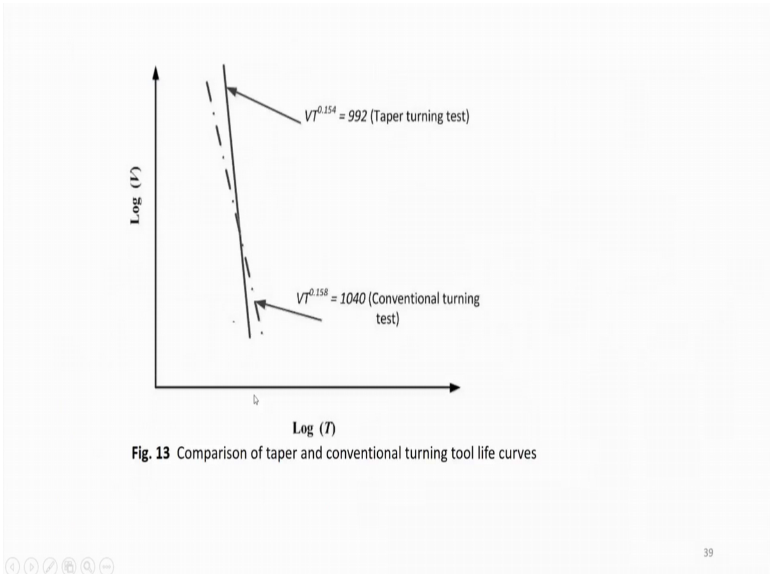

And so they have obtained that suppose, taper turning tests somebody obtained this type of curve and by conventional turning also the same type of curve similar type of thing was obtained.

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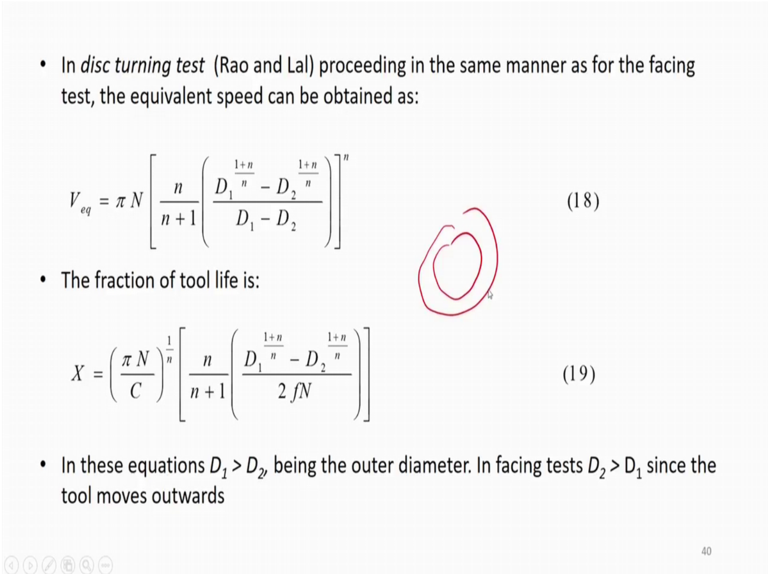

In disc turning test, it is done the same way, but here we do the machining of a disc basically. So, we get this type of expression instead of we have disc not facing it is hollow type of disc that, we are basically machining. So, we are having this type of expression and fraction of tool life is this. So, in these equations D1 is much is greater than D 2 and in facing test D2 is greater than D1. Since the tool moves outwards, but in this one we are machining the basically the disc and from D1 to D2..

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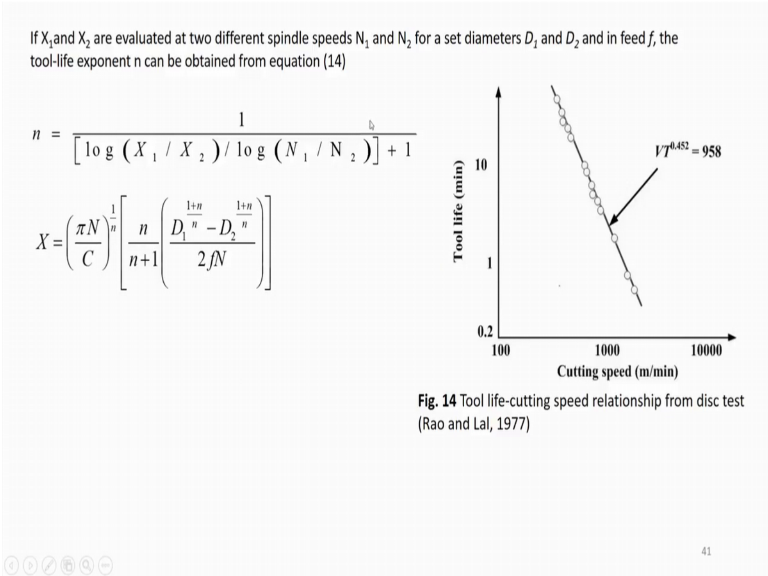

So that means, here we are doing turning disc is getting turned and then we can it can be obtained that here we get similar type of expression and we can also get this one.

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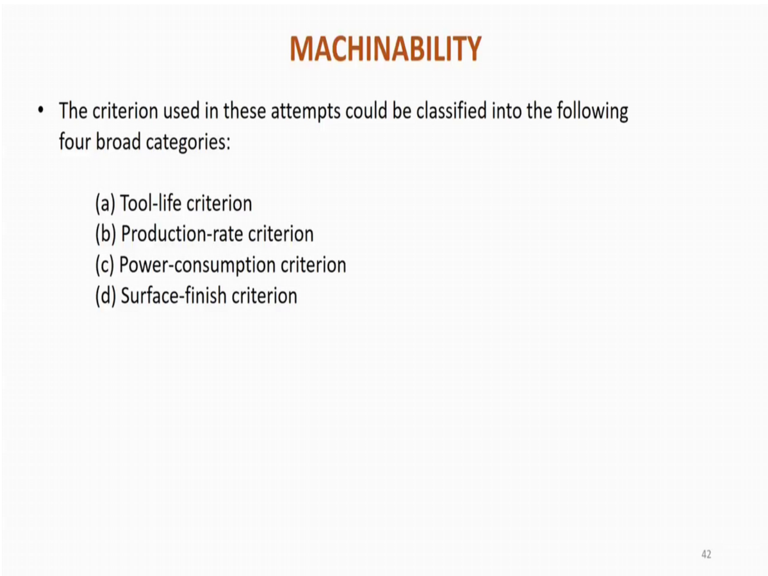

Now, last point is that machinability. What do we call machinability? Criteria used in these attempts could be classified into the following 4 broad categories. Tool life criterion based on the tool life suppose tool life in machining a material is better then we can say the machinability of that material is better. Production rate criteria; if the production rate is high machinability is good, power consumption criterion; if power consumption is less, then machinability is good. Surface finish criterion, if the surface finish is good we say machinability is good.

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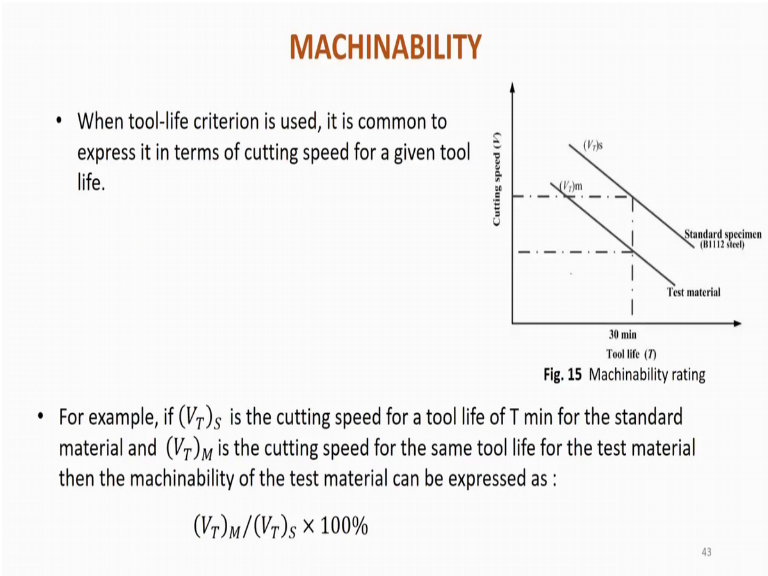

So, when tool life criterion is used it is common to express it in terms of cutting speed for a given tool life. We can have some reference. For example, if V T S is the cutting speed for a tool life of T minute for this standard material and V TM is the cutting speed for the same tool life for the test material then the machinability of the test material can be expressed as V T M by V T S into 100 percent. Suppose, the machine cutting is speed while machining material is same as the standard material, machinability is 100 percent. If the cutting speed much more, then the machinability is more than 100. So, like that otherwise it may be less than 100 percent.

So, these things are there. he expressions for variable tool life machining variable tool speed for finding out the cutting tool life ok, you can easily nicely do because there was lot of mathematics may be you might have faced some difficulty because, I have not derived very slowly, but this you if you see this book you can easily understand these expressions. In the book of GK Raman you can just do simple arithmetic and you can get to do that. So, I have told you today about the tool wear in which I have told that crater wear and flank wear is important and tool life also we discussed about tool life. Usually Taylor’s tool life is very an imperial way to estimate the tool life and then I talk about then machinability of material.

Suppose, you can cut the brass very easily then it is called brass is a has got a good machinability. If you cannot cut some material very easily, it has got poor machinability. And machinability is can be accessed means cutting easily means the force should become should be less, surface finish should be good and tool wear should be less. So, any of these criteria or a combination of so, many criteria can be used and then you can define machinability. In fact, definition of machinability may vary from context to context and person to person. It is basically a subjective measure and this one. So, in the next class we will discuss some more interesting things.

Thank you.