Machining Science - Part I
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Lecture – 14

Hello and welcome to the 14th lecture of Machining Science course. We were discussing the tool wear and tool life. We have seen that Taylor's tool life equation, which is one of the very basic tool life equations, that relates the tool life with the parameter like cutting velocity. And then we said that the Taylor's extended tool life equation relates the tool life not only to the cutting velocity, but also to the feed and the depth of cut.

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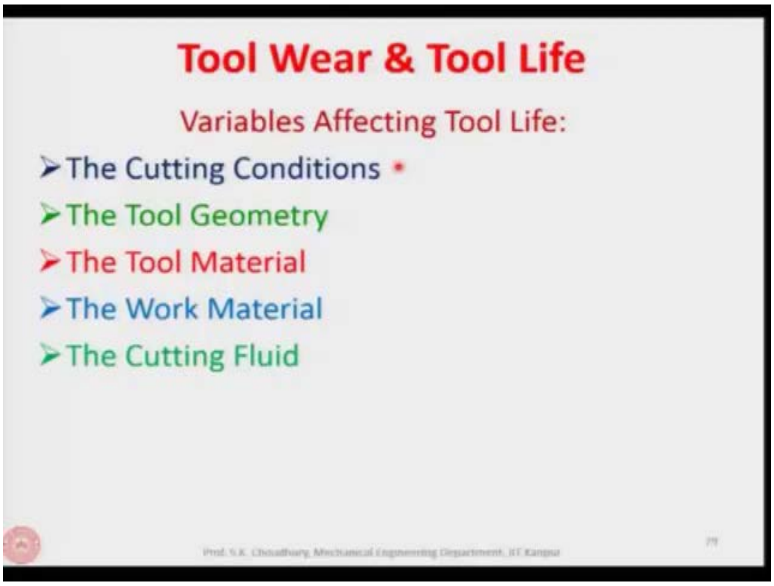

We also said that on the tool life, maximum effect will be of the cutting velocity followed by the feed and then by the depth of cut, because we have seen that experimentally the powers of the velocity is more than the power $\frac{1}{n}$, which is more than $\frac{1}{n_1}$ and which is more than $\frac{1}{n_2}$. This is how we have said in the last lecture.

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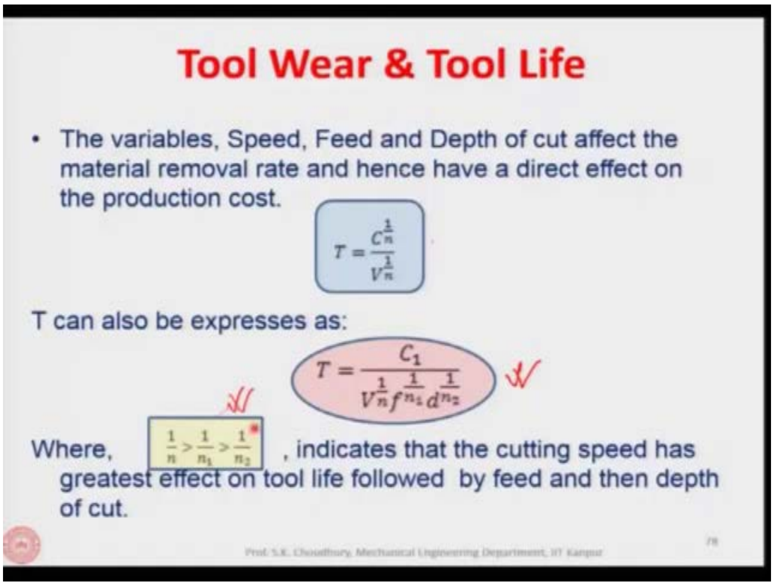

Now, let us see the factors of the variables affecting the tool life. These are the 5 factors which are the cutting conditions, tool geometry, tool material, work material and the cutting fluid. They affect the tool life. And how they affect the tool life we will discuss it right now.

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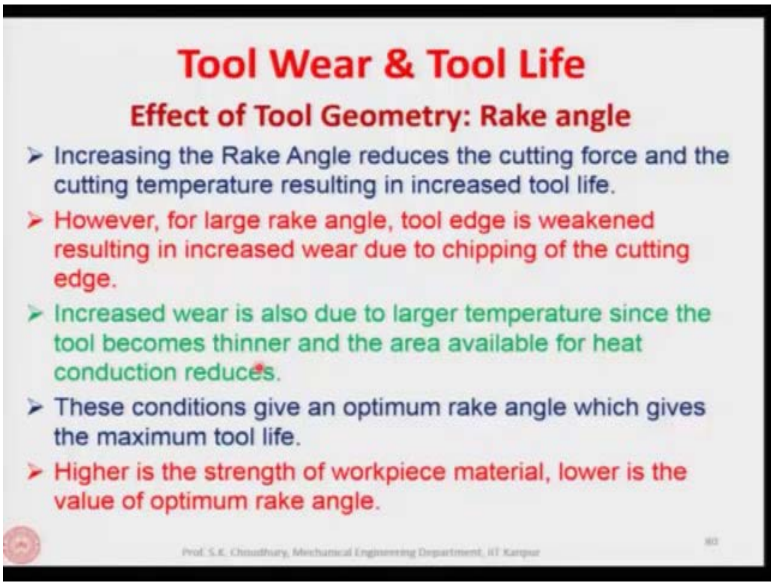

Effect of tool geometry: let us say rake angle. We know that increasing the rake angle reduces the cutting force and the cutting temperature, resulting in the increased tool life. This we have discussed while discussing the selection of the rake angles. So, increasing the rake angle will reduce the force, it will reduce the cutting temperature and the tool life will be increased and the vice versa. However, for large rake angle, the edge is weakened resulting in the increased wear due to chipping of the cutting edge and the tool life decreases. So, there is an optimum value of the rake angle at which the tool life will be maximum.

Increased wear is also due to larger temperature since the tool becomes thinner and the area available for heat conduction or the material available for the heat conduction will be less. This also we have discussed earlier. These conditions give an optimum rake angle which gives the maximum tool life as I said. Higher is the strength of work piece material, lower is the value of optimum rake angle. If the strength of the work piece material is higher in that case the force required will be more and then it will reduce the tool life.

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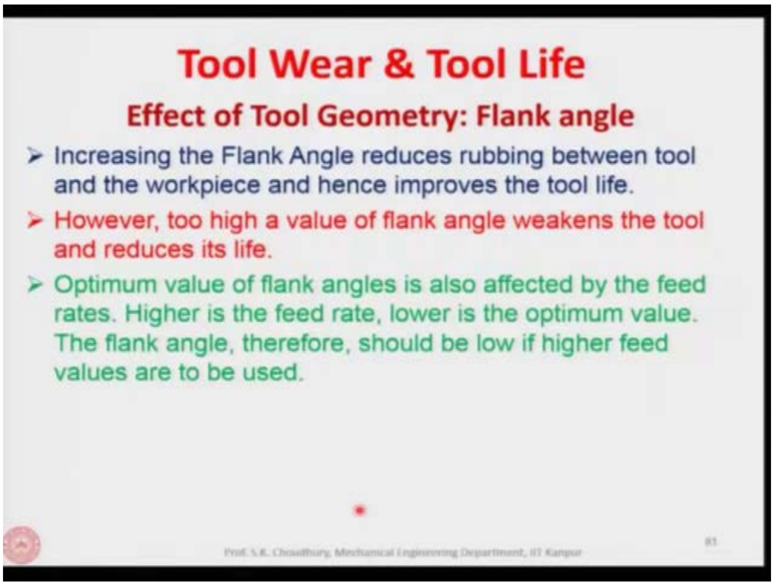

Now, the flank angle: increasing the flank angle reduces rubbing between the tool and the work piece and hence it improves the tool life. So, with increase in the flank angle, as we have discussed earlier also, the cutting angle reduces and the tool again weakens that reduces the tool life. Optimum value of flank angles is also affected by the feed rates. Higher is the feed rate, lower is the optimum value of the flank angle. The flank angle should be low if higher feed values are used. These are the recommendations which are theoretically as well as experimentally obtained.

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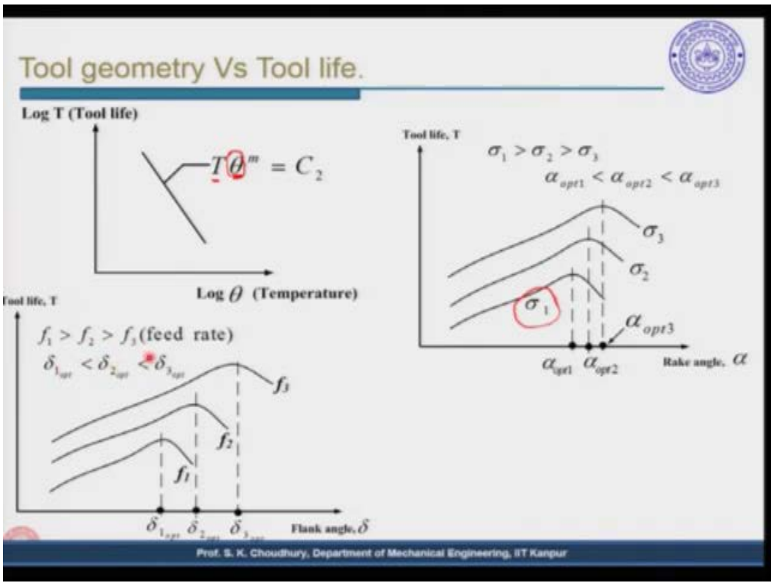

For example, here these are the curves which are similar to the tool life and the cutting velocity curves we have seen earlier. So, what is shown here is that since on the tool life we have the effect of cutting velocity, feed and depth of cut, together they will actually increase the cutting temperature. So, here what is shown is that the relationship of the cutting temperature θ on the tool life which is a combined effect of the cutting speed, feed and the depth of cut because in terms of temperature all these three will enhance the temperature if they are increased.

Now, it is shown that as we are increasing the rake angle, initially the tool life is increasing, but then afterwards it decreases because the tool gets weakened and if we say that this is the harder material than this, then this is a strength of material and in that case the optimum value of the rake angle will be lower. Earlier we have concluded that optimum value of flank angle is also affected by the feed rates. And here we have said that higher is the strength of work material lower is the value of the optimum rake angle. So, this is what is shown here.

Now, here it is the flank angle. So, as we are increasing the flank angle, initially the tool life is increasing because the rubbing is less, but afterwards the tool again weakens and the tool life decreases. And as the feed is increased, let us say this is the maximum feed this is lower than f_1 this lower than f_3. So, with that the optimum flank angle that we will be getting should be less. So, if f_1 is more than f_2, more than f_3, then the optimum value of the flank angle will be less. δ_1 will be less, than δ_2, than δ_3.

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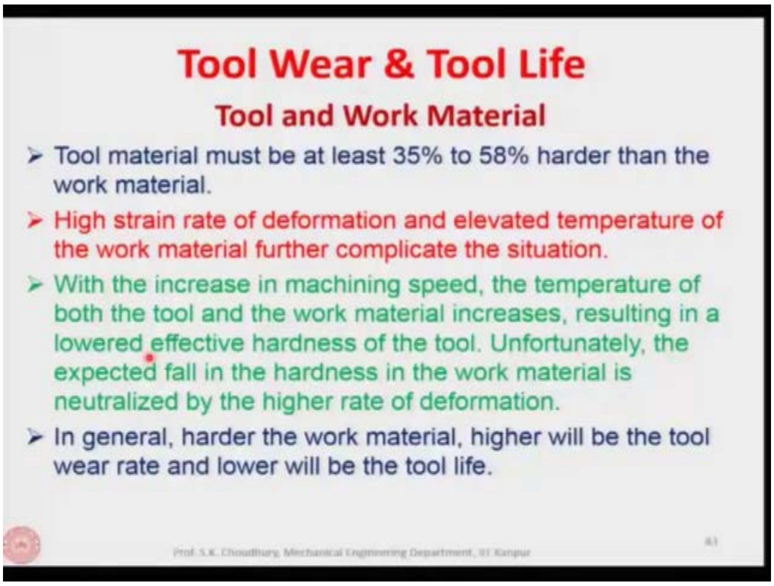

Now, on the tool and the work material the phenomena is very interesting, in the sense that tool work material must be at least 35 to 58 % harder than the work material. This has been established by the experiments.

And the high strain rate of deformation and the elevated temperature of the work material complicate the situation. In a way that, with the increase in machining speed the temperature of both the tool and the work material increases. Machining zone temperature is increasing as the machining progresses, as the cutting velocity increases. This increases the temperature of the tool and work material resulting in a lower effective hardness of the tool.

Unfortunately, the expected fall in the hardness in the work material is neutralized or compensated by the higher rate of deformation. You understand that higher rate of deformation means, high resistance to the deformation - that is high strength.

So, what is happening is that more the temperature, more the plastic deformation being imparted to the work piece, more will be the resistance. So, as if the apparent strength of the work piece is increasing. At a higher temperature the tool and the work piece material both are getting the same temperature, but the tool is thermally getting softened, because the thermal softening of the work piece does not happen, because of the strain hardening, because more plastic deformation is imparted to the work piece, work piece is having the reaction in terms of increased strength. So, the tool wears out more and 30% to 58 % more hardness is required for the tool material than the work piece material.

In general, harder the work material higher will be the tool wear rate and lower will be the tool life. This is understood, this I already said to you earlier.

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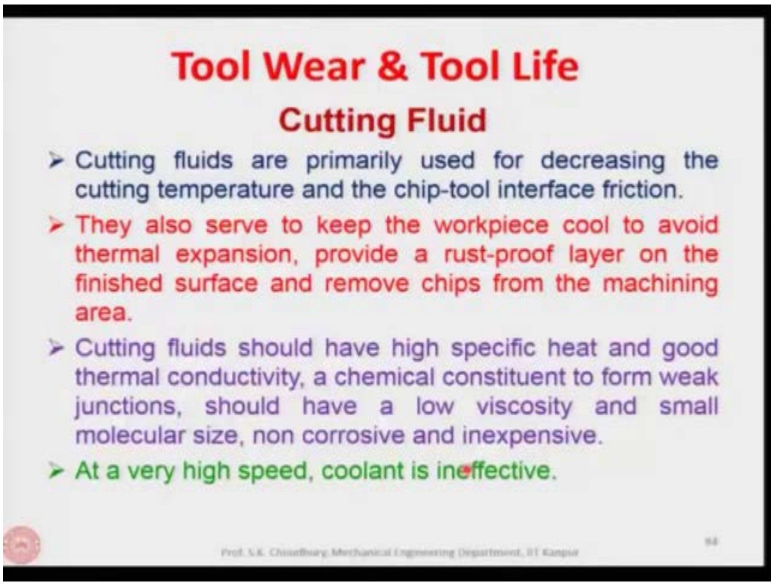

Now, let us see the effect of the cutting fluid. Cutting fluids are primarily used for decreasing the cutting temperature and the chip tool interface friction.

So, there are two functions of the of the cutting fluid: to decrease the temperature and to decrease the friction between the chip and the rake face of the tool. They also serve to keep the work piece cool to avoid thermal expansion, provide a rust proof layer on the finished surface and remove chips from the machining area.

Cutting fluid should have high specific heat and good thermal conductivity this is also understood, so that it actually takes out the heat from the machining zone. A chemical constituent to form weak junctions, so that built-up edge does not happen, since built-up edge happens because of the nascent surfaces. If the nascent surfaces are covered with a layer, they cannot get welded and there is no built-up edge formation. So, this is the mechanism. It should have a low viscosity because it has to penetrate, if it is very thick, very high viscosity in that case it cannot penetrate the machining zone and should have small molecular size, so that it can penetrate easily, should be non-corrosive and inexpensive.

At a very high speed, coolant is inefficient, because it cannot get enough time to reach the machining zone and also it cannot get into the machining zone because of that wedge which is formed by the tool and the work piece and the chip. At that wedge when the cutting fluid is passed at a high speed, it actually creates a hydrodynamic force and because of the hydrodynamic force it actually forces back the cutting fluid from the zone and it does not permit the cutting fluid to reach. So, these are the two reasons basically because of which at higher speed the cutting fluid is not very effective.

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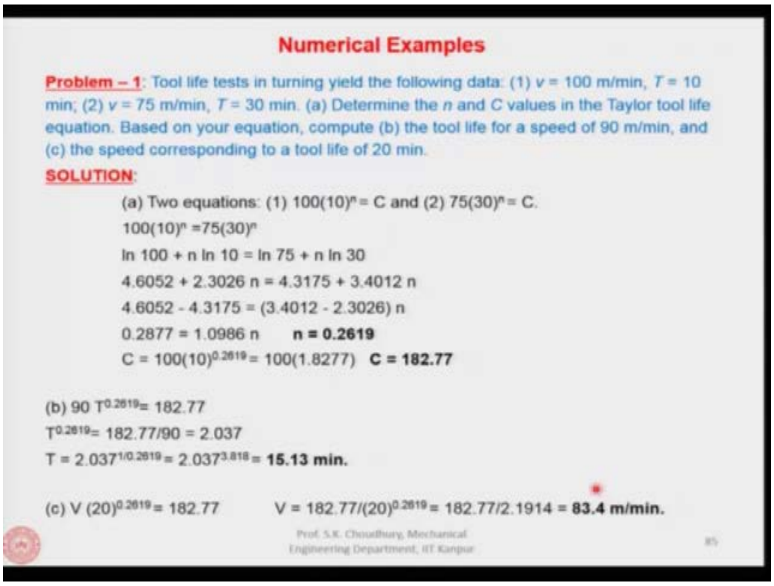

Let me give you some numerical examples. These are self-explanatory. Now, this is the practical implementation of whatever we have learned. For example, tool life test in turning yields the following data. At this speed the tool life is given, at another speed the tool life is given; you have to determine the *n* and *C* values of the Taylor's tool life equation. Based on your equation, compute the tool life or a speed of 90 m/min and the speed corresponding to a tool life of 20 minute.

So, you can see that you can get two equations, Taylor's tool life equation, $VT^n = C$, V given and T given. So, *n* and *C* from these two equations you can find out. Now, you solve these two equations simultaneously, you find out the values of *n* and *C* which are constants.

Once you found out the values of *n* and *C* then for *V* = 90 m/min you can find out *T* which is unknown. You found out *C* and *n*. So, from here you can find out what is the value of *T*.

Similarly, you can find out the *V*, if the *T* is given as 20 min. So, tool life is given, you have to find out the speed similar to that you can find out the *V* is 83.4 m/min.

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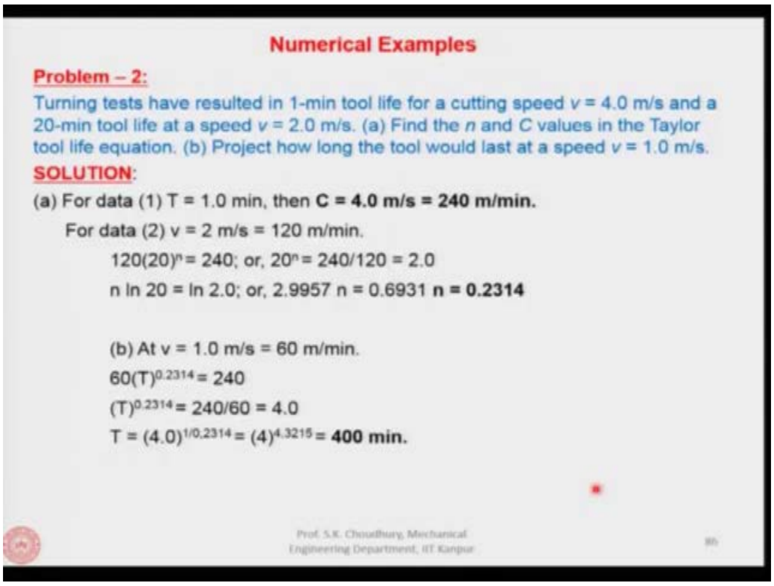

Second example is: the turning test have resulted in 1 minute of tool life for a cutting speed of 4 m/s and 20 minutes tool life at a speed of 2 m/s. Find the *n* and *C* values. It is like in the previous case, for data 1, we have the tool life *T* and then the *C* is this. For data $V = 2m/s = 120m/\min$, you find out the value of the *n* knowing *C*.

So, at *V* =1m/s which is 60 m/min because in the $VT^n = C$, *V* velocity is given in m/min and tool life is given in minute. So, here you put this value *V* here is 60 m/min, *T* is unknown while *n* and *C* are known. Find out what is the value of the *T*. So, this is easy once you know the formula and formula is very simple $VT^n = C$, where, C is constant.

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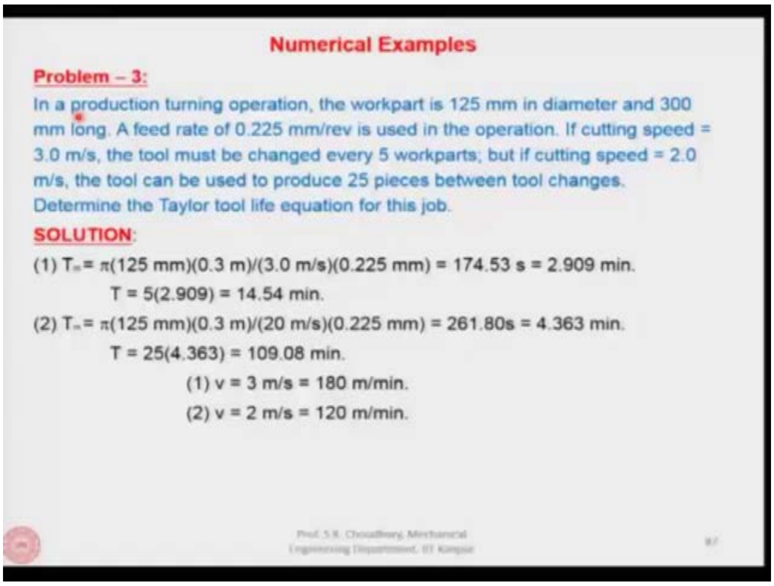

Third example is a very similar one. In a production turning operation the work part of 125 mm in diameter and 300 mm long, a feed rate of this is used in the operation. If cutting speed is 3 m/s, the tool must be changed every 5 work parts. But if cutting speed is 2 m/s, the tool can be used to produce 25 pieces between the tool changes. Determine the Taylor's tool life equation.

So, you have to find out the T_m here, you are converting that into the minute, find out and then for the second case you also find out the *T*. Now, the *V* is given, converted to m/min because as I said, *V* has to be in m/min. And then you put it in the Taylor's tool life equation with the *V* and *T* known. Then with these two equations, with *n* and *C* unknown, you can always find out the two unknown values by solving the equation in the way it is shown here.

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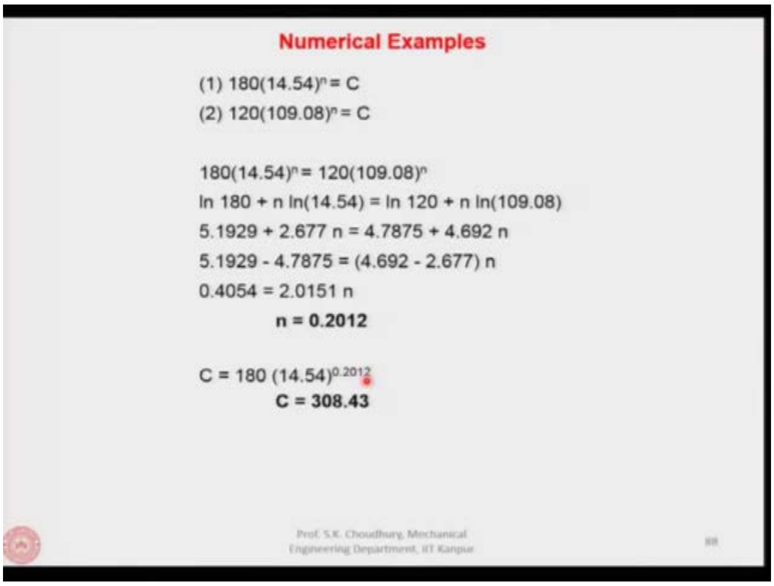

So, these are the simple examples and you can implement the tool life equation and whatever we have learnt earlier in the form of numerical examples.

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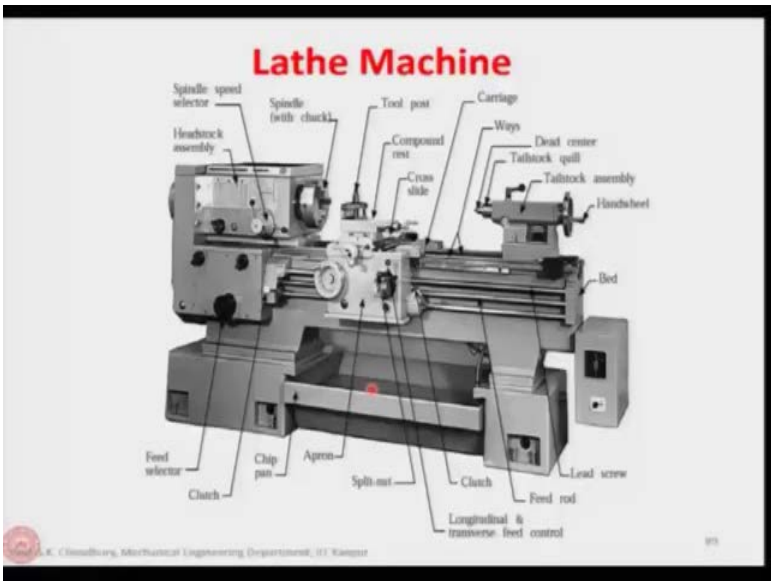

This is the machine tool that is known, I am not going into details of this.

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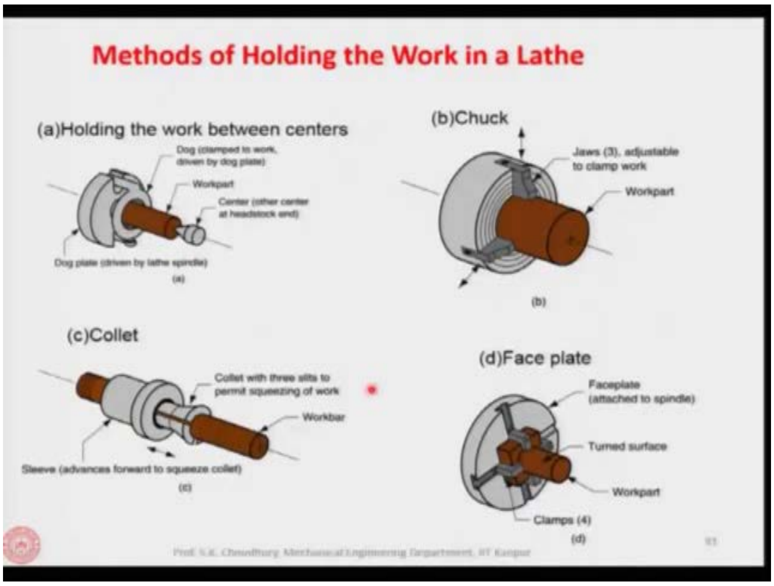

These are the holding devices of the work piece, particularly in the turning.

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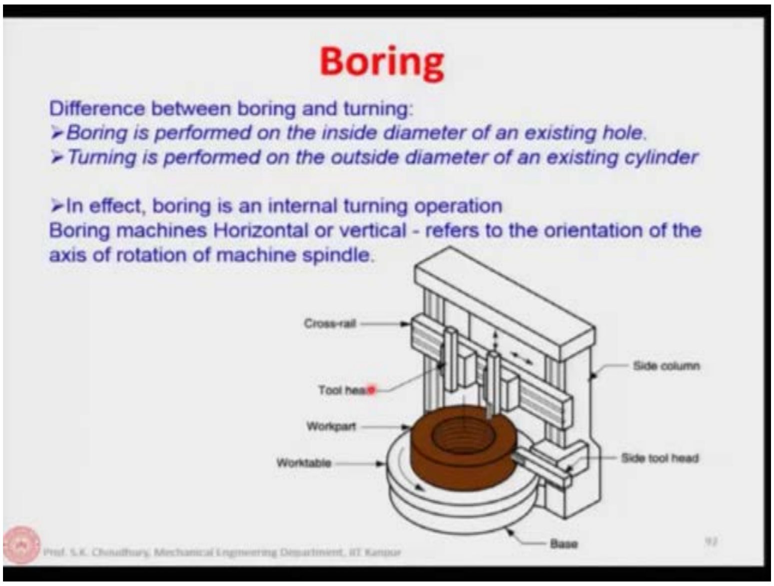

This is the example of the boring. So, I am not going into details because these are simple operations and you must have gone through them in your curriculum.

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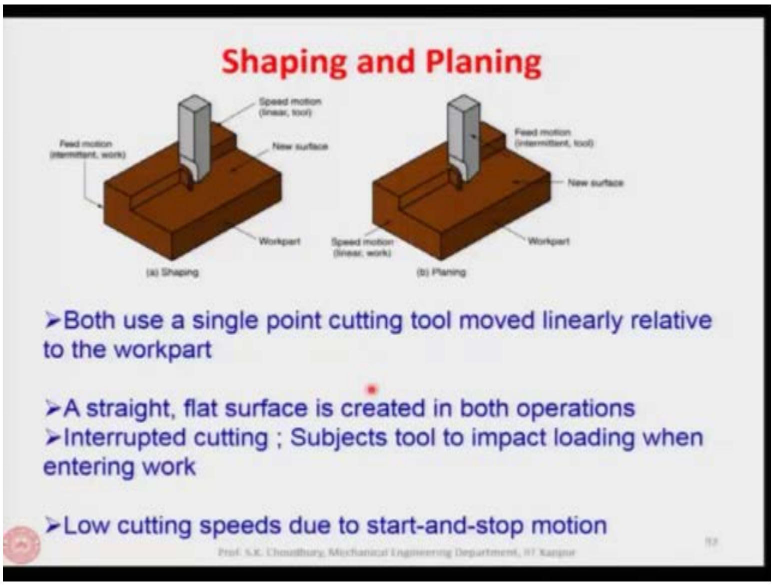

This is the example of shaping and planing. So, whatever we have said I am just giving you the glimpse of those operations.

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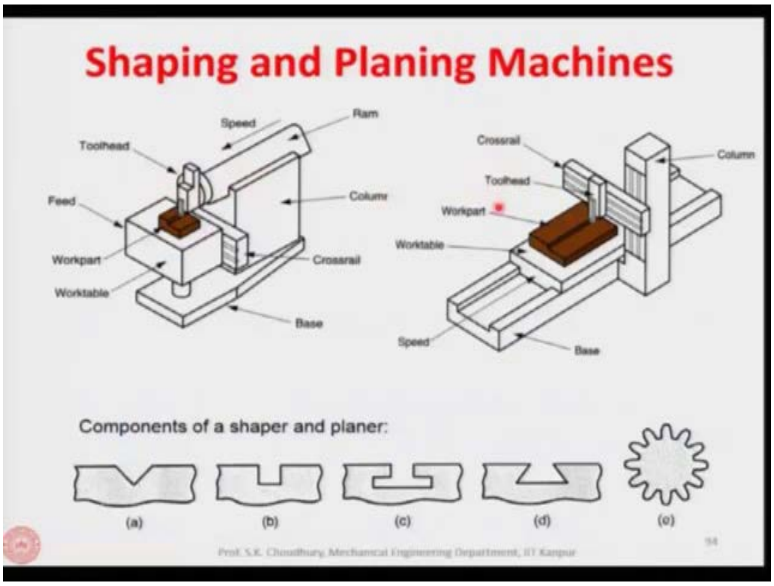

These are the shaping and planing machines.

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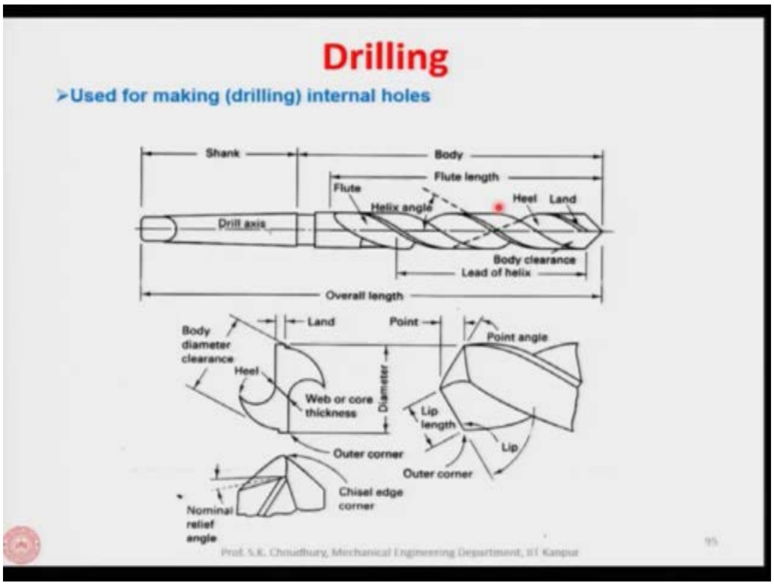

Here is the drill. The entire specification of the drill is shown here and you remember I told you about the point angle, this is the point angle, between the two lips.

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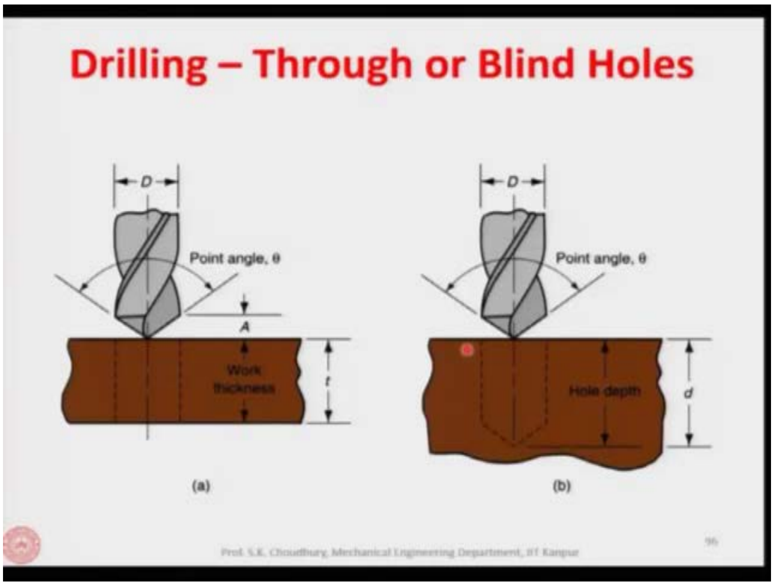

This is how the drilling is made. This is either through hole, this is the through hole or it is a blind hole, it does not go up to the full depth.

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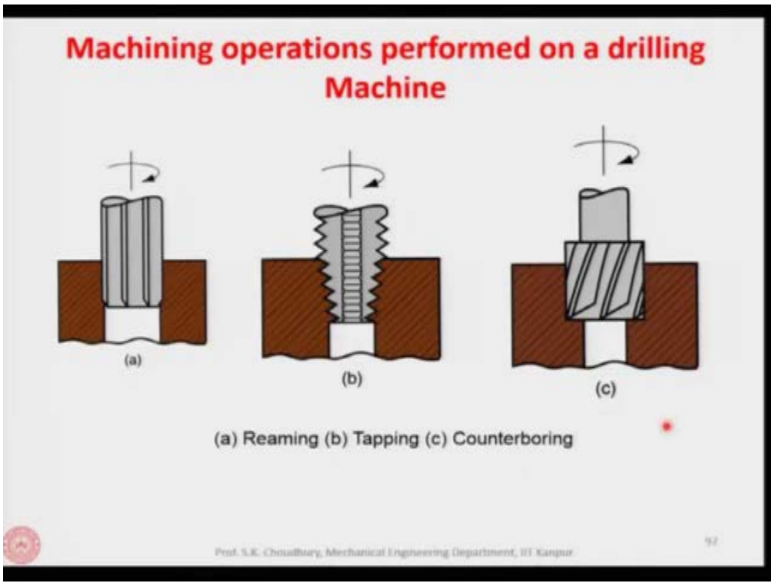

These are the machining operations which are the reaming, tapping, counter boring; just have a glimpse of it.

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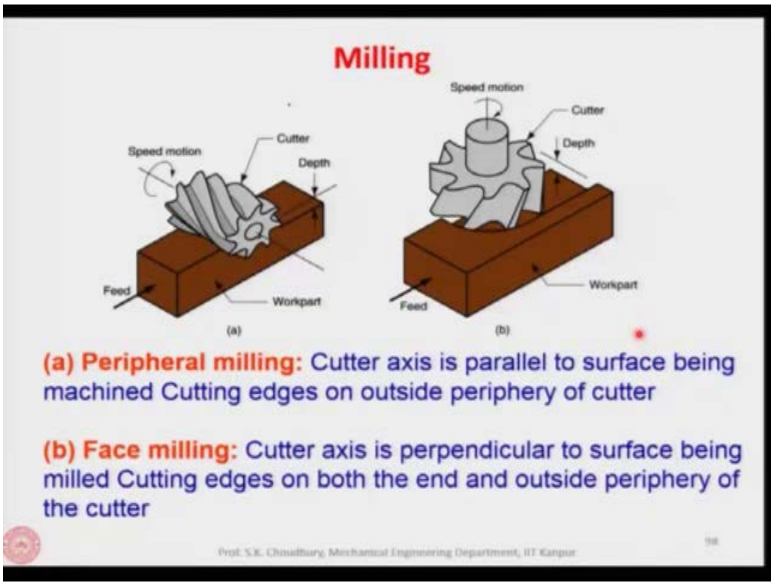

And these are the different types of milling operations like peripheral milling, face milling, slab milling, slotting, end milling.

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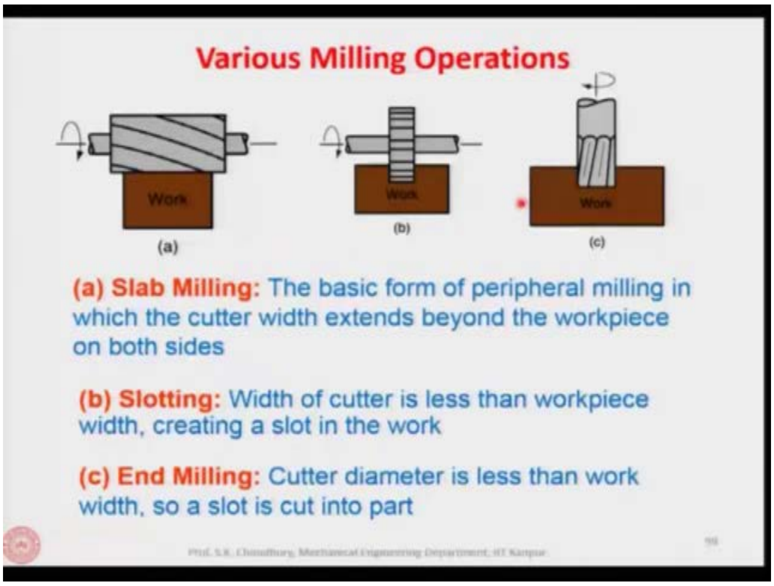

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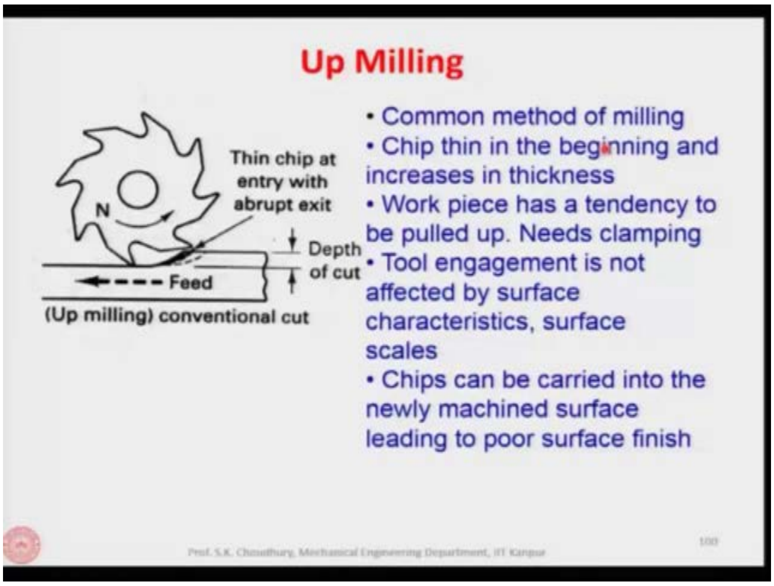

We have the up milling and down milling here. Up milling means the direction of the milling cutter rotation and the feed are different.

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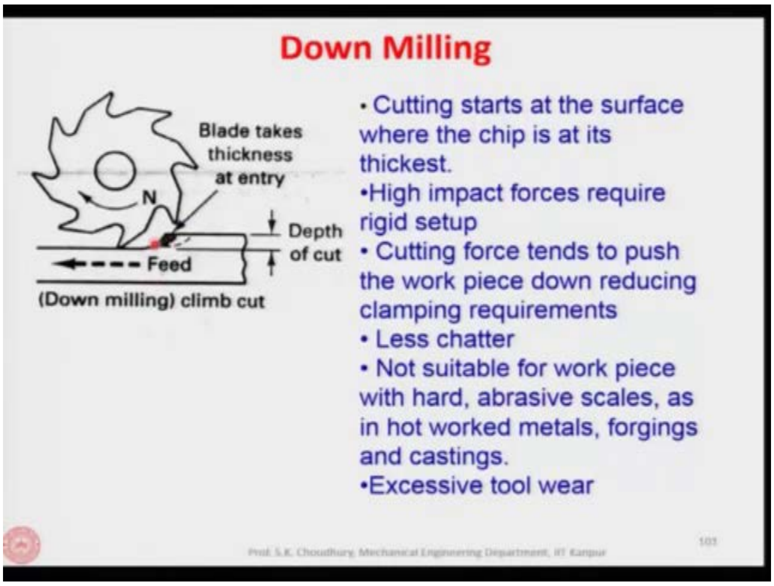

Down milling is the same, except that the direction of the milling cutter rotation and the feed are same. These are the specifications of down milling and up milling.

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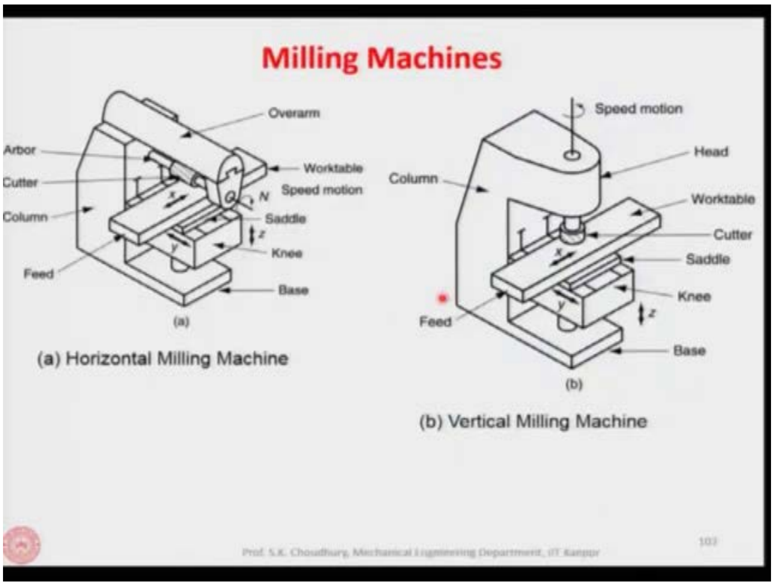

So, you can see this. These are the examples of horizontal and vertical milling machines, depending on the axis of the milling cutter. If the axis is horizontal it is a horizontal milling machine, if the axis is vertical, so it is a vertical milling machine.

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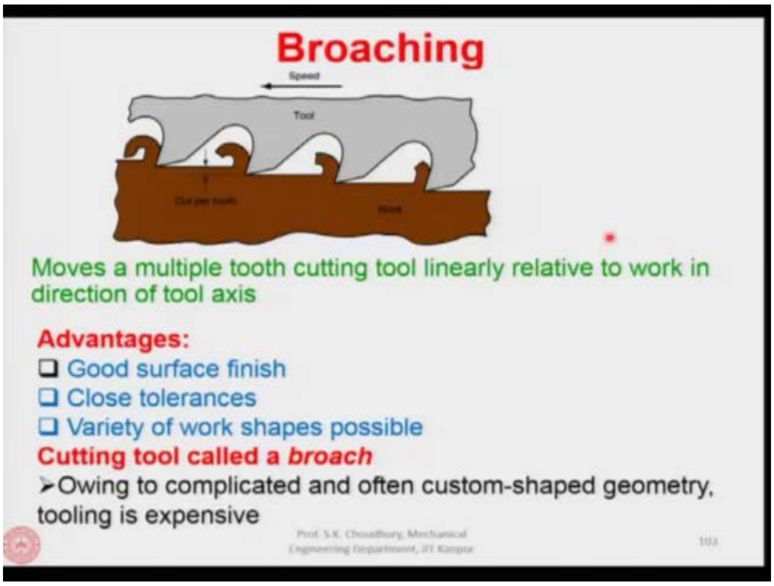

This is the example of broaching. I have told you broaching in the very beginning that you can make internal slots or external slots with high accuracy in broaching. So, this is the broaching operation. Good surface finish can be obtained by broaching.

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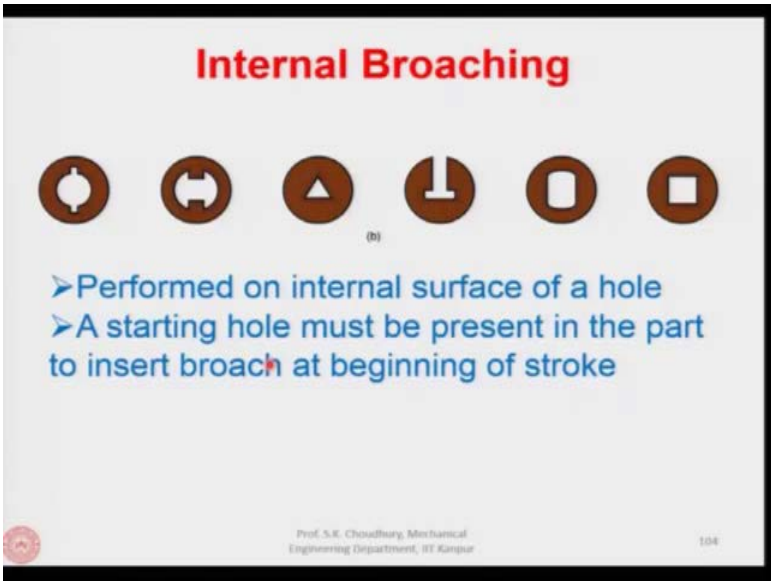

These are the examples of internal broaching, these kind of slots you can make in internal broaching.

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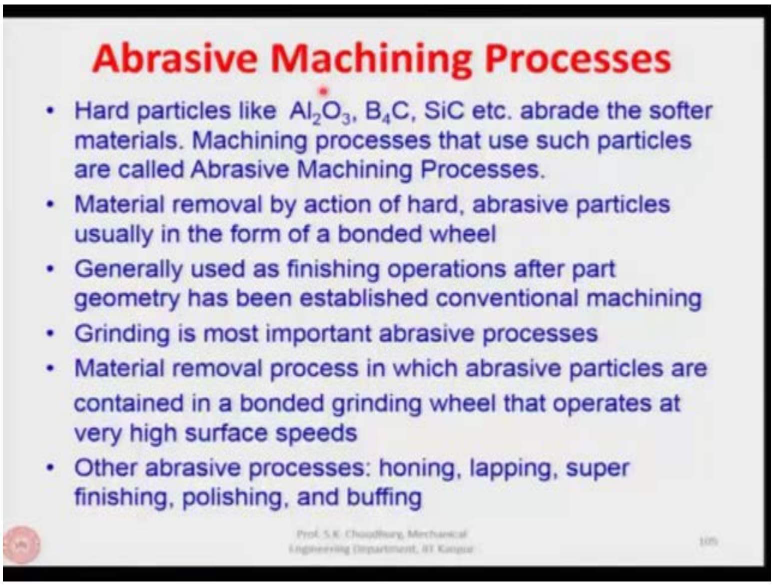

Now, we will discuss the abrasive machining processes. Abrasive machining processes differ from the single point cutting tool or the multi point cutting tool like drilling or milling in the way, that here we have a lot of tools, lot of single point tools and each grain is supposed to be a tool.

Now, hard particles like Al_2O_3, B_4C, silicon carbide actually abrade the softer material. And that is why the machining processes, which use the hard materials like aluminum oxide, boron carbide or silicon carbide are called the abrasive processes or abrasive machining processes.

Now, the material removal by action of hard abrasive particles usually, in the form of bonded wheel, this is particularly in case of grinding. Generally, used as finishing operations, and in grinding although there is a material removal, but in other abrasive machining processes for example, in honing or lapping the material removal is minimum, but it basically uses as the finishing operation, so that the surface finish can be enhanced.

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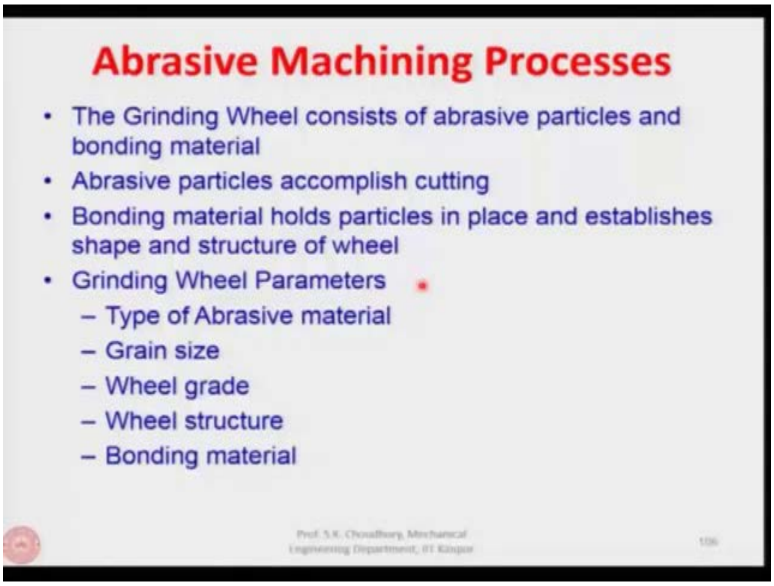

Now, the abrasive machining processes. The grinding wheel has a lot of abrasive particles as I said. Abrasive particles accomplished cutting, bonding material holds particle in place and establishes shape and structure of the wheel. So, the grinding wheel basically has five parameters on which the grinding wheel performance will depend.

These are the type of abrasive material, grain size, wheel grade, wheel structure and the bonding material. So, depending on what kind of abrasive material you are using either Al_2O_3 or silicon carbide or diamond, depending on what kind of grain size we are using; rough, bigger grain size or medium grain size or smaller grain size. What is the wheel grade? Grade is the strength of the bonding material, what kind of grade we are using depending on that we will have the grinding wheel as the hard or the soft.

Wheel structure: what is the gap or the void between the grains in the grinding wheel or the bonding material, either it is a vitrified bond or it is a shellac or it is a resinoid or it is a rubber or it is a metal depending on that you will have the performance of the grinding wheel defined. Let us see.

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For example, the type of abrasive material: it can have either aluminum oxide designated by A or silicon carbide C or the cubic super abrasives are there, there are cubic boron nitride, diamond etcetera.

So, aluminum oxide used for grinding steel, ferrous alloys, bronze and other high strength materials; whereas, silicon carbide which is more expensive used for grinding brittle materials, cast iron, brass, aluminum and hard alloys and the carbides. By aluminum do not get surprised, because on the top of aluminum there is an aluminum oxide which is very hard. Aluminum itself may not be a hard material, but on that, aluminum oxide is present that is very difficult to grind and the carbides which are very hard.

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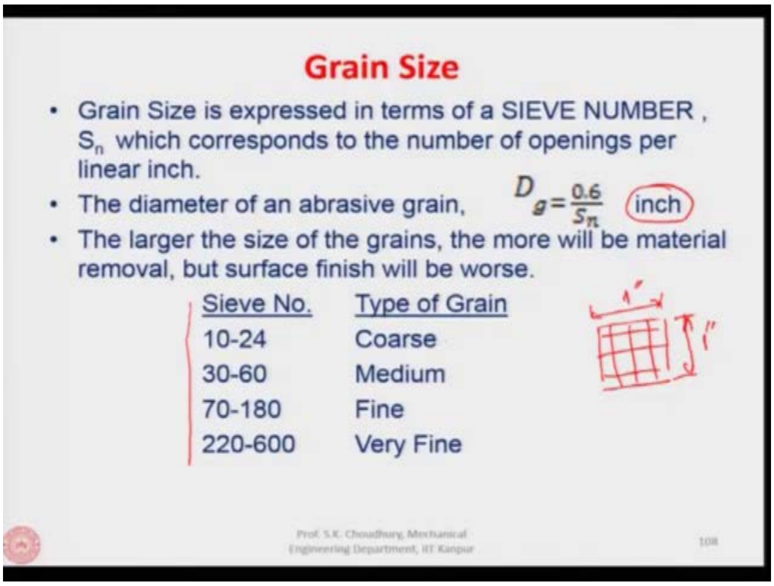

So, grain size is expressed in terms of the Sieve Number. Sieve number is S_n which corresponds to the number of openings per linear inch. So, if you have a linear inch let us say here there is 1 inch by 1 inch, so how many openings you have in that is the sieve number.

And, from that sieve number you can find out the diameter of an abrasive grain which will be $\frac{0.6}{S_n}$, mind it is given in inch, so always you have to convert into micron or millimeter. The largest the size of the grain the more will be the material removal you understand that bigger grains will remove more material and surface finish will be worse.

So, the sieve numbers are given in this way, these are internationally accepted, 10 to 24 for example, these are the coarse or the bigger grains, 30 to 60 sieve number will be medium grain, 70 to 80 will be fine grains and 220 to 600 is very fine grain. So, you understand that more the sieve number since it is inversely proportional less will be the diameter of the abrasive grain. Meaning that for example, if it is a 600 sieve number. 600 sieve number will be a very fine grain, because it is given $\frac{0.6}{S_n}$ which is $\frac{0.6}{600}$ in inch, so you can convert that into micron as these are very small particles or very small grains.

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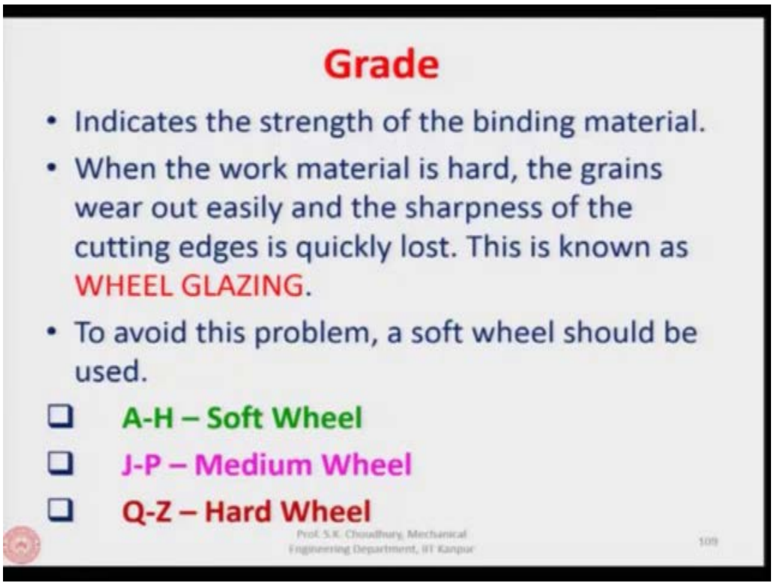

Similarly, the grade indicates the strength of the binding material as I said. When the work material is hard the grains wear out easily and the sharpness of the cutting edges is quickly lost. This is known as the wheel glazing. Meaning that if you have a hard work piece material and a hard wheel, since the wheel is hard and the work piece is hard, the grains on the surface of the wheel will be very quickly worn out and since the wheel is hard those worn out grains will not be dislodged from the surface of the wheel.

So, worn out grains will stay and such a wheel will rub more and consume more power, this is called the wheel glazing. Because, the wheel surface then will look like a glazed surface since they are covered with the worn out grains which are dull grades, they rub more and remove less material, consume more power. So, wheel glazing it not desirable it should be re-sharpened and that layer has to be removed by the diamond pin.

To avoid this problem, a soft wheel should be used because in the case of soft wheel, if the work piece material is hard, the wheel grains will be worn out, but they will be dislodged because the wheel is soft. And why we want the grains to be dislodged? Because behind the dislodged grains there will always be sharp grains. So, those sharp grains will come out and they will remove more material, they will consume less power. So, here the specification of the grade is that A to H, these are also internationally accepted. A to H is the soft wheel, J to P is the medium wheel and Q to Z is hard wheel.

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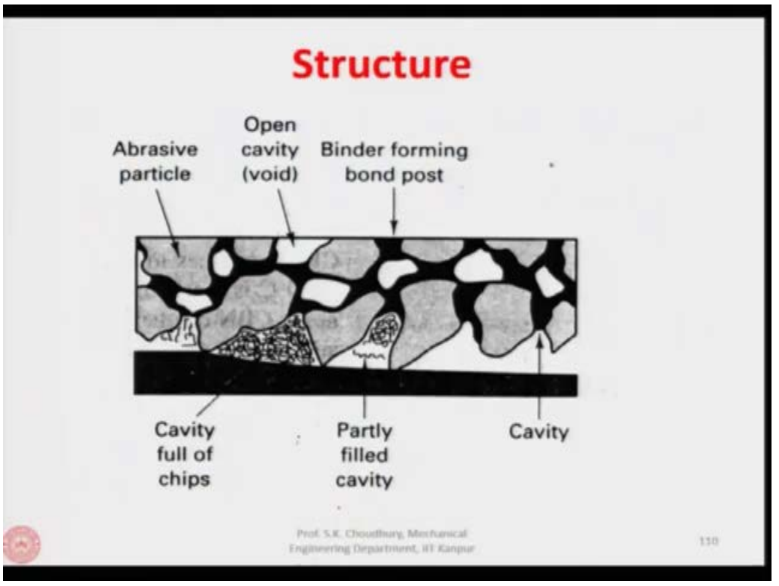

Now, the structure: like in the case of the milling cutter between the milling cutter teeth we have the void or the space where the chips are accommodated. Similarly, in the grinding wheel between the grains there should be some space that will accommodate the chips and if the space is very small, then those small chips will get into the small space between the grains and they will stay, they will not be able to come out. And then we say that wheel is loaded. That is the wheel loading phenomenon.

Like in the case of glazing the loaded wheel will not be cutting effectively, it will rub more and it will consume more power. Because on the surface of the wheel we will have the chips embedded. So, we should not allow the wheel loading and as soon as the wheel loading takes place, as soon as we see that the power is increasing or the force is increasing in that case we have to remove that layer by re-sharpening, it is called the wheel dressing, by dressing of the wheel we have to remove that layer.

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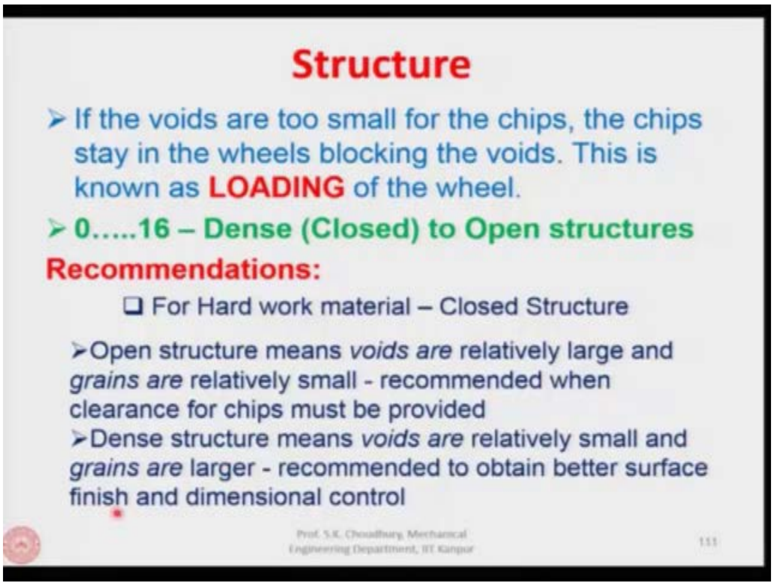

If the voids are too small as I said then the loading will happen. So, here there are 17 structures 0 to 16, dense to open. 0 is most dense. Most densely packed means the voids or the space is very small and 16 is the open. In between 0 and 16, say for example, 10 will be not very open not very dense.

Recommendations are that for hard work piece material we should have the closed structure and open structure should be used for softer work material.

Open structure should be recommended for clearance for the chips. Dense structure means voids are relatively small and grains are larger, recommended to obtain better surface finish and dimensional control. So, for dense, we mean to say by 12, 13, 14 and so on up to 16, so those are for better finish and for more dimensional accuracy.

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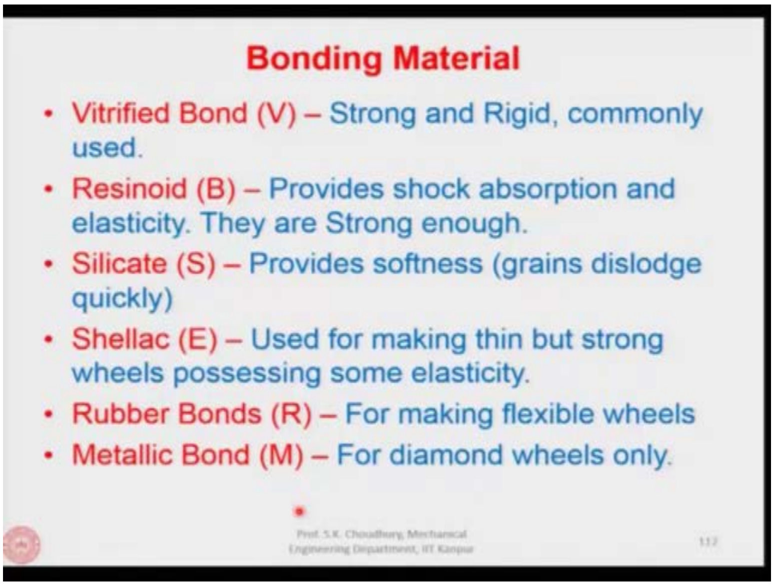

Bonding materials as I explained it to you that there are vitrified bond, resinoid, silicate, shellac, rubber bonds, metallic bonds and each of them is indicated by an alphabet. Vitrified bond is V which is strong, rigid which are commonly used. Resinoid provides the shock absorption and elasticity, they are strong. Silicate provides softness, grains dislodged quickly. Shellac is used for making thin, but strong wheels possessing some elasticity and the rubber bonds are for making flexible wheels.

For example, if the wheel is used for parting of a very thick or high diameter of the work piece, so it has to penetrate the work piece and it should have some flexibility because, it vibrates and if it is very rigid and strong this will break. So, this flexibility is given by the rubber bonds and some sort of elasticity is given by the resinoid also. Metallic bonds are exclusively used for the diamond wheels.

Now, you must have seen that each of these is characterized by a number and a letter.

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For example, abrasive material, here we have an alphabet, next to that we have a letter, next to that we have an alphabet again, then again a letter, letter and so on.

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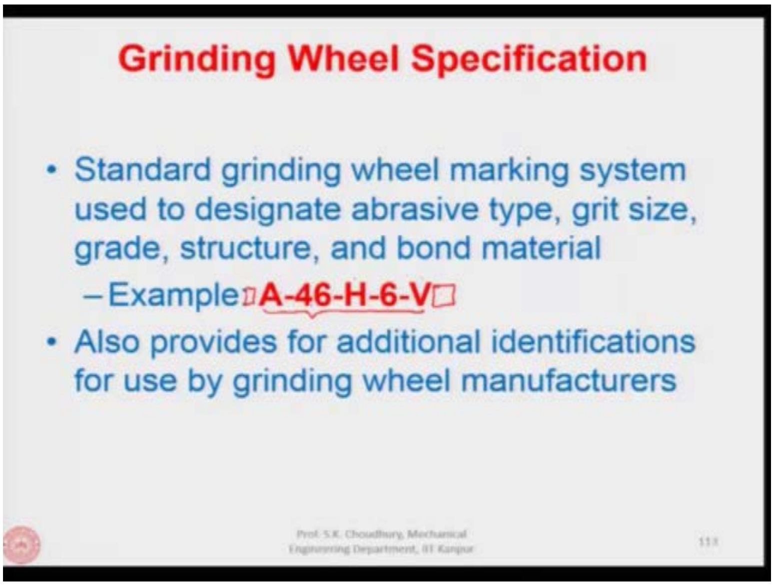

So, the grinding wheel specification - a standard grinding wheel marking system used to designate abrasive type, grit size, grade, structure and bond will be given by this way. You can see that this is the abrasive type, this is the size of the abrasive grain, this is the grade, this is the structure and this is the bond. So, when you buy or purchase the abrasive wheel nobody will tell you that what is the grade actually, what will be mentioned is like this. Only thing is that there would be some kind of manufacturer’s code in the beginning and at the end but otherwise these five parameters will signify the grinding wheel specification.

Once again abrasive type, this is the grain size, this is the grade, this is the structure and this is the kind of bond. Also provides for additional identifications for use by grinding wheel manufacturers. As I said that these will be the manufacturers code plus these five specifications.

Some of the other aspects in grinding which are very important and which need some discussion - that we will do in the next class.

Thank you very much for your attention.