Production Technology: Theory and Practice
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Lecture - 15
Discussion Session

Hello and welcome back to the discussion sessions of the production technology theory and practice course. Let me remind you that in our last session we have discussed in details that how the performance of a grinding wheel can be defined by 5 parameters: , types of abrasive grain, size of the abrasive grain, the grade the structure, and bonding material. In this sequence we have to define by a letter and the digit followed by a letter and then digit and the letter that how the grinding wheel can be selected what kind of grinding wheel you have to select depending on the situation or the combination of the work material and parameters are being used.

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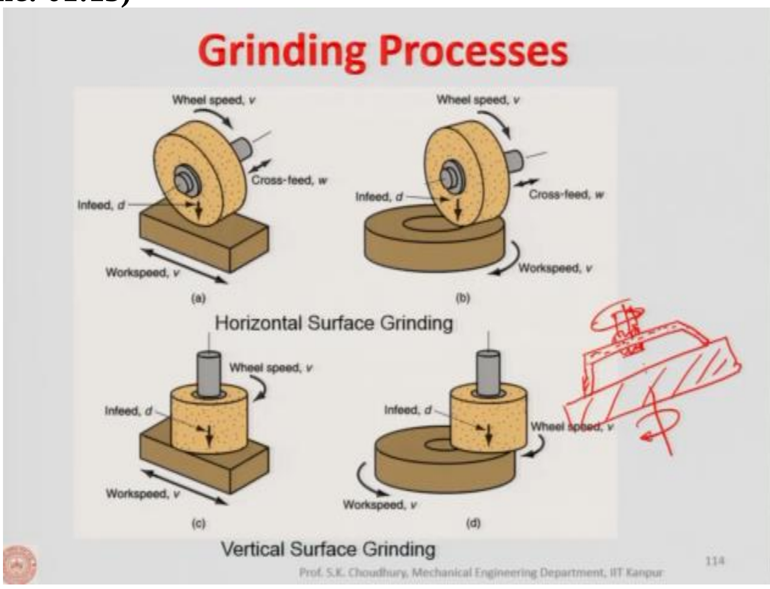

Next, let us see what kind of grinding processes are there in practice. If the axis of the grinding wheel is horizontal then like in case of milling operation it is called the horizontal grinding and since the horizontal grinding is used for making a flat surface so, this is called the horizontal surface grinding. In case of horizontal surface grinding, the rotational speed is given to the wheel that is the wheel speed. It will reciprocate to cover the entire width and of course, there will be a feed given and that feed is called the infeed in case of grinding. The work speed given to the workpiece which will reciprocate so, this is a combination of the relative movements. Wheel rotating like this and getting a cross feed plus the infeed to get the depth of cut. Infeed is given when it will be ground after that it will be again given the infeed if it is required. It is incremental as you understand that in case there is a round shape workpiece in this case the same movement will be done by the wheel that is the wheel will be rotating it will be given a cross feed and an infeed plus the workpiece will be rotating. So, here the workpiece is reciprocating because it is a rectangular workpiece here it is a round shape so it will be rotating about this axis. The axis of the workpiece and the axis of the grinding wheel will be perpendicular to each other.

If the axis of the grinding wheel is vertical it is called the vertical surface grinding and in this case the wheel rotates about its centre and then infeed is given and in case of rectangular workpiece like in here it will reciprocate along the direction of the infeed or perpendicular to the infeed.

The axis of the grinding wheel, infeed given here along the axis of the grinding wheel and perpendicular to the work speed, here the same infeed is given. Wheel is rotating about the axis of the grinding wheel and in case of the rotating job that is a round shape job then the work has to be rotated. Only difference is that in both cases it will be the surface to be made. But here it is with the horizontal axis of the grinding wheel here with the vertical axis of the grinding otherwise this is the similar. For vertical grinding, there is also a grinding wheel which is not shown here which is of the cup type. I am roughly making this so this is the grinding wheel, these are grains and here it will be axis of rotation and this is the workpiece.

The workpiece will be rotating and the grinding wheel also be rotating. This is the cup type here, it is mounted and this is the arbour. This is the cup type grinding wheel for making the flat surface as well. This also vertical surface grinding because it is a surface which is produced ultimately.

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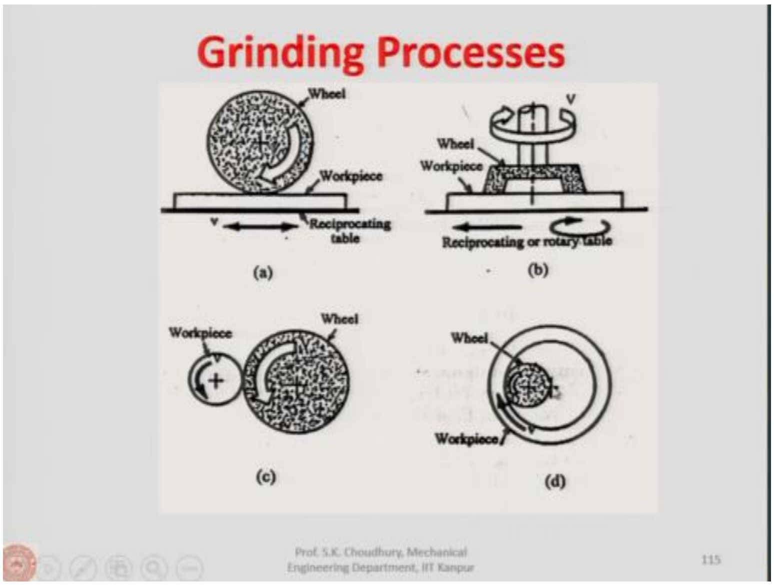

Here it is shown in the 2-dimensional picture the wheel rotation. The horizontal surface here is the cup type actually. This is reciprocating when it is the rectangular job and when it is a circular job, it will be rotating. this is also vertical surface grinding. This is the internal and this is the external cylindrical grinding, that means here is the workpiece and the external cylindrical surface will be ground by this wheel The workpiece and the wheel both are rotating in the same direction and in this case also there is a wheel which is inside the workpiece that means it will be for grinding the inner hole of the workpiece or a cylindrical workpiece. The workpiece will be rotating in the clockwise direction and in the anti-clockwise direction the wheel will be rotating this is how it is shown. This is the axis of the grinding wheel; this is the axis of the workpiece.

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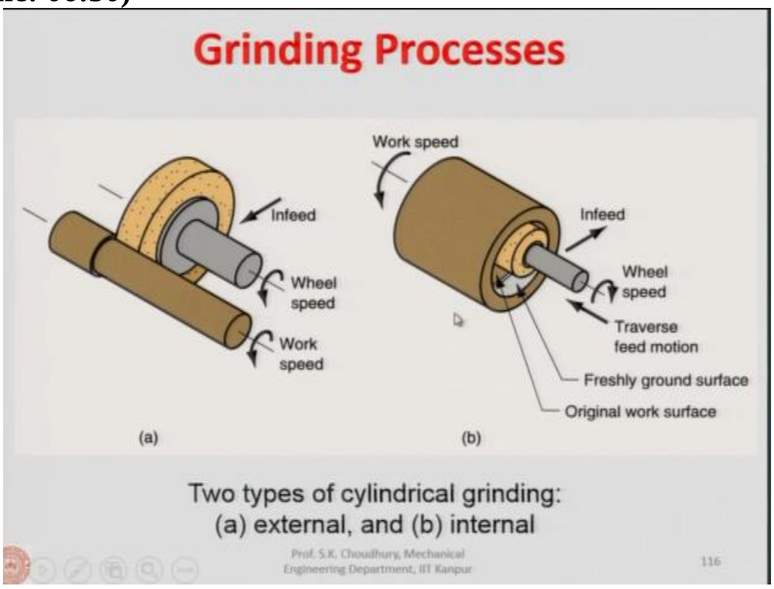

This is how it can be represented in the pictorial view. The same thing is given in the pictorial view that this is for the external cylindrical grindings. Given that the wheels will be rotating about this axis and this axis is parallel to the workpiece axis if it is a cylindrical of course and since the outer cylindrical surface is being ground, therefore, the grinding wheel is in touch with the outer cylindrical surface infeed will be given to take the depth.

And the in case of the internal hole this is the grinding wheel which is on the arbour and the grinding wheel will be rotating in the opposite direction of the workpiece and the infeed will be given to take the depth and here you will see that this is the freshly ground surface. So, in this case what we get is that there is already a drilled hole that drilled hole is reamed and then it is ground and while grinding we are actually increasing this hole diameter a little bit but we are increasing the surface finish more.

The emphasis is given for the internal grinding of a hole on the surface finish rather than removal of the material because most of the material is removed by drilling followed by reaming if it is required a little bit as I said and the reaming also for increasing the surface finish of the internal hole of course here for internal cylindrical grinding the traverse feed motion is given to the mandrel along with the grinding wheel. So, it will be rotating as well as it will be traversing inside the hole of the cylindrical job.

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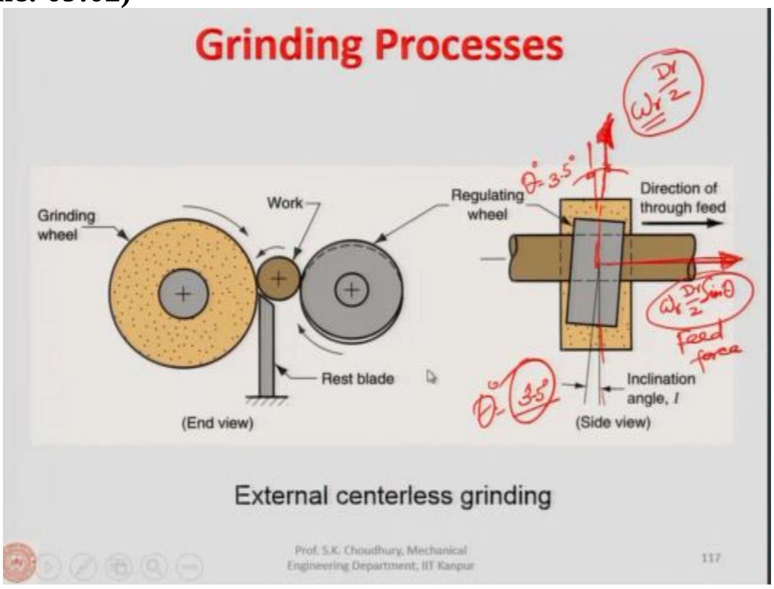

This is an external centerless grinding. This is a unique process where the workpiece is not held by anything it is just loosely supported by the rest blade between the grinding wheel and a regulating wheel this is called the regulating wheel. So, regulating wheel can also be a grinding wheel. Grinding wheel is rotating in the opposite direction. Here in this direction as you can see, in opposite direction the workpiece is rotating and in the same direction the regulating wheel is rotating.

As a result the regulating wheel will determine the surface speed of the workpiece, and the grinding wheel will grind the surface. So, the role of the regulating wheel is to support the workpiece to define the surface speed or peripheral speed of the workpiece and to feed the workpiece in this case the external centerless grinding a very thin and long rods can be ground let us say for example the needles, very thin needles.

You cannot grind those needles, small parts because needles are small in length. Normally what is done is a big part of very big length is ground and then cut off into small pieces. So, that very big but the very small diameter will be very fragile in the sense that this will not be very stable and it will be flexible you cannot hold that at the ends you cannot hold it in a chuck.

Therefore, they have to be simply supported and between the two wheels one is the grinding wheel and one is the supporting wheel. It actually goes in as it is shown here and the regulating wheel is located with respect to the grinding wheel at an angle of roughly about a very small angle 3 to 5^0 angle. The purpose of this is that when this very thin rod which is the workpiece to be ground this is passed through the grinding wheel and the regulating wheel has to be given a feed as well it has to go forward.

So that the entire length which can be very big, the entire length is ground. There is nothing to give the feed meaning that there is no additional device or additional movement given to the workpiece. So, it has to be given by the rotation of the grinding wheel and the regulating wheel. Therefore, the regulating wheel is located at an angle of 3 to 5^0 with respect to the axis of the wheel.

This is the axis of the wheel and this is the axis of the regulating wheel. This is about 3 to 5^0 that is as I said here. Now, since it is inclined so, along this there will be a force $\omega_r D_r / 2$. Let us say *Dr* is for the regulating wheel. I will extend the axis and this angle is 3 to 5^0. Now along this axis when it is rotating, there will be a force which can be defined by $\omega_r D_r / 2$.

ω_r is the angular frequency of rotation, the angular rotational frequency of the regulating wheel and *Dr*s is the diameter of the regulating field so, it is the radius $D_r/2$. Therefore, this force will have a component at this direction along the axis of the workpiece which will be $\omega_r D_r/2$ and the sin of let us say this is theta for 3 to 5^0 $\sin\theta$. This is the feed force we will call it and the feed force is the one which is actually dragging or moving the workpiece in this way.

The workpiece will be then ground along the entire length and the diameter because the rotational frequency to the workpiece is defined by the surface of the regulating wheel. So, this is the mechanism, how the external centerless grinding works and this is used for the pins and needles particularly the pins of the thrust bearing, thrust bearings are used in practice in very large number and the bearing elements are very small rollers or very thin pins.

Those are made with the help of the ground or with the help of the external centerless grinding and there workpiece is not supported by anything. It is just held by a knife this is the rest blade on which it is resting.

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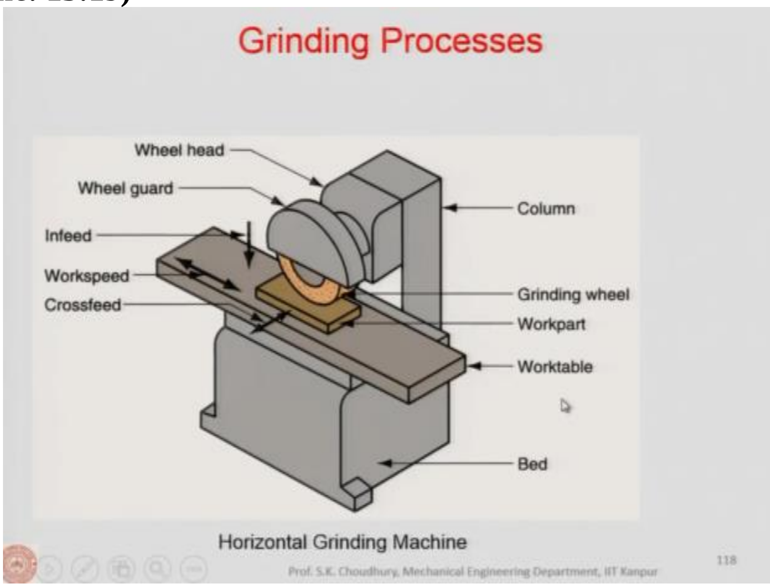

This is a small grinding machine. Like this we can see in the lab also. In this we have the bed like in lathe machines, milling machines and so on we have the column here, we have the wheel head located, this is the apron. This is also called the wheel guard because the wheel rotates at a very high speed of *10 to 80 m/s*.

At this speed the wheel if it breaks then each broken part can actually fly with a very, very high speed and that could be very dangerous. So, always before switching on this grinding wheel or the grinding machine the apron or the wheel guard should be there. Now this is how the infeed is given. This is the feed which is a cross feed this is along the axis of the milling cutter in case it is horizontal milling cutter and this is the work speed that I have already shown it to you in other slides and these are grinding wheels. So, this is the entire grinding machine.

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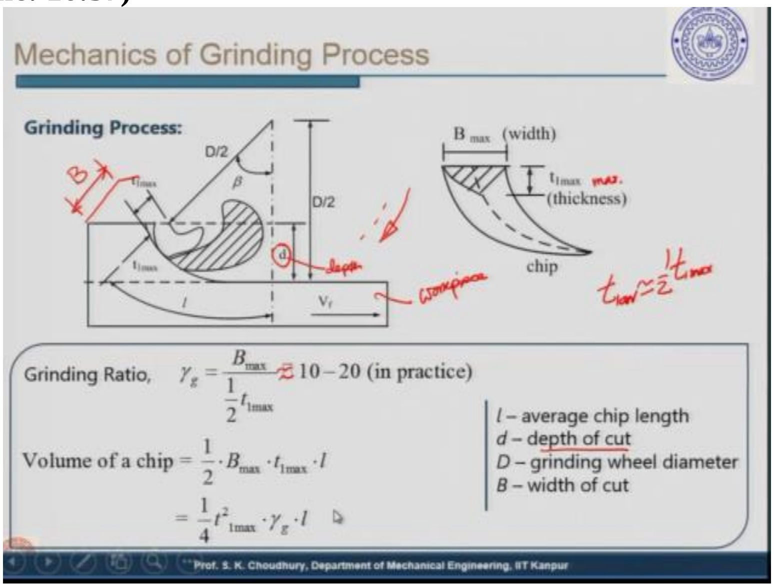

Let us see that like in case of the turning where we have discussed the mechanics of turning process or mechanics of metal removal. So, there we have discussed the models like Merchant's model like Lee and Schaffer model to look into the mechanics of the metal cutting and that mechanics told us that how to correlate the forces with the angles.

This is a little different than the turning in the sense of the tool, which is grinding wheel in case of grinding process. It is absolutely different than the single point cutting tool because in the grinding process, in the grinding wheel each grain can be considered as single point cutting tool but the difference is that in case of single point cutting tool each tool has a certain geometry.

It has the rake angle particular rake angle either it can be a 0^0 rake angle or it can be negative or it can be positive rake angle. But in case of the grinding wheel the rake angles are random or angles are random. We cannot define a small grain of a certain value of the rake angle you should understand that. Therefore, the angles are random and the grains are randomly oriented also how you orient the grain particularly in a position it cannot be defined. Because you are adding them in random and then you are adding the bonding material then you are churning it and you are making the grinding wheel. Grains are in large number and each grain can be considered as single point cutting tool, grains geometry is random. This is randomly located and randomly oriented within the grinding wheel this is how the grinding wheel or the grinding process differs from the turning process.

When we are defining the mechanics of the process, it has to be defined with respect to the grinding wheel in case of grinding, let us see how it is and what it is? In the grinding process we draw this schematically using one grain let us say this is one grain located in the grinding wheel and the grinding wheel centre is here; this is the centre of the grinding wheel. This is of course the workpiece. In the workpiece, one grain is removing the chip.

So this is the small chip which is removed by one grain, subsequently next grain will come and remove such a piece of chip and so on, from this centre of the grinding wheel, this is the radius of the grinding wheel. You understand that from here therefore, this is also radius now I already told you earlier also that you do not get confused because this is a position from here to here, this is the grinding wheel, if I extend it this will be the grinding wheel this is the grinding wheel and this is the centre.

So, as this V_f is given where V_f is the feed velocity of the workpiece. As a combination of the rotation of the grinding wheel and the V_f, the grinding wheel rotates in this direction and the V_f is given. This point moves from here to here; this is the other location of the grinding wheel. It can go like that. Therefore, the centre is shifting like this and one grain is making a chip like this. Now, in this geometrically we can actually establish the relationship between the angle. Let us say this is a small angle and the parameters like the diameter of the grinding wheel. This is the t_1 maximum.

This is the uncut thickness and from here to here, this is the length of a chip that is being formed. Now, this is the depth of cut. d is the depth of cut l is the average length of the chip D is the grinding wheel diameter. B is the width of cut.

Now, from this chip that is being removed by 1 tooth you understand that this will be in the 3-dimensional. It will be the maximum width because this is how the chip is form and since this is the chip length. This distance from here to here will be the $t_{1\max}$.

This is the uncut thickness t_1 maximum is the maximum uncut thickness.Here we will not call it the maximum uncut thickness but let us say the chip thickness otherwise it will be confusing with the t_1 in case of the turning where we said that the $t_1$is the uncut thickness t_2 is the chip thickness. So, here it is the chip thickness actually because this is already produced chip.

Now, there is a concept of grinding ratio, grinding ratio is given by the ratio of the B_{max} here and the half of the $t_{1\max}$, this is approximately given as the 10 to 20 in practice. Now, let me explain it to you why it is half of $t_{1\max}$. I already told you that since the t_1 varies from 0 to maximum and the t_{1av} is taken and t_{1av} is roughly half of the $t_{1\max}$, this is how we take it in case of milling also.

Because they are also the same kind of a chip that is produced and therefore the grinding ratio is given by the maximum width of the chip divided by half of the $t_{1\max}$. This is in practice as I said roughly about 10 to 20 depending on the type of the workpiece material Volume of a chip if the chip is like this we consider this to be triangular, the volume of a chip is given by half of the t_1 maximum into the length of the chip.

If we put the value of the $\gamma_g = \dfrac{2B_{\max}}{t_{1\max}}$ Then it will be 1/4, t_{1max} already here. So, another t_{1max} will give you $t_{1\max}^2 \times \gamma_g \times l$. So, we have put it here the value of the γ_g we are getting this equation for the volume of a chip. Now we have to find out the value of the length, l

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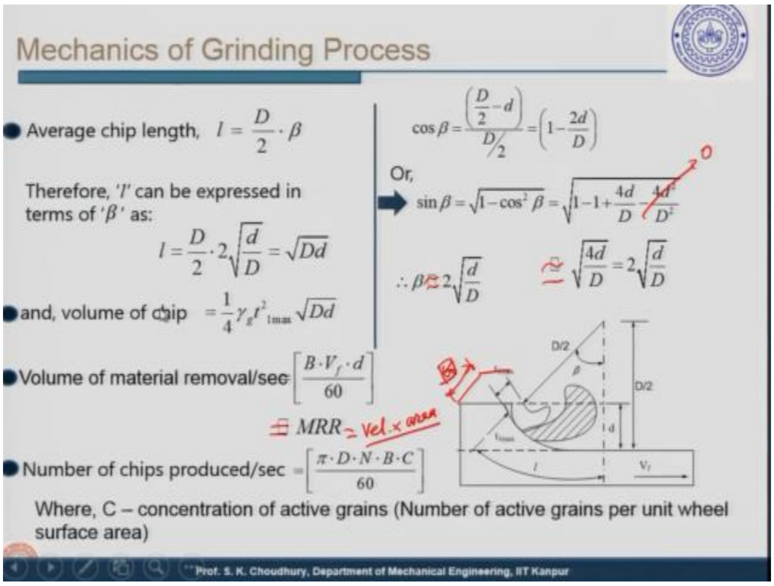

To get that we say that the average chip length can be found out if we consider this to be a very small angle as D/2 approximately $\frac{D}{2}\beta$. This is like this D/2 into this angle this will be roughly the value of the *l*. Now, the *l* can be then expressed in terms of beta as $\frac{D}{2}2\sqrt{\frac{d}{D}}$

From this triangle we are taking that $\cos\beta = \frac{\frac{D}{2} - d}{D/2}$. Now $\sin\beta = \sqrt{1 - \cos^2\beta}$ Then, this will be 1 - 2d/D.

So, this is approximately $\sqrt{\frac{4d}{D}}$ will be equal to $2\sqrt{d/D}$ If the beta angle is small so, $\sin\beta = \beta$. So, this is approximately equal $2\sqrt{d/D}$. Now, we get this value beta and you put this $2\sqrt{d/D}$ which will be equal to $\sqrt{dD}$.

Now, the volume of the chip we have already found out that this is equal to $\frac{1}{4}\gamma_g t^2_{1\max}\sqrt{Dd}$

Now; the volume of material removal per second which is also the material removal rate is given by the velocity into area that we have shown earlier like in case of the any other processes that material removal rate overall will be given as a product of velocity and area. So, here the velocity is V_f that we have to take because this is responsible for the material removal it is given as feed. And the area will be the depth of cut and the width which we already said.

So, this is the width and the D there it was written B but here also it is B so, it is that B, B x d is the area and V_f is the velocity so to make it second we are dividing by 60. This is the material removal rate. We found out the volume of chip material removal rate and then we can find out the number of chips produced per second which will depend on basic 3 things. One is this wheel speed, second is the width and the third parameter is the grain concentration that how much grain is located in unit volume of the unit wheel area. So, here we are writing the same thing that the number of chips produced per second will be the wheel speed πDN, D is the diameter of the wheel, N is the rotational frequency of the wheel, B is the width, C is the grain concentration.

Grain concentration means the number of active grains that is per unit wheel area and divided by 60 because this is in RPM, revolutions per minute. These 3 parameters can be correlated that is the volume of material removal, volume of a chip and the number of chips produced, how? It is very simple that the volume of 1 chip multiplied by the number of chips produced this is in fact is the material removal rate.

Once again volume of 1 chip multiplied by the number of chips produced is the total volume. So, this is the volume of material removal. So, then if you write the equation that $\frac{1}{4}\gamma_g t_{1\max}^2 \sqrt{Dd} \times \frac{\pi DNBC}{60} = \frac{BV_f d}{60}$.

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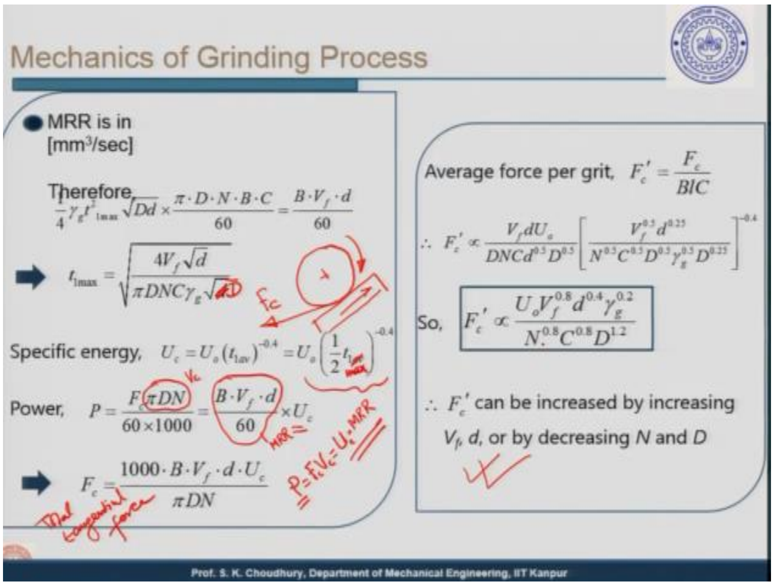

This is what exactly we are writing here. Now, from this equation, we can find out what is the value of the t_{1max} if we simplify that you will see that this will give you $t_{1max} = \sqrt{\frac{4V_f\sqrt{d}}{\pi DNC\gamma_g\sqrt{D}}}$

The average force per grit F_c = ? Let me explain it to you that why we have determined that t_{1max} because the specific energy like in other processes if you remember that specific energy we are defining through the specific energy constant and the uncut thickness.

So, in case of turning in this case it will be t_{1avg} like in case of the milling we will say that the specific energy is equal to the specific energy constant multiplied by t_{1avg} and t_{1avg} we have seen that this is t_{1max} /2 . Therefore, this is that U_c given by this factor then the power is given by $F_c \times V_c$ V_c will be the cutting velocity πDN /60x1000, 60 is to make it in second and this 1000 is to convert the metre to millimetre. So, ultimately what we will get is that the power$= \frac{F_c \times \pi DN}{60 \times 1000}$. And power $F_c \times V_c$ .also it is given by U_c and the material removal rate. So, $Power = U_c \times BV_f d / 60$

F_c is what? F_c is the total tangential force like if it is the grinding wheel for example and this is the workpiece let us say if this is rotating like this workpiece moving like this.

So, this is the F c which is the total tangential force. Now, this total tangential force will be $F_c = \frac{1000.B.V_f.d.U_c}{\pi DN}$ Now, we can say that the average force per grit because what happens is that this is the total tangential force and we are interested in the force which is acting on each of these grains that is more important for us, I will tell you why.

Therefore, the average force per grit will be this force which is distributed to all the grains which are located within that sector where the force is acting. So, here this is the F_c which is the total tangential force distributed to all these grains which is within the width within the length and the grain concentration. So, within that length how many grains are there, that depends on the width and the grain concentration as well along with the length. So, therefore, F_c /BlC will be the average force per grit.

So, this will define how much force each grain is experiencing that can be found out from here. So, you get this get the $U_c = U_o \times \frac{1}{2} t_{1\max}^{-0.4}$ put the value of the t_{1max} here and you will get this equation. So, we are avoiding all these constants 60, 1000 pi, 4 and so on and we are saying that this is proportional to these factors.

So, you will see that actually we will be finding out that $F_c^{'}$ which will be proportional to this. Now, from here you can say that this $F_c^{'}$ can be increased if we are increasing these factors because it is directly proportional that means by increasing the V_f by increasing the depth and by increasing or by decreasing the N and D value see why we are not touching the C.

Because C is the property of the grinding wheel this is a grain concentration we already have the grinding wheel and the grinding wheel is already made. So, the grain concentration is already defined similarly, we are not touching here the U_o γ_g because U_o is a constant, this is specific energy constant and that depends on the power that is given to the process because this specific energy consumed when the t_1 = 1 millimetre.

Therefore, we say that $F_c^{'}$ can be increased if we are increasing the V_f and if we are increasing the small d which is the depth of cut or by decreasing the N and the D because C is constant again. Now, this is important conclusion because you know have a control over the

$F_c^{'}$ because if $F_c^{'}$ is increasing that means, the grain can be dislodged easily. Suppose there is a worn-out grain and it is stuck there it is not coming out because the bond is very, very strong.

But then if that is for a particular force if you are increasing the force on each of these grits, then it may actually facilitate the grain dislodging. So, if we can increase that force per grit the worn out grain can be dislodged easily or we can facilitate the dislodged process of the worn out grains in that case that problem of the hard wheel and the hard workpiece material when we are having the glazing that problem may not be coming.

So, frequently in that case what we are doing is we are making the grinding wheel look softer because we are manipulating these factors that is the V_f , d, N and D. So, this is an important phenomena and important conclusion that how we can have a control over the grinding process by controlling these parameters . The grinding wheel would look softer actually it is a hard grinding wheel but we are manipulating with these factors and then the grinding wheel is facilitated that is the grains are facilitated to be dislodged.

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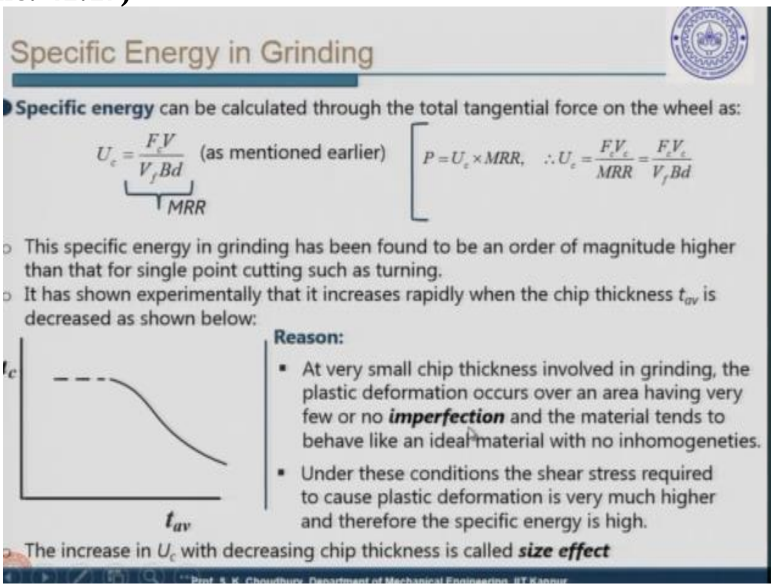

Now, let us discuss some of the factors on which the specific energy depends. Specific energy can be calculated through a total tangential force on the wheel. $P = U_c \times MRR = F_c V_c$

Area into velocity is the MRR, material removal rate. This is how it is obtained. Now the specific energy in grinding has been found to be an order of magnitude higher than that of a single point cutting such as turning.

So, this specific energy in turning with respect to turning in grinding process this is very high and this is explained by the fact that it has been shown experimentally that it increases rapidly when the chip thickness t_{1avg} is decreased. Let us say the curve will be something like this and t_{1avg} is small. For small t_{1avg} the U_c is very high.

Therefore, this curve helped us to understand that why this specific energy in grinding is high at very small chip thickness involved in the grinding. The plastic deformation occurs over an area having very few or no imperfection and the material tends to behave like an ideal material with no inhomogeneties meaning that when we were discussing the defects that when the defects or the imperfections move along with the lattice structure then the force required to deform the material will be less.

I told you that during the discussion on the imperfections. It happens the same way in case of grinding that a very small t_1 uncut thickness or the depth the imperfections are very less normally the imperfections lie at little lower level than the top surface. Therefore, when the grinding happens at the very small t_1, then it is almost without any imperfection and that layer acts like an ideal material and when we have an ideal material, the stress required is very high maybe 1000 times higher. that is $\frac{G}{2\pi}$ r. So, that was for the ideal material, this is what happens in practice in the case of grinding that in grinding, it happens on a very low depth of cut and at that thin layer the material behaves like an ideal material without any imperfection and when there is layer without any imperfection, the force required to deform the material will be very high.

Therefore, the specific energy required will be very high in grinding when the t_1 is small and the U_c is very high because of that this effect is called the size effect. The increase in U_c with decreasing chip thickness, this effect is called the size effect. In case of grinding, the size effect is not the only effect because of which the specific energy is very high.

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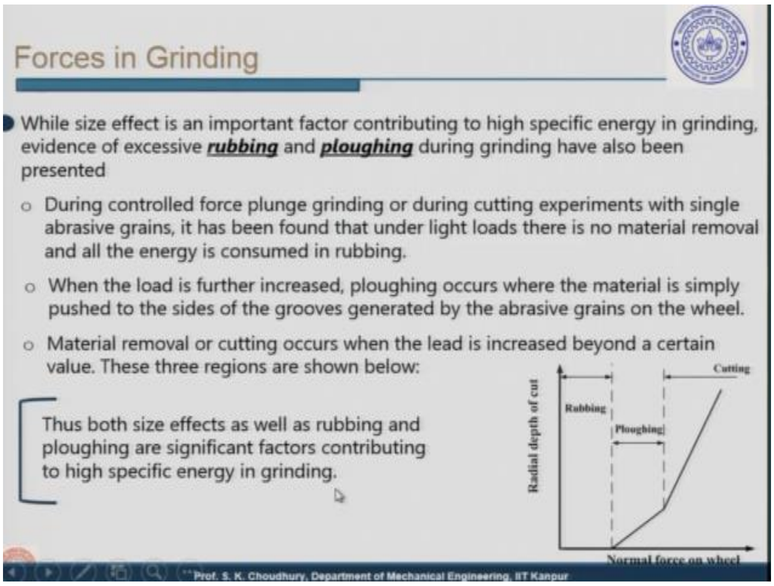

While size effect is an important factor contributing to high specific energy in grinding evidence of excessive rubbing and blowing during the grinding. In case of grinding, unlike in case of turning, when immediately the material removal starts taking place in case of grinding when it comes in contact with the workpiece initially each grain will first rub then it will flow the material then only the material removal takes place.

During rubbing initially and then ploughing when the material is not segregated yet the consumption of the power is very high and the specific energy becomes very high. So that those two factors that means the rubbing and the ploughing along with the size effect because it happens within the very small t_1 the specific energy overall in grinding becomes very high.

If you see the curve during plunge grinding or during the cutting experiments with single abrasive grain it has been found when the load is still light here in this x axis, we have the normal force on wheel and along the y axis we have the radial depth of cut. So, now when the load is further increased first of all let us see that at a very light load there is almost no material removal.

There is no material removal shown here. Radial depth of cut is 0 still and all the energy is consumed in rubbing. Initially, if we consider one grain here suppose the data that we are taking for material removal or the grinding process by one grain. Initially it will start rubbing then it will flow and then it will start removing the material.

When the normal force on the wheel is low at this the radial depth of cut is still 0; no material is removed at this the ploughing action starts and the material removal is not there really because it is ploughing here and it is very low. Energy is consumed in rubbing and ploughing, when the load is further increased ploughing occurs where the material is simply pushed to the sides of the groups generated by the abrasive grains on the wheel.

It is still not removing the material but the material is pushed to the sides like we blow the ground or we blow the rice field. When you will plough the material that means the earth or the mud will be on the sides. Material removal or cutting occurs when the load is increased. At this value of the load, when the load has increased sufficiently, the material starts taking place you can see that the radial depth of cut is significant.

These three regions are shown here. Thus, both size effect as well as rubbing and ploughing are significant factors contributing to the high specific energy in grinding, but this is a very specific characteristic of grinding that in case of grinding, the specific energy becomes very high in comparison to the comparable depth of cut or comparable $t_1$of the other processes like turning.

In case of turning if you compare it with the grinding, the depth of cut is sufficiently large. So, that the defects can be there, dislocations can be there and the same thing happens that instead of $\frac{G}{2\pi}$, the stress that is required for removing the material along with the defects will be 1000 times less. So, in case of turning for example, with a comparable t_1 the specific energy reduces drastically in comparison to grinding. In grinding it happens almost in the ideal depth or through the ideal material.

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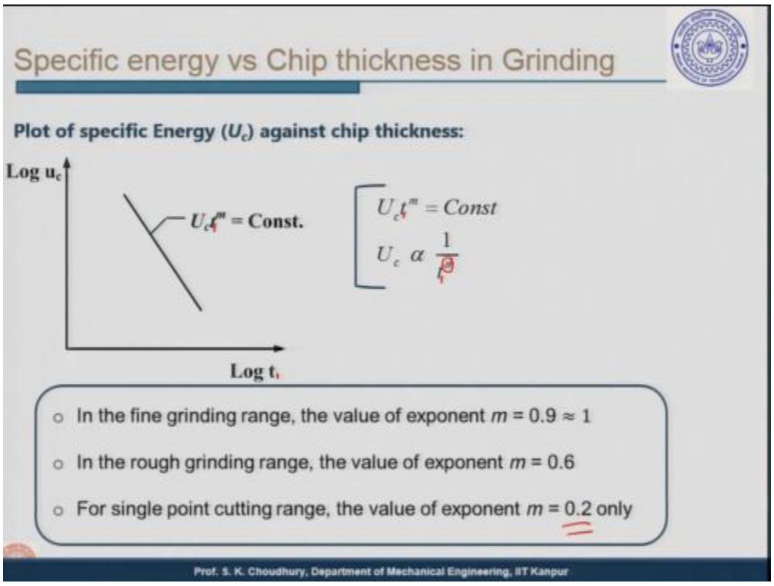

Now, if you see here that if you plot specific energy against the chip thickness in the log scale let us say in the x axis we have the log of the uncut thickness Here it is called the t_1 . Here it is t average in all these cases we have designated this as a t_1.

If you plot that in the log scale the equation will be $U_c t_1^m = const.$ You see it is inversely proportional to the t_1^m . In the fine grinding range the value of exponent m is about 0.9 almost equal to 1 in the rough grinding range the value of exponent is 0.6. And for single point turning or cutting range the value of exponent is 0.2 only.

So, can you see the difference here that in case of grinding this exponent is almost 1. So, $U_c \propto 1/t_1^m$ and in case of grinding this m value is about 0.2. So, this is significantly low in the sense that in case of turning this will not be like in case of grinding, it will not be the size effect. But there will be defects, there will be dislocations and the shear stress which is required to create plastic deformation which will be much less in case of turning.

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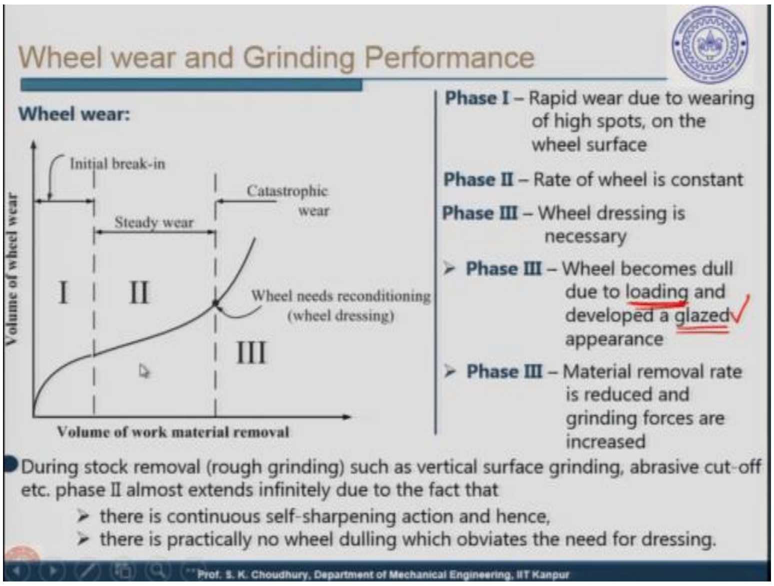

Let us see the wheel wear. The wheel wears out in the following way that we have and the initial where initial break-in, steady wear and the catastrophic wear. This curve is almost the same as we have shown it for the turning tool, if we plot the volume of wheel wear against the volume of work material removal. So, this will be the initial break-in, initially the sharp grains are there.

So, they will have high stress concentration as soon as they come in contact with the workpiece they will be dulled or they will be worn out quickly so, this is the initial break-in. After that it will be very steady because the grains will be wearing out. But this worn out grains will also be dislodged and then new grains will come so the overall wear will be very gradual, it is a steady wear, that is why it is called a steady wear.

After some time the flux will be very high that means the surface will have a very high worn out grains and the wearing action takes place very rapidly and the grinding wheel may fail actually that is called a catastrophic wear. So here it is written phase 1 this is rapid wear due to wearing off high spots on the wheel surface, phase 2 is the rate of release constant as I said that it will be gradual wear. Phase 3 here will become dull due to loading and developed a glazed appearance.

So, loading and glazing I have already explained it to you that once again if the grains are worn out and they cannot be dislodged because the bonding material is very hard in that case it is the wheel glazing and if the wheel structure is very closed that means the voids are very small and the small chips get loaded or get stuck. They cannot come out then that surface will be glazed surface.

In phase 3 also, the material removal rate is reduced because of these 2 factors and grinding forces are increased. Therefore, because of that, high grinding force and metal removal rate or material removal is less, the wear can be more and more and then at a certain point it will actually can break. Now during stock removal, this is the rough grinding such as vertical surface grinding, abrasive cut off etcetera. Phase 2 almost extends infinitely it goes very long.

This is called the self-sharpening action which is a continuous self-sharpening action. The grains on the surface will be worn out, they will be dislodged and then behind them there will be the sharp grains and again those sharp grains will have the varying action. It will go through the wearing and it will be dislodged and then again sharpening and so on.

It will be continuous self-sharpening process and therefore this curve goes very long and it is a steady wear. There is practically no wheel dulling almost which obviates the need for the dressing. Here the wheel racing is not required because it will continuously be self-sharpening and always there will be sharp grains on the wheel surface. So, there will be always more material removal, less force and the less power consumption because always the dull wheels, dull grains will be dislodged and the sharp grains will be coming out from behind the dull grains.

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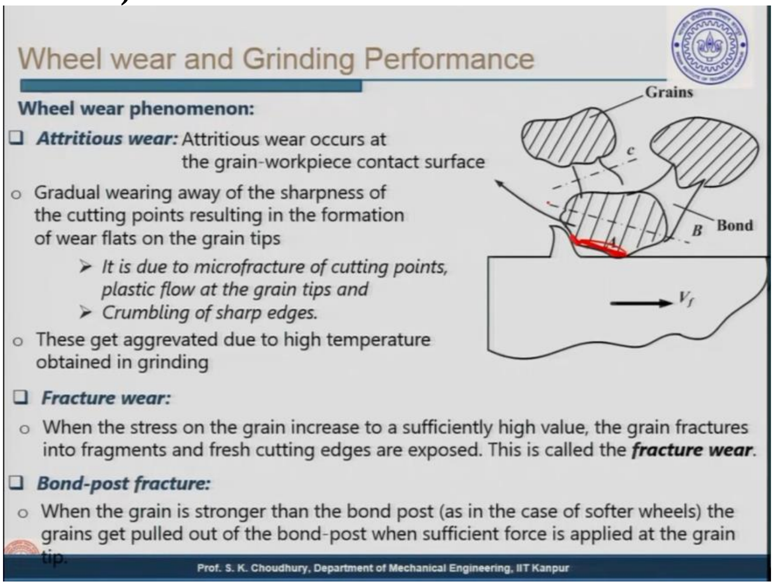

This is the way the grinding wheel actually wears. These are the grains; those grains are rigidly connected to each other in the grinding wheel with the means of this bond; this is the binding material; this is the bond and you know the whole thing is the grinding wheel inside this is exaggerated heavily and it is shown that how the grains are located in the grinding wheel.

Now this is the workpiece and the workpiece is given the V_f which is the feed velocity and the grinding wheel rotates in this direction. Now while grinding when the grinding wheel rotates, since it is in touch with the workpiece, these are the places where the grain will be in touch with the workpiece and gradually the surface will be worn out of the grain. Then the wearing may happen within this line or the grain wear action can happen within the bond also.

So how exactly these wearing action happens though wear out of the grains that I will explain in more details in our next session of discussion. Thank you for your attention.