Production Technology: Theory and Practice
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Lecture – 05
Metal Machining-2: Mechanism of Plastic Deformation

Hello and welcome back to our discussion sessions on industrial or the production technology - theory and practice.

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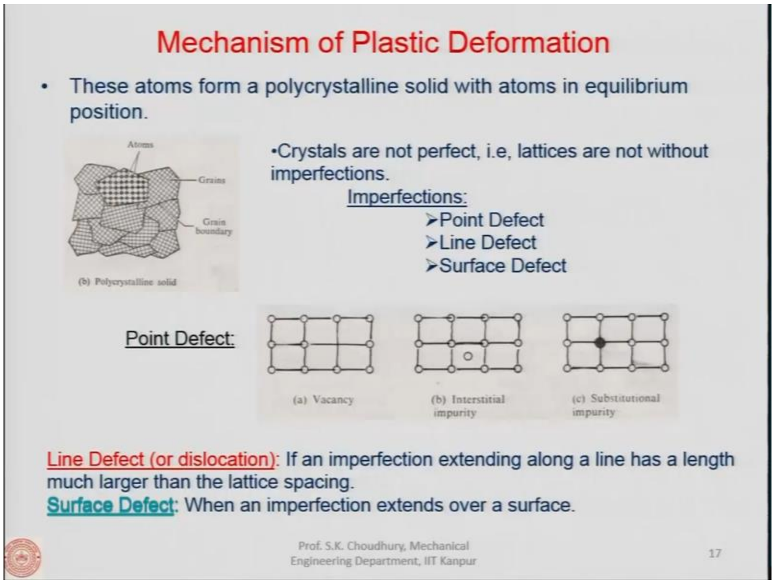

Now let me remind you that so far what we have discussed is the mechanism of plastic deformation and we were discussing that there is a polycrystalline material and the atoms make the polycrystalline solid or the polycrystalline material with the atoms in the equilibrium position as it is shown in here. And then we said that these crystals are not perfect that is lattices are not without the imperfection.

Those imperfections are the defects, which are the point defects, line defects, and surface defects. I explained the point defects through vacancy, interstitial or the substitutional impurity. Then there could be a line defect which otherwise is also called as the line defect, that is if the defect is extended beyond the lattice spacing.

When the defect is extending along the line which is more than the lattice spacing that is the line defect and then when it is all along the surface so that the deformed surface becomes a mirror image of the undeformed surface, this is called the surface defect or you will find that this is also known as the twinning because it is being twined. So, the deformation can also take place by twinning.

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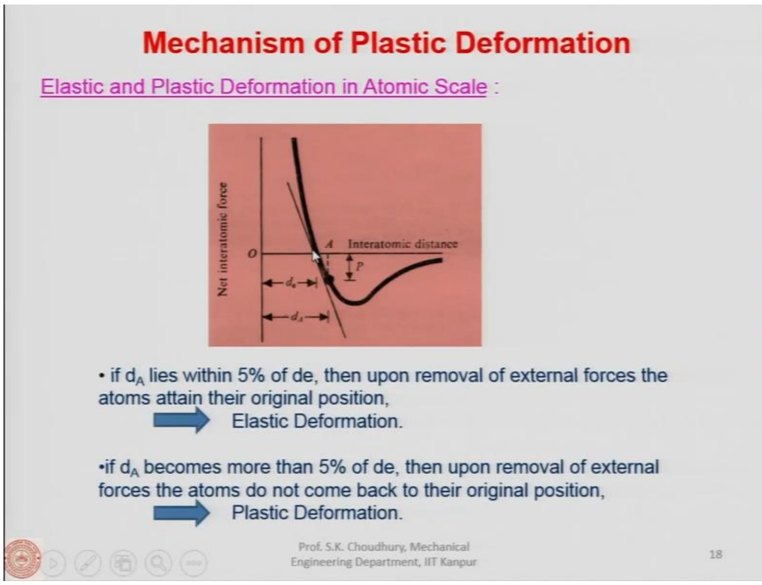

To continue with the mechanism of plastic deformation, elastic and plastic deformation can be explained in the atomic scale in the way that we have the net inter atomic force here along the Y-axis and along the X- axis we have the inter atomic distance. Now inter atomic force and inter atomic distance vary along this line. This is the nature of variation of inter atomic force with respect to the internet atomic distance.

We have seen that when the atoms are closer, i.e. the distance between them is less, the force is more. This curve intersecting the X-axis at a point which is the point of equilibrium where the attractive force and the repulsive force will be the same.

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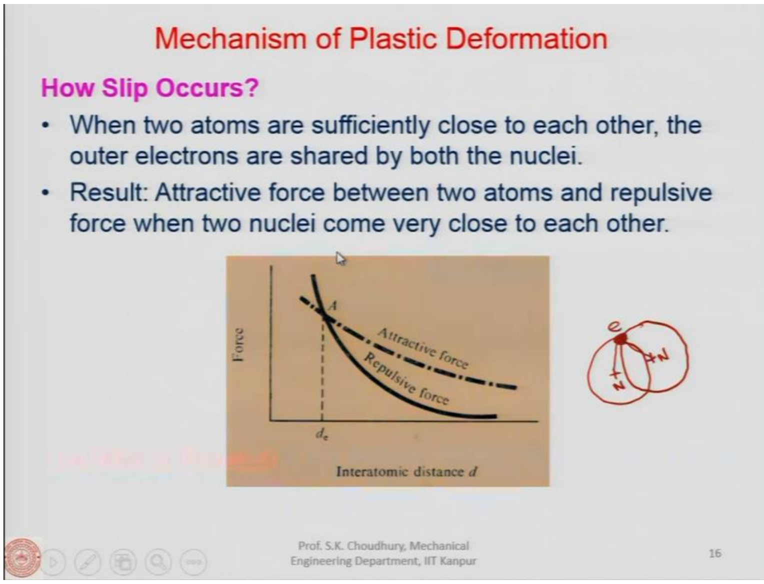

I am talking about this curve if you remember. So, this is the point where the tangent is shown here and this is the 0 point, means here at this point the attractive force and the repulsive force magnitude will be the same. Therefore, this distance shown here is called the equilibrium distance. Now suppose the atom has been moved from this position to this position at ‘A’. ‘Moved’ means there is a shear force applied or strain rate applied.

Because of the high strain rate, the atom in the lattice structure is moved from one position to another position. Let us say from the equilibrium position it has been moved to position ‘A’. This movement will be along this line only because this is the variation between inter atomic force and the distance. Let us say now this distance from here is d_A.

If this distance lies within 5% of the *de*, then upon removal of the external forces, which forced the atom to move from this position to this position, the atoms attend their original position, i.e. it will come back to this position. And this phenomenon is called the elastic deformation because as you understand in the case of elastic deformation it is linear. In that case as the force is removed, the material comes back to the initial length or initial position.

Here also the same happens, that if the atom is forced to move to this position *A* or d_A is the distance which is less than 5%, i.e. 0.5 of the *de*, in that case upon removal of the force the atom will come back to its initial position. This is the reversible process which we call as the elastic deformation. Because there is no permanent deformation. If this becomes more than 5% of the *de* then upon removal of external forces the atoms do not come back to their original position.

So, in that case it will be staying here and the two layers of atoms have moved with respect to each other.Now if you remove the force, still the new position of the atoms will be retained.

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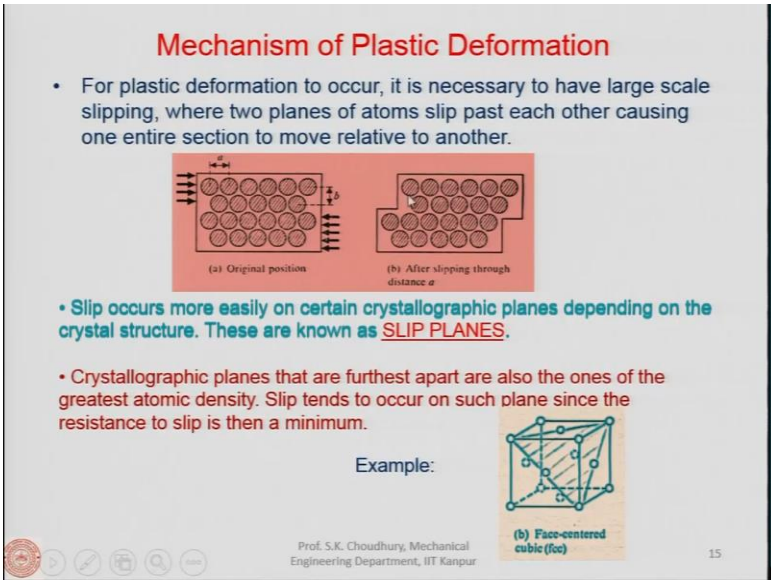

That is like as it is shown here. Initially the shear forces have been applied and because of this the layers of atoms have moved with respect to each other and now it has moved to such an extent or the magnitude of the force has reached to that extent that the plastic deformation started and upon removal of this forces we can see that the layers are not coming back to the initial position; they will stay here.

This is indicative of the plastic deformation. If the magnitude had not been so much, that is less than 5% of the equilibrium position, then it would have come back to the initial position upon removal of the forces.

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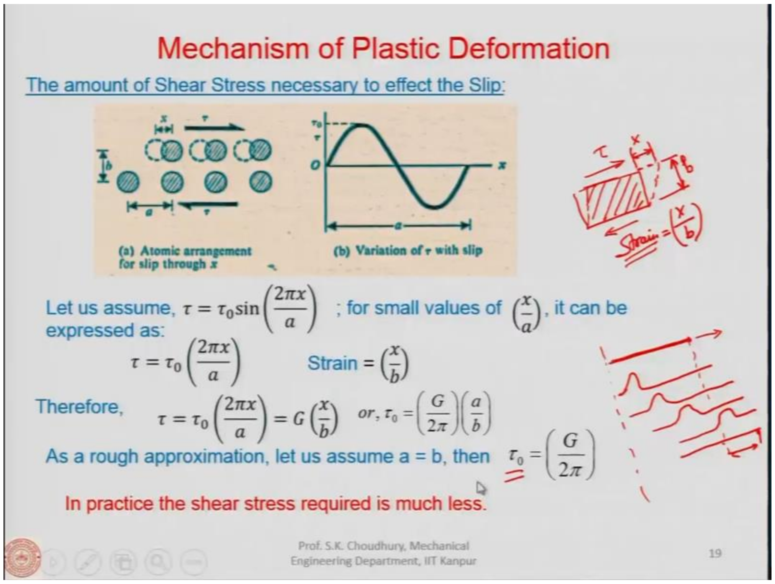

Next, let us see the amount of shear stress that is required for the deformation, meaning that how much force we have to apply for the plastic deformation to occur that we have to estimate because we have to accordingly design the machine because the machine tool ultimately will be involved in removing the material. What is that the movement of the atom we are talking about?

What is the plastic deformation we are talking about? Ultimately, we are talking about the removal of material, that means initially it has to be deformed plastically then it has to be segregated from the main mass that is what is the deformation. Therefore, instead of saying that qualitatively you have to know how much force is required.

This is required for the design of machine tool, so that prime mover can be selected and we can be prepared for the machining. To remove the material from a certain work piece having certain hardness, how much power it will be required? Suppose you have the lattice structure like this; the material that has been given for the plastic deformation has the lattice structure as shown here.

This is the distance that has been moved from here to here because of the application of the shear stress τ . Now there is a shear stress applied here, the direction is like this. This way the shear stress has been applied. The initial position of the atoms in the lattice structure is shown in dotted line and the hatched line is the position it is taking at this moment.

This layer is moving with respect to this layer. Now the distance between the two layers is the *b* and the distance between the atoms that is inter atomic distances *a*. So, these are the 3 parameters *x*, *b* and *a*. Now it has been seen that within the atomic distance *a* the variation of the stress with respect to the displacement is related. As you understand, the stress is related to the displacement.

Because of the stress it is displaced. It will be sinusoidal as shown here and this is one cycle within inter atomic distance *a*. Now this indicates that this is the point which is the maximum stress that is required and that is what we want to find out what is the maximum stress required and this is the shear stress. Normally it has been seen that the sinusoidal curve can be written as $\tau = \tau_0 \sin \frac{2\pi x}{a}$.

This is the equation of the curve since this is a sinusoidal curve. '*a'* is the inter atomic distance, '*b'* is the distance between the layers or the layer thickness. For small values of (*x / a)* we can ignore the sin and then $\tau = \tau_0 \frac{2\pi x}{a}$.

The value of *(x/a)* is really small; you can see that this is the displacement that is in microns; we are talking about the displacement of the atoms that would be very small. Therefore, *(x / a)* can be said to be a very small value. Now the strain is given by (*x / b)* as I explained earlier.

Let us assume a block of thickness '*b*' will be deformed. How much it has been deformed is this, this is the *x* and the distance between these two layers *b*. So, the strain is equal to $\left(\frac{x}{b}\right)$ that is how much it has been moved divided by the layer thickness. This is how we normally find out the strain.

In this case also as you can see that the strain we have written as *x* which is equivalent to this divided by *b* which is equivalent to this distance. Therefore, this shear stress for small values of the x / a is equal to $\tau = \tau_0 \frac{2\pi x}{a}$ which is equal to strain multiplied by Young's modulus or the strength of the material. This into x / b or the strain is the stress or in that case we can find out that $\tau_0 = \frac{G}{2\pi}$.

Now let us assume that approximately $a = b$. In that case τ_0 which is the maximum shear stress required to deform the material to create the plastic deformation, i.e. to create the permanent movement of one layer with respect to another layer of atoms, is equal to $\frac{G}{2\pi}$.

If you look at this equation, this is actually the strength of the material, equivalent to the strength of the material. Now, if we take the value of G of any engineering material, let us say mild steel for example, and divide by 2π , you will see that this value is very high.

In practice the shear stress required is much less; what actually we apply is much less than the $\frac{G}{2\pi}$ and G is equivalent to strength of material. So, G is a constant value for the material and this τ_0 required will vary from material to material depending on the strength of that particular material; more the strength of the material more the stress will be required to deform the material.

In practice it if we had to apply this much of shear stress equal to $\frac{G}{2\pi}$, then the machine should have been very powerful. And it might not have been possible for us to create such a machine so that so much of stress to be created. Since force by area is the stress, the area becoming constant, the force required would have been very, very high.

Force required is very high means that we should have a very powerful motor which will be costlier. Therefore, the entire process will be very costly and the product that you are producing by using that machine and that process will be very costly too. As a result, one cannot compete in the market. Now before I go further why it happens, I should tell you why we are discussing that.

Because the ultimate aim of machining or any manufacturing process is to produce the end part with the proper shape, size, finish, accuracy and the minimum cost. Cost cannot be very high otherwise you cannot compete in the market as a producer, as a manufacturer. In the cost calculation, we will see how those factors can be considered.

Overall, as we have seen that the maximum stress can be found out theoretically which is strength of that material divided by 2π. Now, the shear stress required is less because of those defects that we have discussed earlier. When the shear stress is applied and there is a defect present in the material, and imperfections will always be there in a crystal, in a polycrystalline material.

In that case instead of the entire lattice structure moving bodily, the defects move, as a result what happens? The shear stress which is required will be much less because the defects are the imperfections, they facilitate the plastic deformation process. Therefore, instead of $\frac{G}{2\pi}$ it will be much less and how much less that depends on the kind of density of the imperfection and many other factors.

This can be estimated. Overall, what we are saying is that the imperfections actually help in reducing this value. Let me give you a kind of analogy. If you have seen a carpet being moved, very heavy carpet let us say, carpets are normally very heavy and it is on the floor. This is a reference line I wanted to show you.

Let us say that this is a carpet on the floor and this is the reference line, from here it has to move. If you want to move that carpet bodily it will take large amount of force and a lot of effort because it will have a lot of friction between the carpet and the floor. So, instead of that if you have seen that sometimes it is actually made like this, meaning that a wave is created, this kind of a wave is created.

And then this wave is moved like this, like this, like this as shown in the slide above. Finally, you will see that the carpet has moved to the desired position. It has moved this much from this reference point. This is possible with the help of making this kind of a wave and then instead of the entire carpet moving you can move the wave.

That would be much easier and in that case the force that is required will be much less. Similar phenomenon happens in this case also that in practice when you try to deform a metal plastically, since there are imperfections, the force required will be much less than it is theoretically calculated. As a matter of fact, we will see in one of the processes that the for the plastic deformation within the layer of almost a perfect material, that is an ideal material, the forces will be very high. That means the power consumption for that process will be very high because as I said that power is the product of force and the velocity, $F_c \times V_c$.

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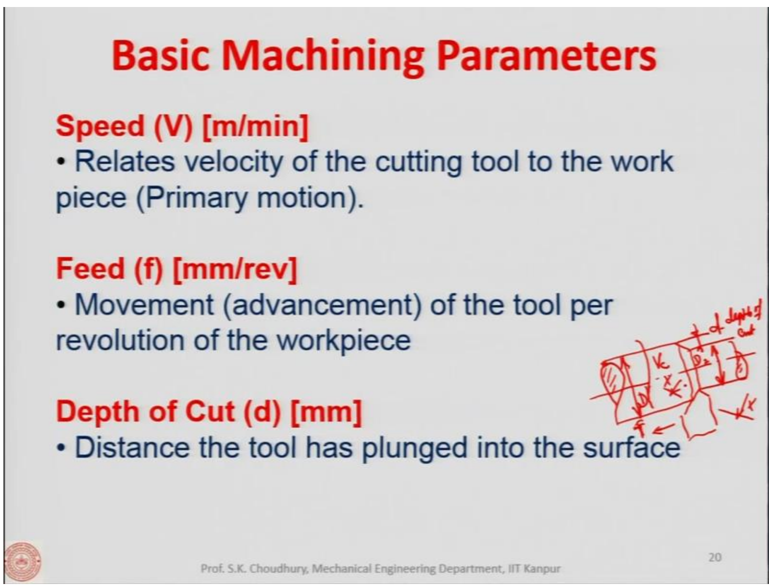

Now let us come back to the basic machining parameters. as we all know and I also told earlier that basic machining parameters are speed, feed and the depth of cut. Speed is normally taken in meter per minute that is that relates velocity of the cutting tool to the work piece that is a primary motion. Now the primary motion that is the cutting speed I narrated it earlier that in case of turning.

For example it is the work piece rotates and the tool is given the feed in case of drilling in case of milling in case of the grinding for example this is the primary motion or the cutting speed is given to the tool either to the drill or to the milling cutter or to the grinding wheel. And the feed is given in all these 3 cases to the work piece, of course in case of shaping it is to the tool as well and the work piece is given the feet.

In case of planning, it is the work piece is given the movement which is the primary motion and the tool is given a feed in that case it is in the case of the planning. it is given in the unit of meter per minute as I said now the feed is the movement in millimeter of the tool in one revolution of the work piece movement is the advancement of the tool per revolution of the work piece, how much the tool has advanced to the work piece material.

Now the depth of cut it is in millimeter, it is the distance the tool has plunged into the surface. for example if we have a part like this and this has been machined like this, let us say this is a cylindrical job this is the tool let us say it is a turning process. Now this is the cutting velocity which is provided to the work piece and this is the feed motion or the feed f this is the direction of the feed which is given to the tool.

Now this is the initial diameter which you started with and we are getting this diameter let us say this is D 1 and this is D 2. D 1 has been reduced to D 2. Therefore, this is the value of the D which is the depth of cut, this is the depth of cut this is the depth of cut how much the tool has plunged into the surface of the material which is being machined.

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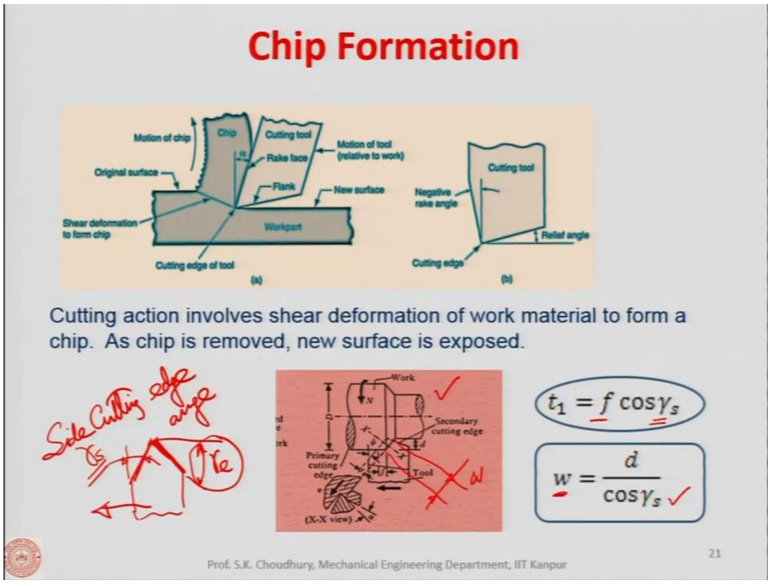

Chip formation: in the case of chip formation we said that this is the plastic deformation and finally it is the fracture which was shown in the stress strain curve or the force elongation curve, i.e. load elongation curve that after the point of instability it goes in a tri axial manner and it fractures means that it actually segregates. So, that is the chip formation. We are getting the chip.

Here suppose you take it in this section, this is the work piece, this is how the chip is moving along the rake face of the tool. This is the cutting tool, here this is the rake face, this is the flank face. Now this is a newly formed surface, newly generated surface; this is how the tool is moved related to work piece. So, this is feed direction. Now this is the chip motion along the rake face of the tool and here is the original surface.

We discussed that the diameters D_1 and D_2 are here. This is the original surface and this is the newly generated surface. The diagram that you are looking at is a sectional view, let us say x, x section of the other one. If you take a section like this you will see this picture.

Inclination of the rake face is defined by this angle. what is this angle? This is the angle between the rake face and a line perpendicular to the cutting velocity vector, here it is not shown but the cutting velocity vector is this V_c which is defined as πDN . N is the RPM; this is the rotation as shown in this diagram. N is the RPM, D is the initial diameter and that you multiply by π toget the V_c .

Perpendicular to the V_c direction is this line. Between this line, perpendicular to V_c and the rake face is the rake angle. So that defines the inclination of the rake face; now there is another angle between the flank face and the already machined surface. This is the angle called flank angle. Flank angle is normally designated by δ, so this is the flank angle these two angles are very important.

Here it is written as relief angle or flank angle; by both names it is known. Either it is a relief angle or it is a flank angle, it is the same angle between the flank face and the already machined surface, this is the line of the edge of the already machined surface. This line indicates this slip line and if you remember I said earlier that the slip line is the line along which the plastic deformation occurs.

Therefore, this is the shear deformation to form the chip and this is called the shear plane, this is the cutting edge of tool. Now the shear plane makes an angle with the direction of the V_c ;this is also an important angle along with the rake angle and the flank angle. This is parallel to V_c and this angle is called the shear plane angle that we normally denote as ϕ. This is the angle between the shear plane and the direction of the cutting velocity vector V_c, this is the ϕ.

So, these three angles that is the shear angle, rake angle and the flank angles are important angles. Cutting action involves shear deformation of the work material to form the chip. As chip is removed, the new surface is exposed. This was the old surface and this is the new surface because this much material has been removed from the blank.

Now here if you see that these are the two same diagrams. If you take and a section X-X, the sectional view is here,you see that this view and this view is the same. So, this view is nothing but another view of this tool. Now here two new concepts are introduced - one is the primary cutting edge, this is the primary cutting edge of the tool, and this is the secondary cutting edge of the tool.

The primary cutting edge lead line is here, this is the tool, this is the work piece and this diagram I have already shown to you and explained that this is the initial diameter, this is the diameter which you have obtained, this is the depth of cut. And if we take the cross section like this, this will be the view, in this view this is the rake angle; the same rake angle that I have already defined.

This is the flank angle here. Now this difference between these two lines and these two lines is that they are at different points of the tool in one revolution of the work piece; that is the feed. This distance that is perpendicular to the line, is called the uncut thickness, t_1. Uncut thickness is given by $f \cos\gamma_s$, where f is the feed and γ_s is the side cutting edge angle, and the width of cut is given by $\frac{d}{\cos\gamma_s}$ where d is the depth of cut. With this dotted line, this is the next position of the tool, that is shown in here in one revolution of the work piece.

Feed is given in millimeter per revolution. So, this is the linear movement of the tool in one revolution of the work piece. Therefore, from here to here this is the value of the feed. And this is the direction of the feed. This is the tool and this is the work piece here, and this is the rake face of the tool.

And the inclination of the rake face with respect to the line perpendicular to the cutting velocity vector, this is the cutting velocity vector, this is the rake angle and between the flank face and the already machined work surface, this is the flank angle that has been shown to you earlier. This is the geometry of the cutting process .

t_1 you can find out from this small triangle, t_1 is here. This is equal to $f \cos\gamma_s$, γ_s is the side cutting edge angle. In the slide the side cutting edge angle is denoted otherwise. If this is the tool in the base plane, as it is shown here, this angle is the γ_s.

So, in this small triangle this value is the t_1 which is equal to $f \cos\gamma_s$. Similarly, the width of cut is from here to here. This width of cut can be found out from the bigger triangle from here. I am just writing this triangle, from this triangle if you see the *w* will be this value from here to here this is the width of cut which is equal to the depth of cut.

Because depth of cut will be this value divided by $\cos\gamma_s$, γ_s is the side cutting edge angle. And as you know that this is the end cutting edge angle. These are the cutting edges; this is the principal cutting edge and this is the auxiliary cutting edge as the tool moves in this way. So, this is the side cutting edge angle.

This is in coordinate system and γ_e will be the end cutting edge angle. This is the geometry of the process and these are the parameters – t_1 and *f* are geometrical parameters, width of cut and the depth of cut are related in this way. So, you realize that the product of t_1 and *w* is equal to the product of *f* and *d*. $wt_1 = fd$ because $\cos\gamma_s$ gets cancelled.

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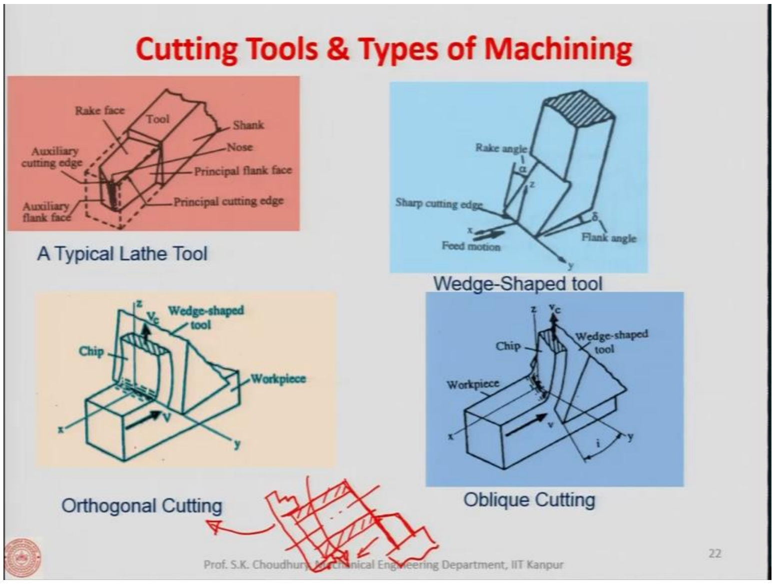

Cutting tools and the types of machining: This is a typical lathe tool and this can be made from a rectangular shape of the work piece as you can see from here. You chop off this much portion. This will be the rake face and this has an inclination which is given by the rake angle. Rake angle defining the inclination of the rake face is the angle between the rake face and the line perpendicular to the cutting velocity vector.

Here this edge is called the principal cutting edge and this edge is called the auxiliary cutting edge. Therefore, with this rake face on which the chip will be flowing we have 2 faces, namely principal flank face here because this is formed by the principal cutting edge and the auxiliary cutting edge and here it will be the auxiliary flank face because this is the auxiliary cutting edge.

Now this portion which is used to clamp the tool in the tool post is called the shank. And here between the principal cutting edge and the auxiliary cutting edge this is not really a very sharp edge and normally a radius is given. That portion is called the nose and the radius which is given is called the nose radius of the tool. Later I will explain why nose radius is important.

This is a 3-dimensional tool as you can find out from the pictorial view of this tool. This is not very convenient and it is not actually easy to take this for the analysis because this has a lot of inclinations you can see that there are quite a few faces. The same tool can be represented as a 2-dimensional tool and here you can see that this is a wedge shaped tool. There is a wedge and this tool can represent easily the lathe tool for analysis.

Because as you can see that this has an inclination and this is the rake face; this is the flank face of the tool. Therefore, the inclination of the rake face can be defined by the rake angle and the inclination of the flank face can be defined by the flank angle. Therefore, it has all the basic characteristics of a tool and from now onwards whenever we will be using a tool for the analysis we will be using the wedge-shaped tool.

Because the wedge-shaped tool has the required parameters like the rake face, rake angles, flank face and the flank angle. Cutting processes are categorized into 2 groups - one is the orthogonal cutting and another is the oblique cutting. Here is a pictorial view of the orthogonal cutting for you to understand that in case of orthogonal cutting the cutting edge of the tool, you see this is also a wedge-shaped tool like this.

This is the cutting edge of the tool which is perpendicular to the direction of the cutting velocity vector. So, the cutting velocity vector and the tool edge cutting edge make a perfect 90^0 angle, i.e. they are perpendicular to each other. If you look at this system of axes, let us assume that we have taken x, y, and z this way since it is strictly perpendicular to the direction of V_c , that is the cutting velocity vector.

Therefore, all the forces will be confined to the x, z plane and the chip will be flowing exactly along the z axis, the x, z plan. There will be no inclination of the chip from z axis because the cutting edge is exactly perpendicular to the cutting velocity vector. When this condition satisfies, in that case we can call that as an orthogonal cutting. In this case all the forces will be confined to one plane, in x, z plane.

For this reason, this condition or this kind of process is called a 2-dimensional process because here the chips will be flowing in one direction that is in the *x, z* plane exactly along the z axis; this is perpendicular to the cutting edge. In case the tool is inclined with respect to the cutting velocity vector, as you can see from this diagram, that the tool edge which is here is inclined with respect to the cutting velocity vector by an angle of *i* which is called the tool inclination angle.

In that case, this kind of cutting process is called the oblique cutting. In oblique cutting apart from the tool being inclined or rather we will say that because the tool is inclined with respect to the cutting velocity vector, the cutting is 3-dimensional because the cutting forces will now be located in all planes like *x, y, z* plane and the chip will no more be flowing exactly perpendicular to the cutting edge.

But it will be inclined with respect to the *z* axis and inclined to that side where the resistance to flow will be less that we will discuss later. Right now we should understand that since it is inclined, therefore cutting forces will be located in all x, y, z planes and the chip will be flowing not perpendicular to the cutting edge but inclined to the z axis. It will not be flowing in x, z plane anymore like in the case of the orthogonal cutting.

Therefore, this condition is a 3-dimensional case and as you understand that in case the tool is inclined, when it will approach the work piece it will grab the work piece gradually. You can see that in case of orthogonal cutting, when the tool approaches the work piece, it will grab the work piece all at a time; the entire cutting edge will be grabbing the work piece at a time.

Whereas, in case of oblique cutting the material will be grabbed gradually because it is inclined and therefore the tool strength available will be more. For this reason the oblique cutting is normally used in practice. You will see in all practical purposes the cutting processes are oblique cutting where the tool is inclined with respect to the cutting velocity vector. Probably one example that comes to my mind at this moment is this.

Let us say if we have a work piece like this, suppose the work piece is mounted in a 3-jaw chuck. Let us say this is a cylindrical work piece mounted in a 3-jaw chuck and this is the tool which is given a feed. This is an example of an orthogonal cutting. As you can see that this is parallel to this.

Therefore, the chip will be flowing exactly along the x, z plane or the z axis. This will be perpendicular to the cutting edge but for any other cases, the chip will not be flowing perpendicular to the cutting edge but it will flow along all the x, y, z planes. Now, you understand the difference between the orthogonal cutting and oblique cutting.

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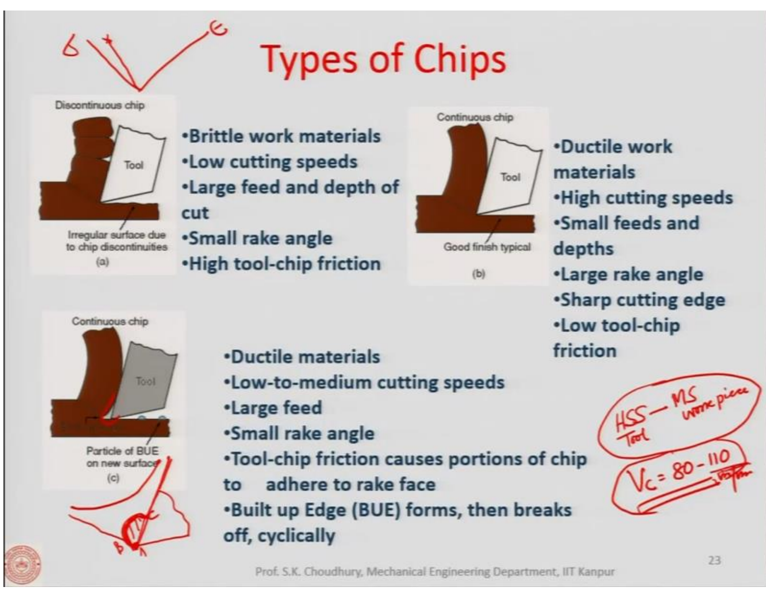

We will see the type of chips. Initially if you remember I told you that depending on the cutting parameters, work piece, combination of the work piece and tool material, and depending on the tool geometry, we will have different types of chips. And by the chip morphology or the type of the chip that is being produced during the process, you can diagnose many of the characteristics of the process.

You can improve the process by improving some of the parameters. Let us say we will start from here - one type of chip is a continuous chip. In case of continuous chip, it occurs when the material work piece material is ductile. Now other factors which affect the formation of the continuous chips are the high cutting feed, small feeds and depths depth of cut, large rake angle, i.e. this rake angle has to be large.

As well as sharp cutting edge; cutting edge cannot be rounded off, low tool chip friction, that is the coefficient of friction between the rake face of the tool and the chip should be low, in that case the continuous chip will occur. Continuous chip will be produced because it is a ductile material and it will be continuously flowing along the rake face of the tool. So, continuous chips need to be broken.

Because we cannot allow the chip to be infinitely continuous. In that case it will entangle with the work piece or with the tool and it can rub against the work piece, it can rub the tool, spoil the tool angle, spoil the already machined surface precision and so on. Therefore, when there is a ductile material which is used as a work piece material then we need to have the chip breaker, i.e. the continuous chip has to be broken.

Chip cannot be broken all the time manually you understand. So, there are different kinds of chip breakers which are normally installed on the the rake face of the tool. When the chip is being formed, it will hit the chip breaker which is often a protrusion on the rake face and it will get broken. Alternatively, we can create a crater kind of thing on the rake face.

Suppose there is a crater deliberately made on the tool rake face, in that case when the chip will be formed it will slide along the crater, it will curve more and this crater will facilitate the chip to be broken. Either way the chip can be broken which is advantage in our case because in that case it will not be disturbing the cutting process. Once again, ductile work piece material, high cutting speed, small feed and depth, large rake angles, sharp cutting edge and the low chip tool friction coefficient of friction are necessary for the continuous chips to occur.

These are important parameters for which the continuous chips occur. Another type of chip when the work piece material is brittle is the discontinuous chip. In this case continuous chip cannot be formed because if you remember from the stress strain curve, I will just remind you that this is the stress, this is the strain and for brittle material it will break here, it will not go to the plastic zone, it will only be elastically deformed and then if we increase the load or increase the stress it will be broken.

Therefore, if the work piece material is brittle, in that case the chips will be broken and the discontinuous chip will be occurring which will be flowing again and coming out on the rake face of the tool. The conditions for the discontinuous chips to occur are the brittle work piece material, like Cast Iron which is the representative brittle material.

Apart from that the low cutting speed is required. Here it was the high cutting speed. So, it is opposite to that. In fact, all the parameters are opposite to the condition for which the continuous chips occurred; large feed and depth of cut, small rake angle, and high tool-chip friction. When all these factors exist then discontinuous chips are produced. Now, is there any benefit, is there any advantage of the discontinuous chip?

I told you that one disadvantage of the continuous chip. In case of discontinuous chip also, we will have certainadvantages and some disadvantages. Since chips are breaking, so majority of the heat will go away with the chip because it is broken and is not in contact with the tool. This is one of the advantages.

For the continuous chip, since it is flowing continuously, it is always in contact with the rake face of the tool. The chip is also very hard. I repeat once again that hard because of the plastic deformation in the shear zone and additionally because of the friction between the chip and the rake face of the tool. The generated heat will be conducted to a large extent to the tool because the chip, while flowing, is in direct contact with the tool all the time because it is a continuous chip.

Whereas, in case of discontinuous chip, since the chip is breaking, it is not in constant touch with the tool rake face and less heat will be conducted to the tool, this you can consider as an advantage of the discontinuous chip. Now the disadvantage of the discontinuous chip is that each time the chip breaks, it actually gives some kind of an impulse. So, there could be a fluctuation in the cutting force.

And that can keep some kind of feed mark on the already machined surface. So, this is a disadvantage while the discontinuous chip occurs. The third kind of chips is the continuous chip with the built-up edge is called the BUE in short form which is very popularly expressed. Built-up edge occurs under certain condition of temperature and pressure.

When the pressure and the temperature reach a certain level then instead of chip flowing along the rake face of the tool, a very thin layer from the chip will be removed. Very high pressure and very high temperature is generated at the tool tip. Similarly, at that temperature and pressure a very thin layer from the rake face of the tool will also be removed.

It is because of high strain rate of deformation, high pressure, and high temperature at a certain level of speed cutting speed. Now since the chip surface is nascent because a thin layer has been removed and the rake face surface is nascent also because the thin layer also has been removed from there, these two surfaces will have the affinity to each other and they will get welded. As they get welded, in that case there will be resistance to chip flow and it will restrict the flow of the chip along the rake face of the tool because it is welded.

So, it will resist the flow of the chip. Therefore, the chip will not be able to flow and it will pile up. This piling will further resist the chip flow. That piling which is the welded junction, will grow in front of the tool tip. When it will grow to a sufficient dimension, sufficient size, it will be unstable and it will break.

When it breaks, if the same condition of temperature and pressure exists, then again it will start getting piled up because those two nascent surfaces again will be welded and it will be resisting the chip flow. Chip, instead of flowing along the rake face of the tool, will get resisted and it will pile up in front of the tool. Finally what happens is that if this is the tool, so in front of the tool it will be piling up.

So, this is the piling in front of the tool which is called the built-up edge. Now when it breaks you can see that a part of it remains on the already work surface, this is the already work surface and part of it will be embedded in the chip and it will also be on the tool tip. What does it mean that it will be on the tool tip is that the tool angle will be changed.

Because once it is piled up here in front of the tool edge, in that case the rake angle as well as the flank angle is change. Moreover, since it is a dynamic process, meaning that the built-up edge piles up, gets bigger and bigger, and then breaks and again it started being built up. Therefore, this is dynamic and all the time this rake angle and the flank angle will be changing.

I will tell you later on, I will derive and show you that as the rake angle changes the cutting force also changes, cutting force changes means the power consumption changes. In that case the cutting force will fluctuate because of the change in the rake angle of the tool. Therefore, the cutting process will not be perfect in the sense that surface finished may be affected because of that.

This is the disadvantage of the built-up edge formation and therefore we should avoid getting the built up edge and as I said that part of the built up edge will remain on the work piece surface. It will spoil the surface finish of the already machined surface and that is another disadvantage.

Here I will exaggerate the piled up built-up edge so that you can all see this. Now the built-up edge material is very hard because it is strain hardened material, because chip is being stain hardened because of the plastic deformation. So, this is a strain hardened, very hard material which gets piled up in front of the tool.

When it breaks what happens is that if we draw the curve of the stress along the rake face , the stress is maximum here because at the tool edge, at the tool tip the pressure is maximum, forces maximum. Therefore, the stress is maximum here and the resistance to the shearing will be maximum along this line. Whereas, as you go inside the chip, the hardness will be less because of this curve as you can see.

Therefore, the resistance to the plastic deformation or to the shearing will be less along this. Let us say this is A, this is B, and this is C. Resistance along the A, B, C will be less because the stress is maximum along the A, C. Therefore, when this piling built-up edge will break, it will break along the A, B, C and not along the A, C.

Had it broken along the A C, in that case it would not have sticked to the rake face of the tool. Since it is breaking along the A, B, C, so it will remain there, it will pile up. So, this will spoil the geometry of the cutting tool, particularly the rake angle and the flank angle and there will be fluctuation of the force. I hope this is understood; that this is the mechanism of the built-up edge formation.

I would like to repeat that the built-up will not form all the time but for a particular condition of temperature and pressure. Let us say for example in case of combination of high-speed steel and the mild steel, mild steel is the work piece and the tool material is high speed steel, for this combination of the tool and the work piece this cutting velocity lies within *80-110 m/min*.

This is the range at which for this particular combination of tool and the work piece material, the condition happens when a thin layer will be ruptured from the chip and from the rake face of the tool and when this cutting speed goes over 110 m/min, this situation does not arises. The reason for that I will explain to you in our next session of discussion. Thank you very much for your attention.