Machining Science – Part I
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Lecture – 03

Hello and welcome to the session 3 of discussion on Machining Science course. While discussing the mechanism of plastic deformation in the atomic scale in the previous session, the session 2, we said that for the plastic deformation to occur, there has to be a large scale slipping where the two layers of atoms slip pass each other causing the permanent deformation; causing the two layers to stay even if the force or the stress is taken out.

We also said that the slip occurs in the plane or within the plane which are farthest apart from each other. That means, in between the two layers of atoms which are farthest apart from each other because when the atoms are farthest apart from each other, in between them the resistance to plastic deformation will be minimum. The plastic deformation occurs along that line which is called the slip line or slip plane.

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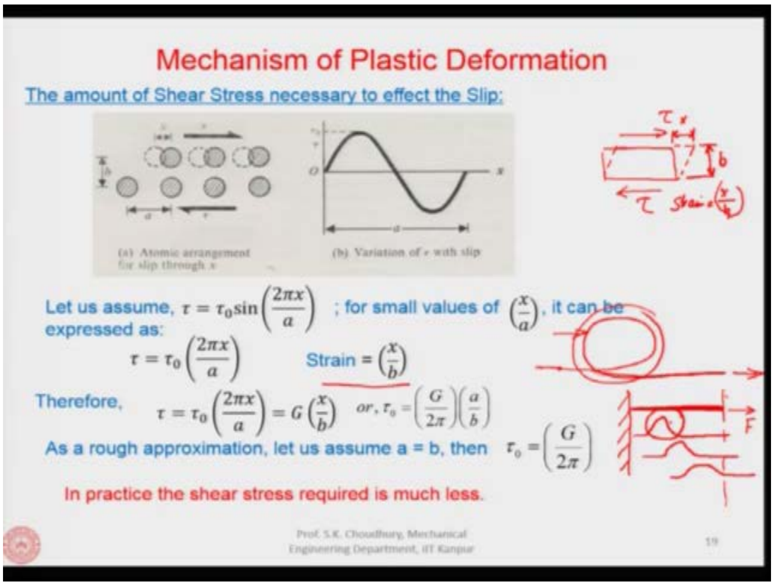

Then we started discussing the amount of shear stress necessary to affect the slip. Here we said that if we had the equilibrium position or equilibrium lattice structure and when a stress is applied with sufficient shear force, in that case the atoms will be moving from the stable position to the next position because of the high strain rate of deformation and the distance moved by the atom is *x* and the distance of between two layers of atoms is *b* and the atomic distance is *a*.

Within the atomic distance the stress can vary sinusoidally. Let us assume that this curve can be written as $\tau = \tau_0 \sin\left(\frac{2\pi x}{a}\right)$ where, τ_0 is the maximum stress that is required for the slip to occur or the maximum stress which is required for plastic deformation.

Now $\frac{x}{a}$ is a very small value. Therefore, for small values of $\frac{x}{a}$, $\sin\left(\frac{2\pi x}{a}\right)$ can be assumed as $\left(\frac{2\pi x}{a}\right)$, because *x* value is very small.

Now the strain because of the stress applied τ which is the shear stress applied, the strain can be considered to be this movement, *x* divided by the distance between the layers - $\frac{x}{b}$.

Similarly, if *x* is the movement of the atoms and *b* is the distance between the two layers, it is equivalent to the thickness of this block, then the strain can be given as *x* upon *b*. Now, this $\tau = \tau_0 \sin\left(\frac{2\pi x}{a}\right)$. This can be said to be equal to the strain multiplied by the shear modulus, i.e. $G\left(\frac{x}{b}\right)$, where *G* is the shear modulus.

Therefore, τ_0 can be expressed as $\tau_0 = \left(\frac{G}{2\pi}\right)\left(\frac{a}{b}\right)$ which is the maximum stress that is required for the slip to occur. As a rough approximation, let us assume that *a* is equal to *b*, then τ_0 is equal to $\tau_0 = \left(\frac{G}{2\pi}\right)$.

Now, if you see the value of $\left(\frac{G}{2\pi}\right)$, this is the strength of the material. So, take any material, take the strength of the material, Young's modulus and divide by 2π, you will see that this is a very high value and it is almost impossible to apply that much of a stress so that the permanent deformation or the plastic deformation occurs.

In practice, however, the value of the maximum stress that is required for the permanent deformation or for the material removal is much less than the value that you are theoretically getting. Why so, let us see.

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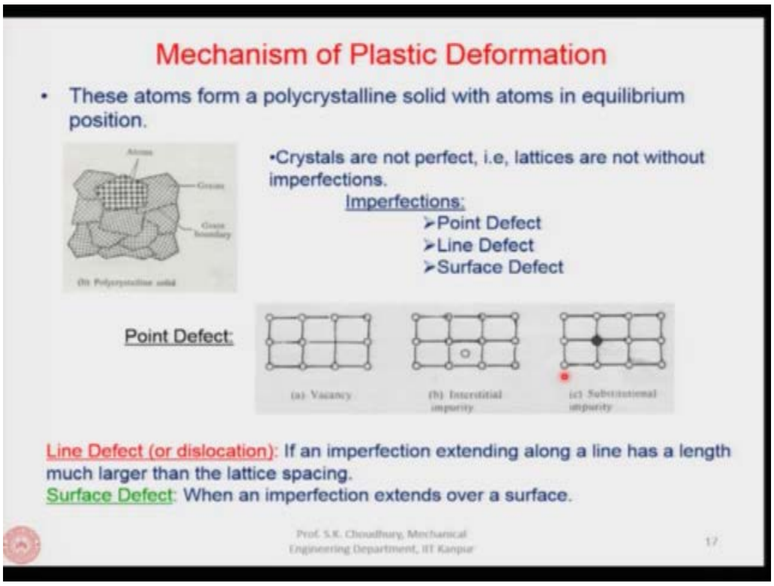

Now, coming back to the defects or the imperfections, we said that any polycrystalline solid does not come as a perfect solid and all these polycrystalline solids normally have some kind of a defect, either it is a vacancy or it is an interstitial impurity or substitutional impurity. It may be a line defect, it may be a point defect or it may be a surface defect.

Now, when the shear stress is applied to the material with the imperfection or with the dislocation or with the defects then instead of the bodily moving the material, the imperfections move. Now what is the imperfection? Let us try to find out what is a defect. Defect means something that the lattice structure does not want.

Now for example, suppose a human being got sick; what it means is that we have temperature, we have fever because we are not well; some virus, some bacteria has gone in. Those are the foreign materials and our organism does not want those materials or those bacteria and the virus to be in, and through the temperature the organism is reacting in that way to take them out.

So, normally if you have noticed, the experienced doctors advice not to take any medicine for reducing the temperature because temperature or the fever is the natural way of organism to take out the virus or the bacteria or whatever is inside because of what we are ill. This is an analogy. Similar phenomenon happens in the lattice structure of the material. These are the defects which the material does not want to be there and for example, in case of vacancy the material will always try to have one atom in the vacant place.

So, this atom will come here, next will be vacancy here. So, this atom will come here and so on. Here for example, this will be moved because this is something which the lattice structure does not want, it is a defect. For example, in case of substitutional impurity, this atom which is substituted which is substituting one atom in the original lattice structure, this atom will be pushed out.

Meaning, that when this stress is applied, these defects, whatever defect there is, these defects will be moving instead of the bodily movement of the whole lattice structure or the material. In practice this will be much less than the $\left(\frac{G}{2\pi}\right)$ and it is actually thousands of times less than that which makes us possible to apply sufficient force which is possible to remove the material. Otherwise, the machine tool which is actually creating this stress, the shear stress would have been very bulky and had to be very powerful to apply this much of shear stress.

I will give you an analogy: for example, if you have noticed sometimes on the roads the laborers are laying the long and heavy cables of large diameters.

If you have noticed that, those cables are in the big wooden bobbins. So, to pull those kinds of big and fat and higher diameter and heavy cables bodily is very difficult. So, the laborers actually make a loop kind of a thing like this and they actually push this loop, so that this loop being round, can actually be rolled.

So, instead of frictional μ that is the coefficient of friction, it will have the rolling friction which is much less. So, instead of moving that the whole cable heavy cable bodily, if you actually roll that, then it can be moved the same way, but with much less force.

Same thing can be said about the defects in the lattice structure. For example, you must have noticed that in case you have to move a very heavy carpet on the floor and if you have to move that bodily you have to apply a large force. Instead of that if you actually make a wave and then if you move that wave, then ultimately what you see that the whole carpet will be moving, but the force which is required to move that will be much less.

So, this is an analogy; it is kind of a defect in the lattice structure; And all these defects are made so that the shear stress or the force required for creating the plastic deformation or the slip could be much less.

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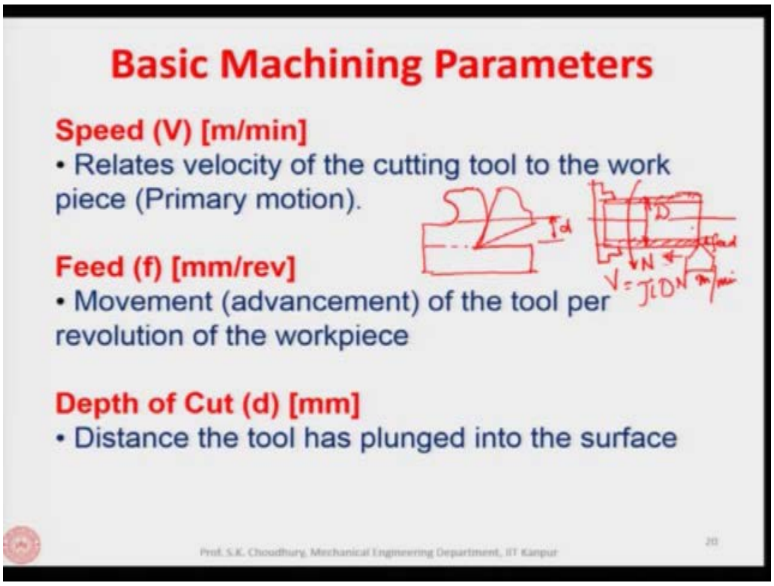

Next, we will discuss the basic machining parameters. In machining there are three basic parameters. One is the speed which is given in meter per minute or millimeter per second or meter per second. This relates the velocity of the cutting tool to the work piece. This is the primary motion, meaning, that it is the cutting speed.

Let us take an example of the turning process. In turning process the primary motion is the revolution per minute of the work piece. Let us say this is the turning process for this work piece which is fixed in the three jaw chuck. And if the diameter is D, the rpm is the N, then the cutting speed is the πDN . This is the cutting speed, V which is in meter per minute.

Take for example, the drilling process; in drilling process the drill rotates and the work piece is stationary. So, the primary motion for the drilling operation is the rotation of the drill. In case of turning, the tool moves parallel to the axis of the work piece. This is known as the feed; that means, the material is fed to the tool so that the material can be removed.

This is called the feed which is given in millimeter per revolution, this refers to the movement or advancement of the tool per revolution of the workpiece; that means, in one revolution of the workpiece, how much the tool has moved in this direction if you are giving the feed in this direction.

So, how much the tool has moved in this direction when the work piece has moved one rotation. This is particularly applicable to the turning process. In case of milling and drilling also it is similar. In case of milling, it is little different because there are teeth. So, we will discuss it separately.

Next is the depth of cut; this is the distance the tool has plunged into the surface. For example, in this case this was the original diameter and the tool is cutting or taking this much, removing this much material. So, this is the material or this is the value of the depth of cut.

If we look at this in the other view, suppose this is the work piece material and this is the tool. So, here we have the tool and this tool is interacting with the work piece because of which this much material has been moved. So, this is the depth of cut and in case of drilling or in case of a milling, the concept remains the same meaning that the concept of the distance the tool has plunged into the surface for all turning, milling, drilling, are remaining the same.

So, the speed, feed, and the depth of cut are the basic machining parameters for all machining processes like turning, drilling and milling. Depth of cut is given in millimeter obviously, because it defines how much the tool has plunged into the material to remove the material.

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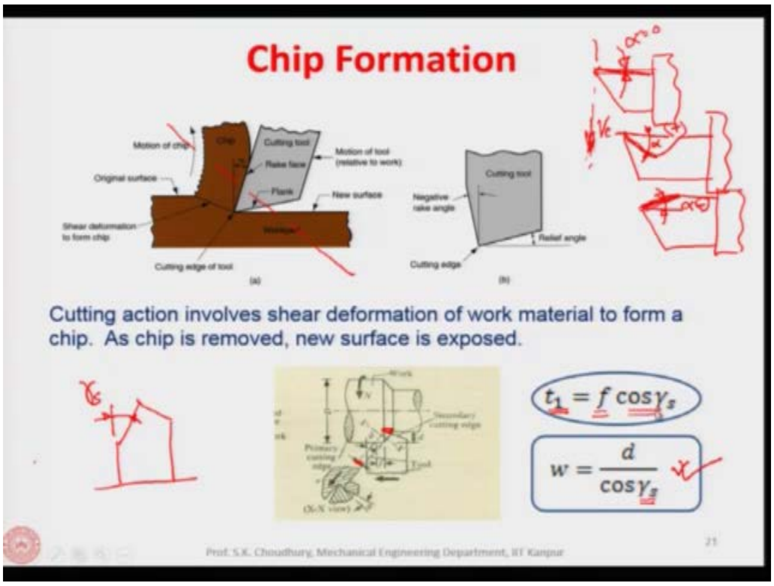

Now, let us see the chip formation, how the chip is being formed. I have shown you this picture, it is similar to that, this is another view, and here what is shown is the cutting tool. This is the cutting tool, this is the work piece and when the tool has plunged into the work piece of this much distance, this is the depth of cut, then the material is being removed because there is a permanent plastic deformation. This is the rake face, and the rake face makes an angle with the line perpendicular to the cutting velocity vector which is called the rake angle.

This is the new surface which is being generated after the removal of the depth of cut. And this is the shear deformation to form the chip and this plane is called the shear plane. We will call it as a plane at this moment because here it is shown as a line. The angle between the shear plane and the cutting velocity vector will be the shear plane angle.

Cutting tools can be of different kinds with different rake angles; that means the different inclination of the rake face with respect to the line perpendicular to the cutting velocity vector. And depending on that you will have the positive rake angle, 0 rake angle or the negative rake angle. For example, the tool can be like this, tool can be like this or the tool can be like this (refer to the slide above), with different rake angles as mentioned earlier.

So, as we said the rake angle is the angle between the rake face and a line perpendicular to the V_c. What is rake face? Rake face is the face along which the chip moves. Always you can determine, if you look at the cutting process, you will see the chip flows along the rake face.

So, here the chip will be flowing along this surface, the chip will be flowing along this surface or the chip will be flowing along the surface which are rake surfaces. So, this is the angle between the rake face and this is the line perpendicular to the cutting velocity vector; cutting velocity vector is here and this is the line perpendicular to the cutting velocity vector. So, this will give you an angle which we will call as a rake angle and this rake angle is a 0, meaning it is a straight plane.

In the second diagram, this is the line perpendicular to the cutting velocity vector again and this is the angle which is forming with the rake face of the tool and this angle is also rake angle and here the rake angle is positive. This would be the positive rake angle. This rake angle is called a negative rake angle in the third diagram; this α is negative. So, for example, here you can see the negative rake angle all these aspects in details we will also discuss little later.

Now, the cutting action involves shear deformation of work material to form a chip; as chip is removed the new surface is exposed. As you can see here, chip has been formed and because of that the newer surface is generated.

In the sketch a cross section X-X is shown which will reveal the view as shown in the other diagram. This sectional view also reveals the value of uncut thickness t_1 and the rake and flank angles of the tool.

In this picture as you can see that this is the value of the depth of cut and if you again take a cross section - cutting edge here. So, in that case you will find a picture which is similar to that and here you have seen that this is the rake angle. So, this rake angle is shown here, this is the between the rake face and a line perpendicular to the cutting velocity vector, this is the cutting velocity vector.

Here it has not been shown, but this is the one which is the width of cut. This is the width that is expressed as $\frac{d}{\cos\gamma_s}$, where d is the depth of cut and γ_s is the side cutting edge angle.

Now if you take this triangle alright, this triangle will explain this equation; this is w, which is equal to $\frac{d}{\cos\gamma_s}$. Suppose if the tool is like this so, this is the side cutting edge angle. This is in a particular nomenclature; we will discuss that the in different nomenclatures it is called in a different way. So, in the coordinate system particularly, going ahead I should tell you, that this is called the side cutting edge angle.

So, if you take the $\frac{d}{\cos\gamma_s}$, this will give you the width and the t_1 which is called the uncut thickness; the uncut thickness is given by $f\cos\gamma_s$. So, this you can find out from this very small triangle, you can find out the t_1 which is the uncut thickness. These parameters we will discuss in a more details at a later stage.

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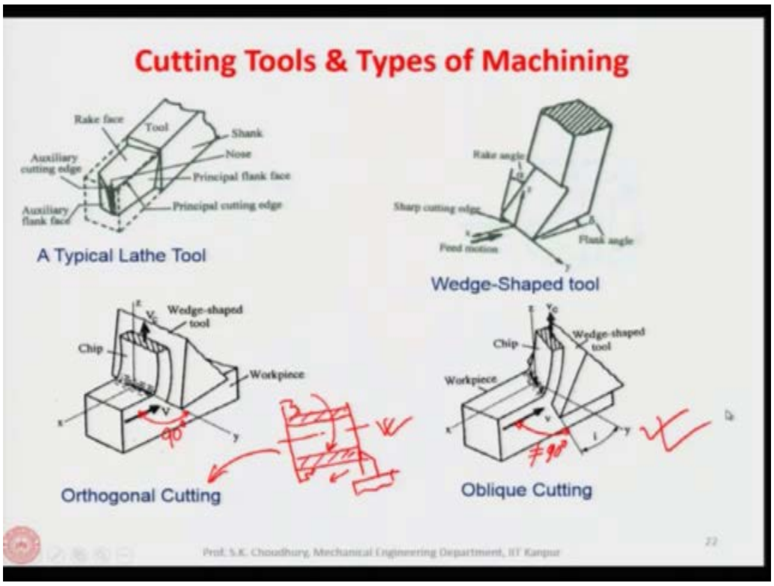

Now we will discuss about the cutting tools and the types of machining. This is a typical lathe tool, as shown in the slide. Here we have the shank, this is called the shank which is the portion by which the tool is clamped in the tool post and then we have the rake face, we have the principal flank face, this is the principal flank face.

This edge is actually taking part in the machining. This is therefore, called the principal cutting edge, and since it is principal cutting edge, this is the auxiliary cutting edge and since this is the principal flank face, this one, this side, is the auxiliary flank face. These parameters, such as, rake face, principal flank face, principal cutting edge, auxiliary cutting edge and the auxiliary flank face - are the most important parameters or important factors in the turning tool.

The lathe tool is quite complicated because this is the three-dimensional. Now to represent or analyze the tool in the 2-D, in the two-dimensional sketch, this is easier. So, in all analyses, in most of the analyses in the book you can see and we will also take example of the wedge shaped tool. This is called the wedge shaped tool.

Here the basic parameters are the same; that means, we have a rake face here and we have a flank face. So, in a wedge shaped tool we are simplifying this keeping the rake face and the flank face here so that we can get the rake angle and the flank angle, and all the analysis purposes are now become easier if you represent the turning tool as a wedge shaped tool.

Overall the machining process can be subdivided into two basic forms; one is called the orthogonal cutting as we know and another is the oblique cutting. The basic feature of the orthogonal cutting is that when the cutting edge is absolutely perpendicular to the direction of the cutting velocity vector. Meaning that between this line that is the cutting edge of the tool and the V_c there is a 90^0 angle.

Meaning that cutting edge makes an angle of 90^0 with the cutting velocity vector. So, this is the orthogonal cutting and in case of oblique cutting the tool is inclined as you can see. And here, the angle between the cutting velocity vector and the cutting edge no longer remains 90^0. So, the is tool is inclined.

You understand that when the tool is inclined, the material that will be grabbed by the tool will be gradual. In case of orthogonal cutting, when the tool is not inclined the tool will be grabbing the entire material at one time. The work piece material will be grabbed by the tool gradually because it is inclined.

So, the strength of the tool available will be more in case of the oblique cutting and that is the reason why the oblique cutting is normally used in practice because of the availability of the more strength or because of the more strength of the tool.

We do not want the tool to be a worn out faster and if the material is grabbed at a time, then there will be crumbling of a tool material. Tool maybe broken in one word and the life of the tool will be decreased. Therefore, in most of the cases, practical machining operations are actually the oblique cutting where the tool is inclined with respect to the cutting velocity vector and the cutting edge is not perpendicular to the cutting velocity vector.

This is the basic difference between the orthogonal cutting and the oblique cutting. There are certain orthogonal cutting, very few, and one of the examples what I can recall is the turning of a pipe as shown in the slide. Let us say, this is clamped in a three jaw chuck. This is the tool which is given feed when the workpiece is rotating.

So, this is one example of the orthogonal cutting, otherwise very few examples are there, most of the cases it is the oblique cutting in practice. More details we will discuss in the next discussion session.

Thank you very much.