Basics of Mechanical Engineering-2

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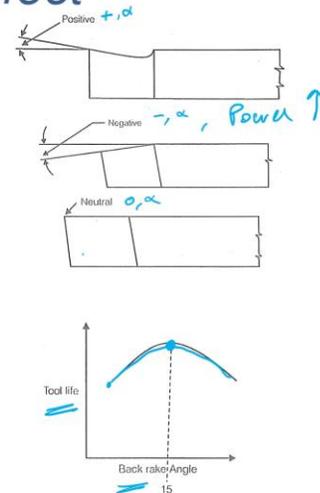
Week 09

Lecture 34

Basics of Machining (Part 2 of 7)

Welcome to the continuing lecture in Basics of Machining.

Now, let us try to see the effect of these angles. So, this is the rake angle. So, now it is called as positive rake angle, it is called as negative rake angle and it is called as neutral, zero rake angle. So, machining strong or brittle materials, smaller rake angles are used.

So, that means to say positive. So, brass and other material we try to choose zero or positive rake angle. If the tool material is brittle like ceramic and carbide, negative rake angle is used. So, if the tool is brittle why in brittle means what happens there are already

several cracks brittle like ceramics and carbides negative back rake angle have to be provide because they want the tool to be stronger. Because in ceramic cracks can be easily done, you will give a larger depth of cut.

While providing negative back rake angle, energy required to overcome the friction increases which increases the overall power. So, when we use a negative rake angle, the power increases because there is large area of contact. This is negative, this is zero, this is positive. So, when you have, there is more contact of the tool to the workpiece. If that is the case, then you will have lot of power required.

But negative rake angle are required for tool stability. So, when you do a depth of cut, you will try to have a stronger tool. Otherwise, due to impact, the tool might break. So, here if you try to see the tool life with back rake angle, there is a maxima at one point. The tool life increases and then it reaches maxima and then it tries to reduce. So, back rake angle has an influence on the tool life.

Single Point Tool Geometry: Effect

Back rake angle :

- Machining ductile materials tool life increases by increasing back rake angle because of decrease in contact length between chip and tool over the rake face.
- But when this angle becomes more than a particular value, lip angle of the tool decreases.
- This decreases the strength of tool hence tool life decreases.
- The optimum back rake angle of ductile materials is around 10-15°
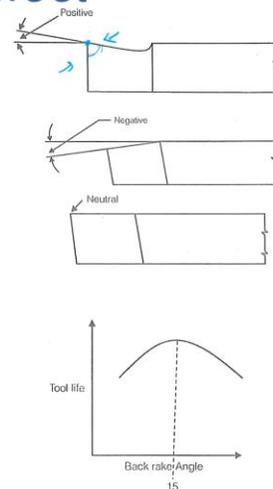
Machining ductile material tool life increases by increasing the back rake because of decreasing the contact length between the chip and the tool over the rake phase. So, when I said positive this is what is positive. So, here what is happening you will have a sharp edge and the amount of material in the tool is also reduced. But when the angle becomes more than a particular value, the lip of the tool decreases. This decreases the strength of
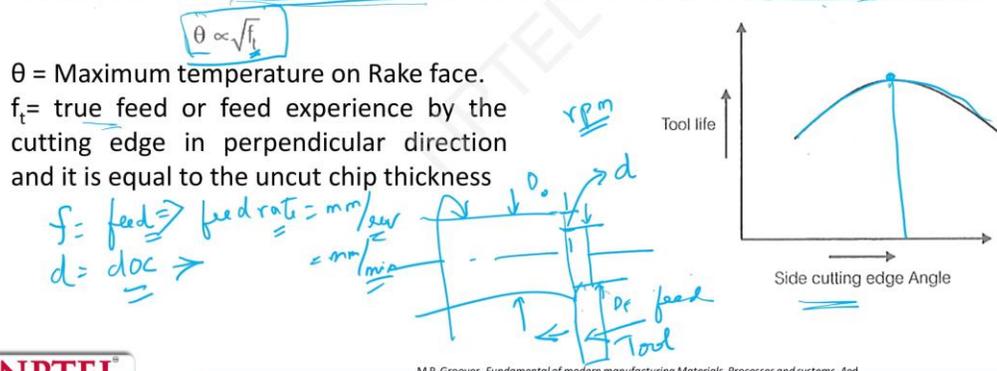
the tool. So, the back rake angle for ductile materials are generally chosen between 10 to 15.

Single Point Tool Geometry: Effect

Side Cutting edge angle:
- It is the angle between the side cutting edge and the line extending the shank.
- The angle is measured in a plane parallel to base.
- Feed represents uncut chip thickness and depth of cut represents width of chip as:

$$\theta \propto \sqrt{f_t}$$

θ = Maximum temperature on Rake face.
f_t = true feed or feed experience by the cutting edge in perpendicular direction and it is equal to the uncut chip thickness

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When we talk about side cutting angle, it is the angle between the side cutting edge and the line extending the shank. Side cutting edge, if you go back you can see. The angle is measured in a plane parallel to the base.

So, here the feed represents the uncut chip thickness, and the depth of cut represents the width of the chip thickness. Here, the feed represents the uncut chip thickness, and the depth of the cut represents the width of the chip. So, two things. So, here what we have is the temperature is directly proportional to the root of the true feed or the feed rate, whatever it is. So, here if you see the side cutting edge angle, again it follows the same trend wherein at one particular angle you have a maximum tool life, and then you have a reduction on both sides.

So, now let me introduce the terminology f and d. f is called the feed, and d is called the depth of cut. Depth of cut means it is the—when you try to machine an object or a workpiece—your tool is pushing from this side. Perpendicular to the axis of rotation, whatever you give is called the depth of cut. So, here it was d original, and this is d final. So, now the difference, whatever you call it, this is called d, which is the depth of cut.

When we move along this direction, along the axis of rotation, if we move, that is called the feed. So, the tool—this is the tool, right? I will make a tool here. Assuming that this is a tool, the tool which moves along the axis is called the feed rate. This is called the feed.

The feed will be always defined as feed rate. So, feed rate will be defined as mm/revolution or mm/minute. So, why is that mm/revolution there? Because the workpiece rotates at a given RPM. So, you can try to see what will be the advancement of the tool along the axis of the part in one revolution.

Other way round, so this is declared as RPM (Revolutions Per Minute). We can also try to find out mm/minute. So, once we put revolution or minute, it is called as feed rate. If that is not there, it is called the feed. The feed can be 0.2, 0.3 millimeter.

When we put with respect to rate, 0.2 mm/revolution, 0.3 minute per minute, you can try to say. So, the feed what we define here is the true feed or the feed experienced by the cutting edge in perpendicular direction and it is equal to the uncut chip thickness. So, uncut chip thickness is there. So, we will see in detail what is chip thickness, uncut chip thickness as and when the lecture flows.
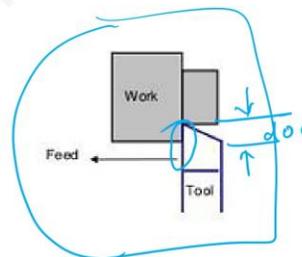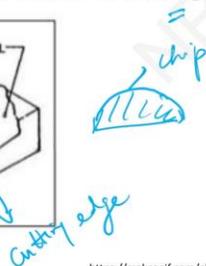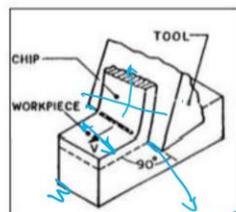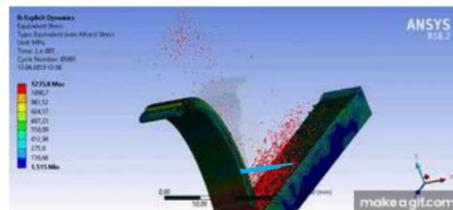

https://makeagif.com/gif/ansys-orthogonal-cutting-NHDqn7
https://engineeringlearn.com/what-is-lathe-machine-types-of-lathe-machine-their-uses-complete-guide/

The cutting process. There are two types of cutting processes. One is called orthogonal cutting. The other one is called oblique cutting. So, the video running here is a representation of orthogonal cutting. The cutting edge is straight.

The cutting edge is straight. So, the tool—this is the tool that moves here. The cutting edge is straight. It is not angled. So, this cutting edge is straight.

So, the cutting edge is straight, parallel to the original plane surface of the workpiece, and perpendicular to the direction of cut—this is orthogonal cutting. So, this is called the cutting edge. This is the tool's cutting edge. It is at 90 degrees to the workpiece. So, parallel to the original plane in 2D of the workpiece and perpendicular to the direction of cut—this is orthogonal cutting.

So, examples of orthogonal cutting will be shaping. We will see that later. So, this is the schematic representation. If you want to express it in 2D, it is given here. So, now you can see here the feed what I discussed in the previous slide is given here. And this is called as the depth of cut.

Cutting Process: Type

Oblique Cutting

- Cutting edge of the tool is inclined to the line normal to the cutting direction. In actual machining, Turning, Milling etc/ cutting operations are oblique cutting

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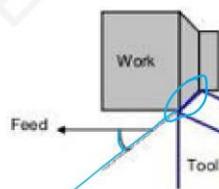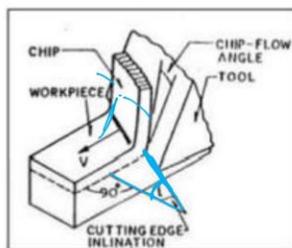
Oblique cutting. Where the cutting edge is at an angle. The cutting edge of the tool is inclined to the line normal to the cutting direction.

In actual machining like turning, milling etc. cutting operation are always oblique cutting. So, the angle and this is the feed which we have defined. So, if you see both the figures you will clearly understand. This is orthogonal cutting and this is oblique cutting. Look at the cutting edges.

Look at the cutting edge here and look at the cutting edge here. This is oblique cutting. In reality, it is always oblique cutting, but for simplification in measurements and other derivations, we always assume it to be orthogonal cutting.

Orthogonal v/s Oblique Cutting

Sl. No.	Orthogonal Cutting	Oblique Cutting
01.	The cutting edge of the tool is perpendicular to the direction of cutting.	The cutting edge is inclined at an acute angle with the normal to the direction of cutting.
02.	The chip flows over the tool face and the direction of chip flow velocity is normal to the cutting edge.	The chip flows on the tool face making an angle with the normal on the cutting edge.
03.	The cutting edge is longer than the width of the cut.	The cutting edge may or may not be longer than the width of the cut

Orthogonal v/s Oblique Cutting

04.	The maximum chip thickness occurs at its middle.	The maximum chip thickness may not occur at the middle.
05	The tool is perfectly sharp and it contacts the chip on rake face only.	Frequently, more than one cutting edge is in action.
06.	Only two components of cutting forces act on the tool. They are mutually perpendicular to each other.	Three components of the cutting forces act on the cutting edge of the tool.
07.	Tool life is less.	Tool life is more.

So now, let us see the difference between orthogonal cutting and oblique cutting. In reality, the majority of cutting processes fall under oblique cutting.

In orthogonal cutting, the cutting edge of the tool is perpendicular to the direction of the cut. Here, it is inclined to the normal to the direction of the cut. The chip flows over the tool face, and the direction of chip flow velocity is normal to the cutting edge. So, the chip flows over the cutting face. The chip flows over the cutting face.

So, this is cutting; this is a tool, and the chip flows. This is a chip which tries to flow. The chip flows on the tool face, making an angle with the normal to the cutting edge. The chip flow makes an angle to the normal. The cutting edge is longer than the width of the cut.

The cutting edge you see here is protruding. It is longer or larger than the cutting chip, whatever flows. The cutting edge is longer than the width of the chip. What is the width of the chip? The width of the chip is this.

This is called the width of the chip, W. So here, the cutting edge may or may not be longer than the width of the cut. The maximum chip thickness occurs at the middle. So, when the chip flows, suppose you take a cross-section, the maximum thickness of the chip would be in the middle. So, this is a chip cross-section. The tool is perfectly sharp, and it contacts the chip on the rake face only.

Only two components of cutting force act on the tool; they are mutually perpendicular to each other. The tool life is less because the chip is completely in contact and perpendicular to the cutting edge. So, all these things lead to these three points. The tool is perfectly sharp because the cutting edge is normal and is contacting the chip at the rake face only. The two components, when you try to resolve them, you will have only two components. One is the thrust component, Ft, and the other one is the radial component, Fr.

So, you will have only two components, they are mutually perpendicular to each other. The tool life is less since the chip always moves on the rake face, it is less. So, when we go for oblique, the frequently more than one cutting edge is in action. Three components come because since it is at an angle, you have to resolve Ft and Fr, you will have an angle component. So, you will try to have cutting force Fc, Ft and Fr.

You will have three forces acting on it. The tool life is larger than the orthogonal cutting. So, this comparison tries to give you a better understanding about orthogonal cutting and oblique cutting.
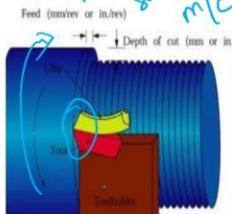

The machining conditions. So generally, these are the conditions which is set in the machine. So, this is called as a depth of cut. You can see depth of cut which is defined here. The feed, whatever I have discussed earlier, feed is given here. Depth of cut is discussed. Now, the speed is the rotation with which the workpiece rotates.

So, these are the three parameters which are process parameters set in the machine. Process parameters are set at the machine. So, the other environment can be lubrication because there is going to be metal-to-metal contact, and there is friction. So, friction will generate heat. So, the heat has to be cooled down, and the friction has to be reduced.

So, we add a coolant or a lubricant, which is an environment around the cutting process. The presence of oxygen in the atmosphere will try to react with the nascent surface and form oxides. The third thing is the temperature. At the cutting zone, the temperature is very high. So, these are the three environments which are going to play an important role.

As we saw in the first course, when the temperature is applied, there is a softening of the material. So, if you can apply heat prior to cutting, it softens the workpiece, and the

moment it softens the workpiece, your forces will go down. So, this talks about the temperature. Then, the last one talks about the work holding. Fixture, jig, chuck, and collet.
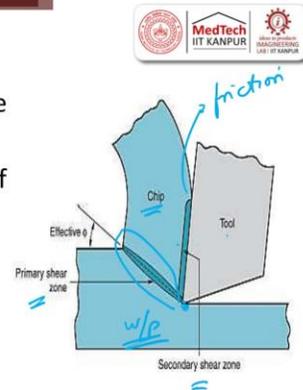
The collet, whatever we saw, was put on the tailstock. You can also have it in the headstock. The chuck is holding the device. There are three-jaw chucks and four-jaw chucks. A jig is basically used to guide the tool.

Suppose you are trying to drill from the tailstock. Then you have to guide the tool. Then, we call it a jig. If the workpiece is to be held, we call it a fixture. So, these are the work holders.

Work holders and tool holders. The cutting speed V is the primary motion, the speed at which the workpiece moves around. The speed at which the workpiece moves with respect to the tool is called the cutting speed, which is $v = \pi DN$. F is the secondary motion. The primary motion is the speed, the secondary motion is the feed, and then comes the depth of cut.

So, heat dissipation in chip formation. When we try to perform orthogonal cutting and when the tool is perpendicular, the cutting edge is perpendicular to the chip moving, or if the chip moves.

So here we are discussing orthogonal cutting. In orthogonal cutting, the cutting edge is straight, and this is the workpiece. So now the chip moves on top of the rake face. When the chip moves on top of the rake face, it is metal-to-metal contact, so there is going to be friction. The friction that occurs while the chip moves along the tool creates a heat phenomenon.

So it is not only here the heat phenomenon; it is also along the shear plane where there is going to be heat. So this is called the primary heat zone, and this is called the secondary heat zone. The maximum heat occurs in the primary heat zone, and compared to the primary, lesser heat occurs in the secondary heat zone. The chip formation during machining operation leads to the distribution of heat during the cutting operation. The chip formation in machining occurs due to shear deformation.

So, this machining happens only because of shearing. So, the shear happens. So, that plane is called the shear plane. Due to shear deformation of the workpiece as it interacts with the tool surface. There are three major heat distribution zones.

One is the primary cutting zone, the secondary cutting zone, and a very small tertiary cutting zone. Primary deformation happens along the shear plane. The secondary deformation happens along the chip-tool contact area, and the third one happens between the tool and workpiece contact area, which is very small. So, the primary deformation zone, the secondary deformation zone, and the work-tool contact zone. In the primary deformation zone, 70 to 80 percent of the heat is dissipated.

This is because of the plastic deformation of the metal. What is shear? Shear is this action—this is shear, right? So, shear is the dominating phenomenon for cutting here. This is because plastic deformation happens at the shear plane.

About 20 to 25 percent of the heat is dissipated between the chip and tool contact surface. And the rest—the residue, whatever is the balance—goes through the tool-workpiece contact. So, after machining, the workpiece will also be hot. Why is it? It is because of the tertiary deformation zone happening here.

So the total sum has to be 100. So accordingly, there will be only 1 to 5 percent happening in the tool-workpiece contact. The chip temperature will be phenomenally high.

Chip Formation: Mechanism $V = \pi D N$

- The **shear plane** is the region where plastic deformation occurs before the material separates as a chip. The effectiveness of chip formation depends on the **shear angle (φ)**, which influences the **chip thickness, cutting forces, and power consumption**. A higher shear angle generally reduces cutting forces and improves machining efficiency.
- As the cutting tool moves at a **cutting velocity (V)**, the chip flows along the rake face of the tool at a **chip velocity (V_c)**. The **rake angle (α)** of the tool plays a significant role in determining chip formation characteristics.

$F \propto P$

$\phi - \uparrow \rightarrow F \downarrow$

$P \downarrow$
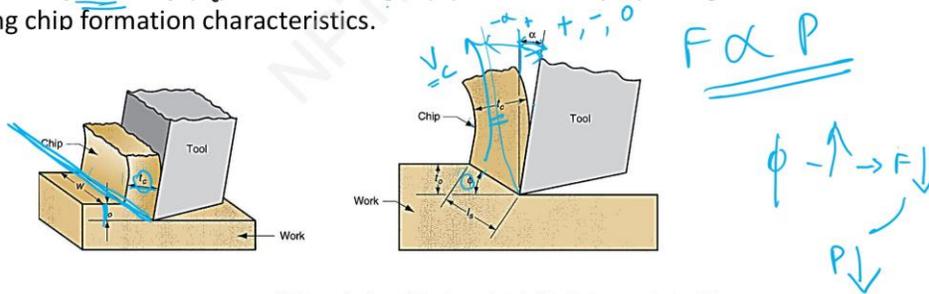
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The chip formation: mechanism. The shear plane is the region where plastic deformation occurs before the material gets separated as a chip. So here is the shear plane. This is the shear plane. So, the shear plane is the region where there is a large amount of plastic deformation. This plastic deformation allows it to go further and form a chip, which gets separated from the workpiece. The effectiveness of the chip formation depends on the shear plane angle, which is called the shear angle.

It depends on the shear angle. So, what is the shear angle? Φ is the shear angle, which influences the chip thickness. What is chip thickness? This is tc. tc is the chip thickness. Cutting force: while cutting, there is a force encountered during this process. So, cutting force—from that cutting force, power is derived. So, the effectiveness of chip formation depends on the shear plane angle (Φ), the thickness of the chip, the cutting force, and the power consumption. A higher shear plane angle generally reduces cutting force and improves machining efficiency.

When is the shear plane higher? The angle is going to be higher. When Φ is large, you will have reduced cutting force, which improves efficiency. Shear plane high—then forces are less; because the forces are less, the power is also less. Force and power are directly proportional.

When the force is high, the power will also be high. As the cutting tool moves at a cutting velocity v, what is v? v = πDN. As the cutting tool moves with a cutting velocity v, the chip flows along the rake face of the tool at a velocity of Vc. So, the chip that exits out goes through a velocity called Vc. So, this is called the rake angle.

The rake angle plays an important role in determining the chip formation characteristics. So, if you look at it, we have taken an orthogonal cutting process, drawn the schematic of an orthogonal cutting process, seen the shear angle, and then observed the chip thickness. So, prior to chip thickness, whatever is there—the feed, as we call it—this is to. It is called the uncut chip thickness, though some argue that since the chip itself is not formed, how can you call it uncut chip thickness?

So, this is called to, and this is called tc. So, tc is the chip thickness, and you should understand it is a constant-volume process. Whatever material was here will also come out. If the chip thickness is large, then the width will reduce. Because it is a constant-volume process.

You cannot add or remove material here. It just goes like that. It extrudes. It is almost like an extrusion. So, we saw the influence of chip thickness.

We saw cutting force and power consumption. We also understood what cutting velocity and chip velocity are. Chip velocity is Vc. And for cutting, the angle that plays a very important role is the rake angle. So, you can make the rake angle positive, negative, or 0.

That means if it is positive, if this is positive, when it is negative, the rake angle will be something like this—this will be the rake angle. This will be a negative rake angle, and in between the center, you will have a positive one. So, you will have a positive rake angle, a negative rake angle, and a zero rake angle. This is what we saw in the prior slides for discussion.

Chip Formation: Mechanism

- A **larger rake angle** facilitates smoother cutting, reduces cutting forces, and improves chip flow, while a **small rake angle** increases tool resistance and can lead to higher power consumption.
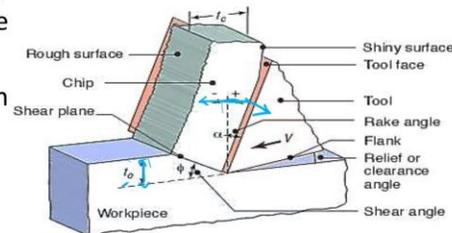- A lower value of r indicates higher deformation and greater energy consumption.

Chip thickness ratio $(r) = \dfrac{t_o}{t_c}$ $\dfrac{1}{2}; \dfrac{1}{4}; \dfrac{1}{6}$

where
r = chip thickness ratio;
t_o = thickness of the chip prior to chip formation; and
t_c = chip thickness after separation

- Chip thickness after cut is always greater than before, so chip ratio is always less than 1.0

https://www.minaprem.com/machining/cutter//

So, the large rake angle facilitates—this is large, right? So, this is positive. So, a positive large rake angle facilitates smoother flow of the chip, isn't it? So, you have a tool; the chip moves. So, now you reduce the angle, reduce the angle of that chip.

So, now the chip will flow easily. The larger rake angle facilitates smoother cutting, reduces cutting force, and improves chip flow. While a smaller rake—smaller rake means you are moving from positive toward 0—a smaller rake increases tool resistance and leads to higher power consumption. So, this is what we discussed in the previous slide, saying that the force and power are directly related. The rake angle influences the cutting force and the chip formation.

The lower value of r—what is r? r is the chip thickness ratio. What is the chip thickness ratio? to/tc is called the chip thickness ratio. The lower value of R indicates higher deformation and greater energy consumption.

So now you can see this. So, what is to? Where does this To come from? To comes from the process parameter, whatever you make it on the machine. So, the chip thickness ratio will be r = to/tc, where r is the chip thickness ratio.

To is the thickness of the chip prior to the formation is to and tc will be there. So if tc is very large, let us take a value 1/2, 1/4, assuming just I am just putting 1/6. If tc value is

large, assuming to is small, then the ratio will start reducing. The chip thickness after separation is tc. The general chip thickness after cutting is always greater than before.

So the chip thickness ratio will be always less than 1. Because there will be, you are measuring only the thickness. You are not measuring the width, the thickness. Because here it is, as I told you, it is only an extrusion process. Whatever is the material here, this material goes there. So the material, when it flows, it tries to spread. So the thickness can go low. The thickness cannot be higher than to.

Chip Formation: Mechanism $\gamma ; \alpha ; \phi$

The geometry of the orthogonal cutting model allows us to establish an important relationship between the chip thickness ratio, the rake angle, and the shear plane angle. Let l_s be the length of the shear plane. The following substitutions can be made:

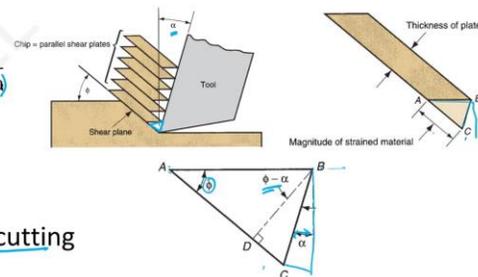$t_o = l_s \sin \phi$, and $t_c = l_s \cos(\phi - \alpha)$. Thus,

$$r = \frac{l_s \sin \phi}{l_s \cos(\phi - \alpha)} = \frac{\sin \phi}{\cos(\phi - \alpha)}$$

This can be rearranged to determine ϕ as follows:

$$\tan \phi = \frac{r \cos \alpha}{1 - r \sin \alpha}$$

The following definition of shear strain in metal cutting

$$\gamma = \tan(\phi - \alpha) + \cot \phi$$

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So the geometry of the orthogonal cutting model allows us to establish an important relationship between the chip thickness ratio, rake angle and the shear plane angle. So we have seen only these three.

So, what are we seeing? We have seen r, we have seen the rake, and we have seen Φ. Now, I am trying to establish a relationship between them. Why? Because if I establish a relationship, I can try to figure out what the material property should be, which I can use to control the machining process.

So, if you see here in this orthogonal cutting diagram, we are trying to establish a model that allows us to have a relationship between the chip thickness ratio t, the rake angle alpha, and the shear plane angle Φ. So, let us try to take the length of the shear plane

angle. Let the length of the shear plane angle be ls. Shear plane—this is the shear plane. The shear plane angle—sorry, the length is ls.

Following the substitutions can be made: $t_o = l_s \sin \phi$. You have to use all the graphs. This is the rake angle. This is the shear plane angle, Φ. The shearing operation happens, and because of that severe plastic deformation, the chip is formed. So now, I try to take a small triangle. I try to draw the small triangle into this. This is the thickness of the plane. So, what is this? This is a thickness, right? A plane or a plate. We will try to assume it as a plate or a plane, whatever it is. You try to take it as a plate. A plate means a small thickness.

So, the thickness of the plate. So now, this is a triangle which is drawn A, B, and C. I zoom this and present it here. So, I have A, B, and C. I try to draw a normal which is D. I know the angle between A and B. The angle between AB and AC, this angle is Φ. And I also know the angle with which it is tilted.

So, this normal I draw is BC, and this normal is trying to represent alpha, which is the rake angle. Now, when I draw a normal B which intersects at AC, it will be D. So, this angle it creates is Φ - α. Now, I try to draw a relationship. $t_o = l_s \sin \phi$, and $t_c = l_s \cos(\phi - \alpha)$. It is α, thus r is what?

to/tc which is

$$r = \frac{l_s \sin \phi}{l_s \cos (\phi - \alpha)} = \frac{\sin \phi}{\cos (\phi - \alpha)}$$

So, this can be rearranged to determine Φ as the following:

$$\tan \phi = \frac{r \cos \alpha}{1 - r \sin \alpha}$$

So, this tries to tell me a relationship between the shear plane angle, cutting chip thickness ratio, and the rake angle. And why is it important?

Because this will, in turn, try to dictate my force, and that, in turn, will try to dictate my power. So that means the smooth flow of the chip. The following definition of shear strain in metal cutting can be derived from this.

$$\gamma = \tan (\phi - \alpha) + \cot \phi$$

And why is this important? Because the shear strain can be calculated by doing a universal tensile testing test, and you can try to do and get this relationship. Can I measure Φ? No, it is not possible practically. α, can I measure it? Yes.

Alpha is what you set as the rake angle on the tool. Can I measure r? Yes. r is nothing but tc, which is the output, what you give in the process parameter.

Chip Formation: Factors

- **Cutting Speed & Feed Rate:** High speeds and small feeds promote continuous chips, while low speeds and large feeds cause discontinuous chips.

- **Tool Geometry & Rake Angle:** A sharp tool with a large rake angle reduces cutting forces, improves chip flow, and enhances surface finish.

$$\phi \uparrow \rightarrow t_c$$

- **Workpiece Material & Shear Angle:** Ductile materials form continuous chips, brittle ones produce discontinuous chips, and a higher shear angle reduces chip thickness.

Chip Formation: Factors

- **Friction, Cutting Fluid & Built-Up Edge:** Proper lubrication minimizes friction, reduces tool wear, and prevents built-up edge formation for better machining.

- **Chip Breakers & Depth of Cut:** Breakers prevent long tangled chips, while depth of cut affects chip thickness and cutting forces.

- **Machine Stability, Temperature & Vibrations:** A rigid setup, controlled temperature, and minimal vibrations improve chip control and surface quality.

So now the chip formation: factors, these are the factors: cutting speed, feed rate. Higher cutting speed and smaller feed rates promote continuous chips, while low speeds and large feeds cause discontinuous chips. We will see continuous chips in the upcoming slides. So, the continuous chip will always try to have lower power. Discontinuous chips will try to have an improper surface finish. Tool geometry and rake angle: a sharp tool with a larger rake angle reduces the cutting force, improves chip flow, and enhances surface finish.

The workpiece material and the shear angle: ductile materials form continuous chips, while brittle ones produce discontinuous chips. A higher shear angle reduces the chip thickness (tc). Friction, cutting fluid, and built-up edge: proper lubrication minimizes friction, reduces tool wear, and prevents built-up edge formation. Chip breaker and depth of cut. Breakers prevent long, tangled chips (the continuous chips), while the depth of cut affects chip thickness and cutting force. Machine stability, temperature, and vibration: these are all machine-related parameters. A rigid setup, controlled temperature, and minimal vibration improve chip control and surface quality. So, these are the factors that help in chip formation.
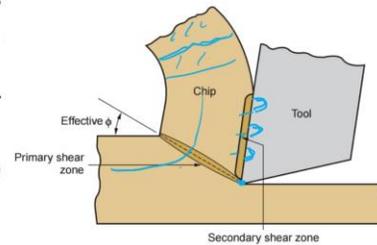

Actual Chip Formation

- It should be noted that there are differences between the orthogonal model and an actual machining process.

  - **First**, the shear deformation process does not occur along a plane, but within a zone.
  - If shearing were to take place across a plane of zero thickness, it would imply that the shearing action must occur instantaneously as it passes through the plane, rather than over some finite (although brief) time period.
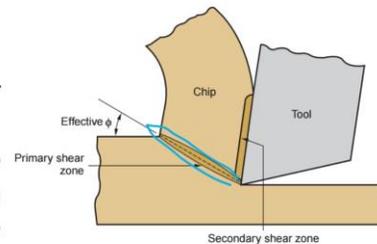
Actual Chip Formation

- **Second**, in addition to shear deformation that occurs in the shear zone, another shearing action occurs in the chip after it has been formed.
- This additional shear is referred to as secondary shear to distinguish it from primary shear.
- Secondary shear results from friction between the chip and the tool as the chip slides along the rake.

- **Third**, formation of the chip depends on the type of material being machined and the cutting conditions of the operation.

The actual chip formation we will see. It should be noted that there are differences between the orthogonal model and the actual machining process. We said all the models we explain here are orthogonal, but in real time, it is all oblique. First, the shear deformation process does not occur along a plane, but it occurs along a zone.

So, in the previous case, just for simplicity we took it like a plane. We took it like a plane. So here for simplification of model, we took like a plates. There are series of plates and then these plates are moving or series of cards. These cards are shearing.

So then we took a card with a thickness. But in reality, it is not going to be a plane. It is going to be a zone. So then it is called as shear zone. So since it is first happening, it is called as primary shear zone.

First, the shear deformation process does not occur along a plane but across a zone. If shear were to take place across a plane, of 0 thickness it would imply that the shearing action must occur instantaneously as it passes through a plane rather than over some finite time period. Which is in reality, why do we always consider it as a plane simplicity but in reality it is a zone because if you try to take it as a plane it has to be formed instantaneously but there is a small lag in time while cutting happens. The second is the in addition to the shear deformation that occurs in the shear zone, another action happens

along the chip back end and the tool. The addition shear is referred to secondary shear to distinguish itself from the primary shear.

The secondary shear predominantly is friction based. And that is why what we do is we try to have discontinuity here. So, when we have discontinuity here on the tool, it is called as chip breakers. So, this chip breakers what happens is will try to shear off the secondary deformation zone and that leading to discontinuous chip. The third, the formation of the chip depends on the type of material being machined and the cutting conditions of operation.

So, there are three zones, primary zone, secondary zone and the tertiary zone. So, these are the chips which we were trying to talk about.
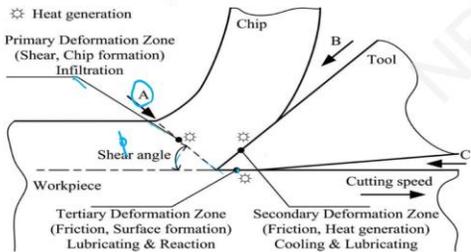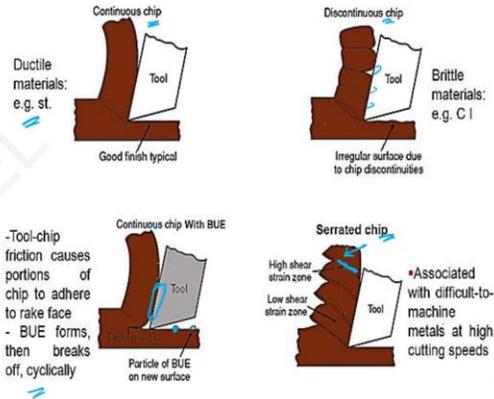

Types of chip, it is continuous, discontinuous, continuous with built up heads and serrated one. So here if you look at it, when you try to take a ductile material and the proper choosing of rake angle and other process parameter, we might get a continuous chip. And when we try to machine polymer, the chip continuously runs for even a kilometer.

That means to say without rake, it keeps on be going. Those chips are called as continuous chip, predominantly seen in ductile material. So, discontinuous chip, when you have a chip breaker or when the material is brittle, in brittle material what happens,

there are already several cracks which are there in the workpiece. So, as and when you start machining, the cracks initiate and move faster and it tries to join at a place and it tries to remove as a chip. So, you always try to get discontinuous chip.

So, the discontinuous chip can happen because of brittle material, and the rake angle can be negative. An improper choice of process parameters can lead to discontinuous chips. In discontinuous chips, there will always be vibration in the machine, which will lead to a poor surface finish. The third one is going to be a continuous chip with built-up edges. As I told you, there is a lot of friction that is going to happen here. So, once there is a lot of friction and the metal is moving, the chip is moving out like this.

So, what happens is it removes all the impurities and other things on the surface, and here it tries to increase the temperature, and the nascent surface of the tool comes in contact with the chip. So, now you see very high temperature and high pressure as it is moving on. Now, you have to take the analogy of welding. So, welding happens here. So, when the welding happens here, a built-up edge is getting formed on top of the cutting edge.

So, the moment it is formed, it is called a built-up edge getting formed on top of a cutting tool. This built-up edge destroys the cutting geometry. So, now the rake face that was there is now changed. The cutting edge will be shifted from the sharp cutting edge to some other point. So, discontinuous chips with built-up edges, or continuous chips with built-up edges, is another phenomenon that is seen.

Tool chip friction causes the portion of the chip to adhere to the rake phase. Built up edge formation then breaks off cyclically. Thus, leading to half getting stuck on to top of the workpiece, half getting on along the chip. So, the tool material will go along with the chip. The last one is going to be serrated chip.

The serrated chips are those chips where you form alternative. And then next high shear zone and then we have a low shear zone. When there is a shear zone, this shear zone, the material will move through the shear zone and keep moving. So here you will try to have high shear zone and then in low shear zone. When there is an alternative of high shear and low shear zone formation, it will lead to serrated chips. So here you can see, high shear zone strains. So, here strains will be very high.

Then in between the two high shear, it will have a low strain. So, there is a tool associated with difficult to machine metals at high cutting speeds we generate serrated chips when machining titanium it generates serrated chips. So, or improper choosing of

material process parameter you might get. So, this diagram clearly says you can see here the chip is getting formed. So, here is A. This is the shear plane which we assume it as a plane but generally it is a zone.

And then this is Φ, the work piece is seen. So, here we talk about the tertiary deformation zone which is happening because of tool work piece contact. Here it is secondary. So heat is generated. And generally what we do is, we try to pour lot of coolant around it so which gives you lubricating effect and cooling effect. So, heat is dissipated here as well as heat is dissipated at the bottom So, primary deformation zone you will try to see here.
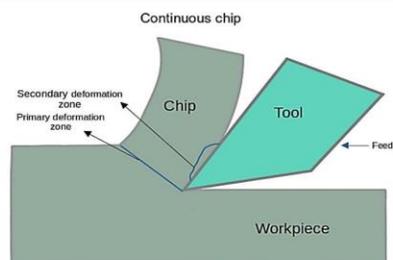

So, continuous chip formed in ductile materials like low carbon steel, copper, aluminium alloy occurs at high cutting velocity. What is high cutting velocity? Pi DN and low friction between the tool and the chip leads it.

Produces a very good surface finish, the force is less, power is less. Chip breaker prevents them from getting chip entanglement. Continuous with condition for continuous chip formation; ductile material, high cutting velocity, smaller feed rates and smaller chip thickness, larger rake angle, positive rake angle, sharp cutting edge and proper choosing of cutting fluid and lubricant.
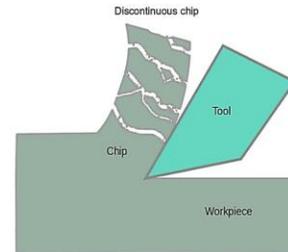
Chips Formation: Type

Discontinuous Chip

- Formed in brittle materials (e.g., cast iron, bronze, high carbon steel).
- Occurs at low cutting velocities with high friction and large feed.
- Leads to poor surface finish and reduced tool life.
- Shorter chips are easier to handle and dispose of.

Conditions for Discontinuous Chip Formation

- Brittle materials
- Low cutting velocity
- Large feed, high chip thickness
- High friction, inadequate cutting fluid
- Rough and uneven workpiece

$t_o \boxed{t_c}$

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Discontinuous chip generally forms in brittle material like cast iron, bronze, high carbon steel, occurs at low cutting velocities with high friction on tool. So, once there is a high friction on tool, the tool is going to get worn out very fast.

So, low cutting velocity, larger feeds. Now, you can assume feed is along the axis you give this, that is feed. So, large feed, high friction and low cutting velocities. So, leads to poor surface finish and reduced tool life. Shorter chip break are easier to handle and dispose off.

Continuously, it is long and difficult. So, the discontinuous chip falls on top of the pan, which is the chip pan collector. Or, when we study more about the lathe machine, we will see where the chip gets collected. So, what are the conditions? It has to be a brittle material, low cutting velocities, larger feed, higher chip thickness (T_o/T_c), high friction, inadequate cutting fluid, and rough or uneven workpiece surfaces.
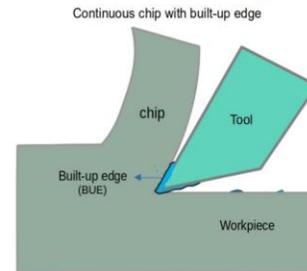
Chips Formation: Type

Continuous Chip with Built-up Edge (BUE)

- Formed in ductile materials at low/medium cutting velocities.
- High friction causes material to weld to the tool rake surface.
- Can be minimized by using a sharp tool, high cutting speed, and proper cutting fluid.
- Leads to poor surface finish but reduces tool wear.

Conditions for Continuous Chip with BUE Formation

- Ductile materials
- Low/medium cutting velocity
- Small rake angle, large chip thickness
- High friction, rough feed, large uncut thickness
- Ineffective cutting fluid

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What are built-up edges? These built-up edges, as I said, involve the welding of the chip material to the tool. They form in ductile materials at low and medium cutting velocities. High friction causes a welding operation on the rake face. It can be minimized by using a sharp tool, high cutting speed, and proper cutting fluid to reduce built-up edge formation.

It leads to poor surface finish, and sometimes it forms a cover, which prevents the tool from wearing out. The conditions for continuous chip with built-up edge: ductile material, low to medium cutting velocities, smaller rake angle, larger chip thickness, high friction, and ineffective cutting fluid—all these lead to continuous chips with built-up edges.

Chips Formation: Type

Serrated Chip (Segmented Chip)

- Formed in difficult-to-machine materials (e.g., titanium alloys, austenitic stainless steels). *My Inconel*
- Has a saw-tooth appearance due to alternating high and low shear strain zones.
- Occurs at high cutting velocities.

Conditions for Serrated Chip Formation

- Difficult-to-machine materials (e.g., titanium alloys)
- High cutting velocities

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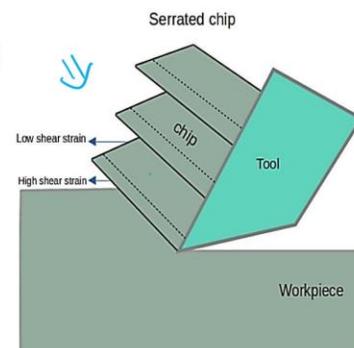
Serrated chips form in difficult-to-machine materials like titanium alloy and austenitic stainless steel. You can also have magnesium. You can have Inconel. These are all difficult-to-machine materials. They have a sawtooth-like appearance, which has alternating high shear strains and low shear strains, right? High shear zones and low shear zones occur at very high cutting velocities. Difficult-to-machine materials can be machined. High cutting velocities are the condition for it. So, now how do we reduce it? We apply external heat so that the material is softened and you can start machining.

Thank you very much.