Basics of Mechanical Engineering-2

Prof. J. Ramkumar

Prof. Amandeep Singh Oberoi

Department of Mechanical Engineering

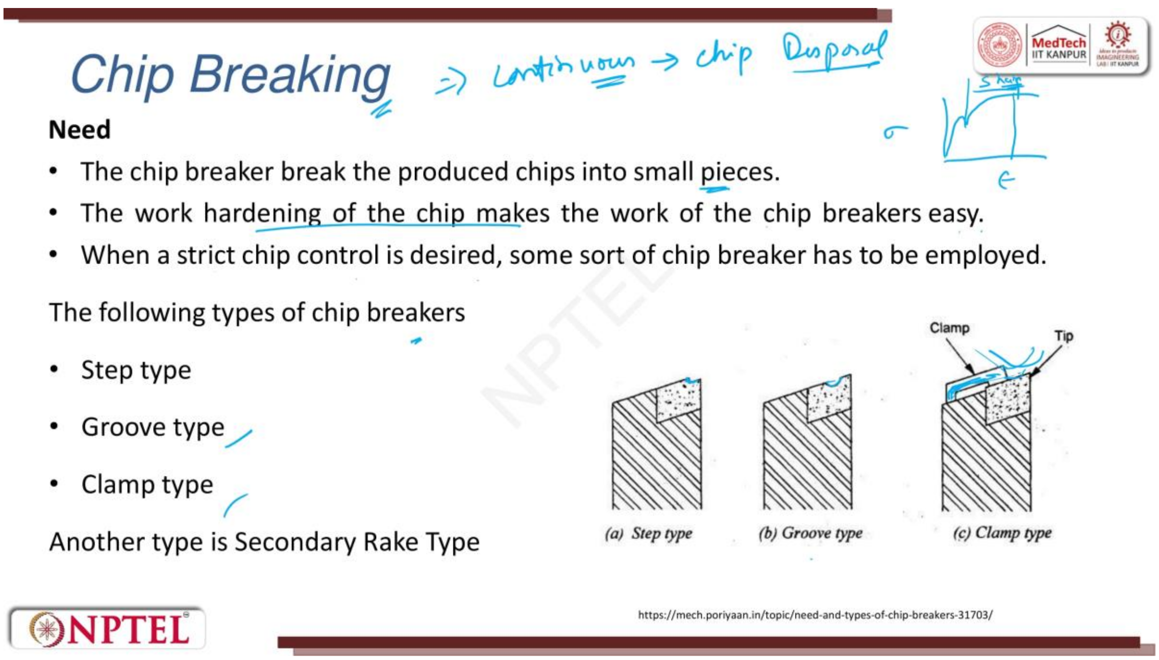
Indian Institute of Technology, Kanpur

Week 09

Lecture 35

Basics of Machining (Part 3 of 7)

Welcome to the Basics of Machining.

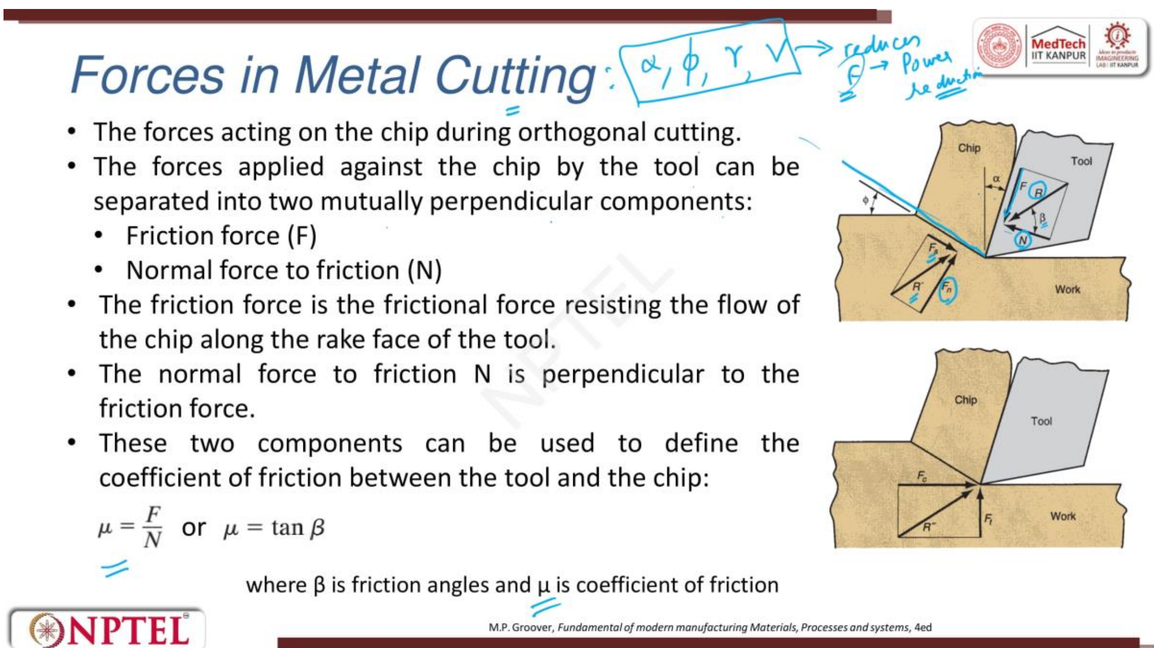


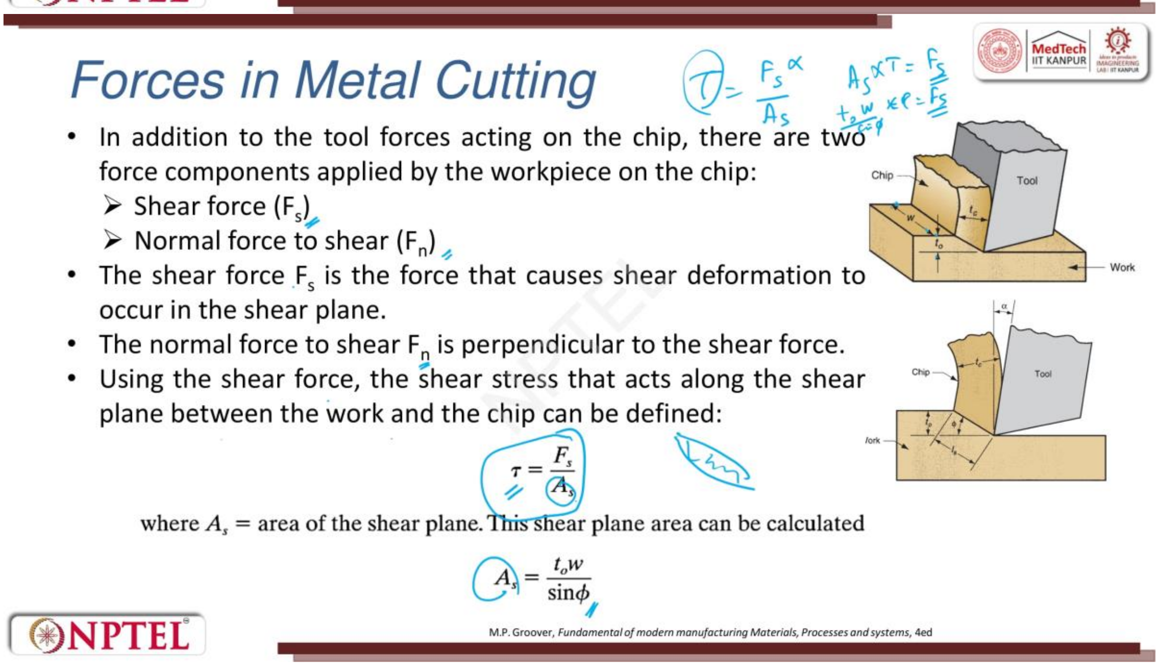
Now, let us try to see chip breakers. A chip breaker can be integrated into the tool itself, or you can use a supporting system to break the chip. Why do the chips need to be broken? In continuous chip formation, chip disposal is a challenge.

The purpose of a chip breaker is to break the chip into small pieces so they can be collected more easily. The work hardening of the chip makes the chip breaker's job easier. Generally, what happens if you refer back to tensile testing? This phenomenon is called strain hardening. That is why we say work hardening of the chip makes the chip breaker's job easier.

When strict chip control is desired, continuous chips can get entangled during machining and damage the machined surface. When strict chip control is required, we can use chip breakers as shown here. We can place it at the cutting edge, slightly offset from the edge, or use an external support for the tool. When the chip moves, it hits the clamp and breaks.

So, there are three steps. One is the step type. The other one is the groove type. The third one is a clamp, which is given on the top. When the chip moves, the clamp restricts it, and the continuous chip hits it. Because of that, it starts curling and then tries to break along with the other type of rake faces you can think of.





Now, let us try to go a little bit inside and see the forces which are involved in metal cutting. So, why is this? Because everywhere, you see, I have been talking about the rake angle. I have been talking about the rake angle, I have been talking about the shear plane, I have been talking about the chip thickness ratio, and I have been talking about the velocity. So, all these things are important. Why?

Because we have to reduce the forces, and this leads to power reduction. So, now I can experimentally measure it, but that needs a lot of instrumentation and other things. Now, I want to calculate how I can reduce the force. So, I want to do some small theoretical work and try to figure out how I can calculate the force which comes. Here, it is a theoretical, idealistic force.

So, based on the force, I can go back and iterate all the parameters such that my power consumption goes low. So, now what we are doing is trying to put effort into understanding the force. How do I calculate the force with respect to the parameters which I give to the machine or apply on the tool? The force acting on the chip during orthogonal cutting is shown here. You can see here these are the forces that are involved.

Let us see what the forces along the shear plane are: you will have a force acting, which is called the shear force, and normal to that is the normal force. The shear force acts along the shear plane, and normal to that shear force is the normal force. So, the resultant of these two is calculated as R. Now, this is on the workpiece zone. On the tool zone, let us see. There is a friction component that occurs along the tool-chip interface.

So, there is a friction force called F, and normal to the friction force is N. When I resolve these two, it is called R. So, there are two R's. For more clarity, I will denote the resultant between Fs and Fn as R'. The angle between the resultant force R and the normal force is given as β. B is the friction angle.

So, this is what happens while machining in orthogonal cutting. So, let us go through the slides. The force applied against the chip by the tool can be separated into two mutually perpendicular components: friction force (F) and normal force (Fn). The force applied against the chip by the tool can be resolved into F and N. The friction force is the frictional force resisting the flow of the chip along the tool face. The tool face is the rake face. That is F perpendicular to N. These two components can be used to define the coefficient of friction occurring here.

The coefficient of friction is nothing but F/SN. So, you see μ (coefficient of friction) is defined as F/N or given as μ = tan β, where β is the friction angle and μ is the coefficient of friction. So, now I can try to find out what friction is occurring here. In addition to the two forces acting on the chip, there are two more components applied by the workpiece on the chip: Fs (shear force) and Fn (normal to the shear force). The shear force Fs is the force that causes shear deformation to occur along the shear plane, and normal to that is Fn. Using Fs and Fn, we can try to determine the shear force.

So, the shear force can be measured by conducting experiments in a universal tensile testing machine. We can try to determine the shear force. The shear force is nothing but the shear stress acting along the shear plane divided by the area. So, τ is nothing but Fs/As, where Fs is the shear force and As is the shear area. So, using the shear force, the shear stress acting along the shear plane between the work and the chip can be defined as τ = Fs/As.

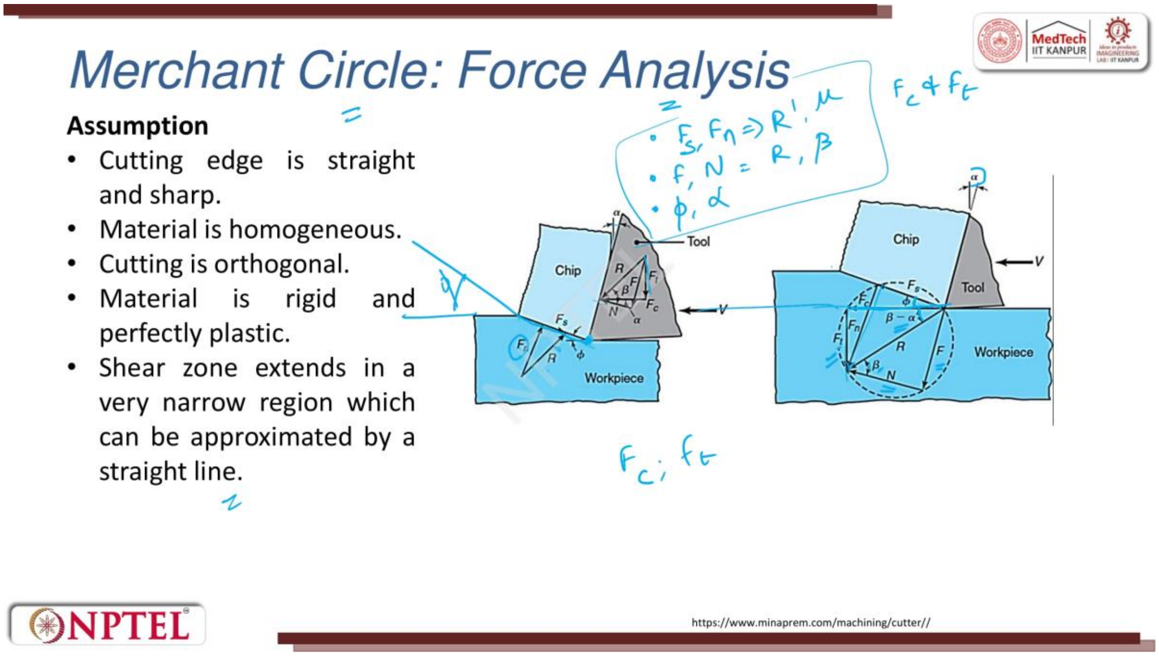
What is As? The area of the shear plane is called as As. How do I calculate the As? As can be found out by

$$A_s = \frac{t_o w}{\sin\phi}$$

Now, we are trying to find out what is the shear force which is coming into action. So, generally tau can be figured out, Fs will be not found out and As is also you can see here you can figure it out, right. So, we try to calculate τ = Fs/As, Fs will not be known. So, what we do is (As x τ) will try to give us Fs. So, that As is nothing but

$$A_s = \frac{t_o w}{\sin\phi} \quad \boxed{\times\ \tau = F_s}$$

Now, I can try to figure out Fs.



So, the entire thing whatever is there is being derived into a simple form which is called as Merchant Circle. Merchant Circle force analysis is the very simplistic version through which you can try to figure out what are all the forces which are involved in orthogonal cutting. So, before we get into the merchant circle, there are assumptions which are made because it is too difficult to do a realistic model prediction. So, we use first principles. The cutting edge is straight and sharp and it is assumed to continue to be there.

The material is homogeneous; there are no impurities, and there are no defects. The cutting is orthogonal. The material is rigid and perfectly plastic. So, the response will be perfectly plastic. The shear zone extends in a very narrow region, which can be approximated to a straight line.

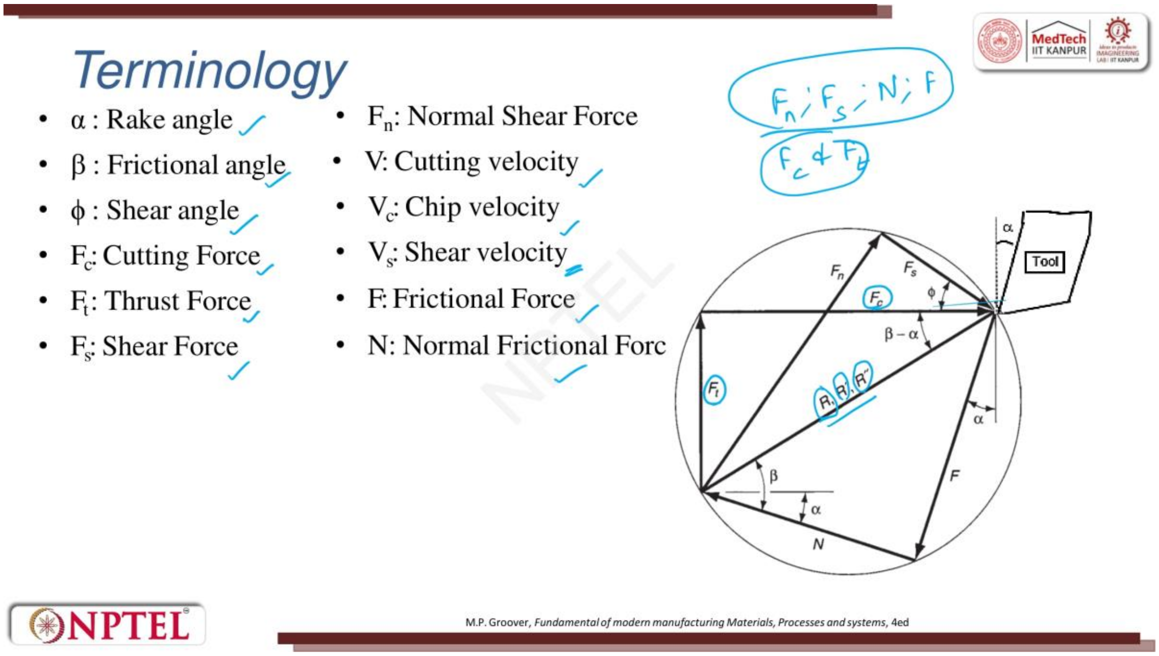
So, what we say is, the area is very small. These are the assumptions, and as we have already seen, all of these are there. Now, we will try to draw a circle and then try to mark all those things. That is it. So, if you see here, this is Fs acting, and perpendicular to Fx is Fn. So, now when we resolve Fs and Fn, we get R. So, this R is R double dash or R dash, and the shear plane angle.

So, this is the shear plane angle. Then, this is the friction force which comes here; this is the rake angle. This is the friction force Ff along the line, and normal to that is Fn, right? So, if you go here, you can see all we have made. So, this is the friction force F, normal to the friction force is N, and the angle between these two is the friction angle β. The R is going to be the same because it is going to balance the force, and the reaction forces are balanced.

So, this is R. Then, this force which acts along this is Fs. Normal to Fs is going to be Fn. So, the angle between Fs and the straight line is going to be theta. This is going to be theta.

So, now the rake angle is given here. So, now the angle which is subtended here is going to be the friction angle minus the rake angle. Now, if you see, we have not done anything new. Fs and Fn you already know. F and N you already know. Then, we have already explained Φ and the angle, right? So, now this has a resultant force R', this has a resultant force R. Now, between these two, I have introduced a terminology called the friction angle β.

And then, between Fs and Fn, I have introduced a terminology called nu. So, these are the forces which are there. Now, from this, I will have to find out what is the cutting force required while machining. So, that is the cutting force. The cutting force is Fc, and the thrust force which comes because of this is Ft. So, now I have introduced Fc and Ft. Fc is the cutting force because of the resistance given by the tool on the chip. That direction is Fc, the cutting force, and perpendicular to the cutting force is Ft. Now, we have found out the cutting force and tangential force.



So, the rake angle is known, the friction angle is known, the shear angle is known, and then the shear force is known. Then, the cutting velocity is known. We have already seen v = πDN, the chip velocity is known, the shear velocity we will see, the friction force is known, and the normal to the friction force is known. So, until now, what is not known is the cutting force and thrust force. What is the cutting force?

When the tool is acting, the force which is the resistance given is Fc here, and perpendicular to Fc here is Ft. So, these two are also known. So, now what is the other thing which is not known is the shear velocity. Shear velocity is the velocity with which the shear plane moves, called Vs. Now, with this, we will try to form an interlink such that we can calculate the cutting force. So, this diagram is called the Merchant Circle Diagram.

Why are there three Rs? R1, this R is between Fs and Fn. The next R is between F and N. The third one is between FC and FT. So, the resultant of all three are equal, and that is how we try to draw this Merchant Circle Diagram.

Merchant Circle: Force Analysis

- Equations can be derived to relate the four force components that cannot be measured to the two forces that can be measured.
- If cutting force and thrust force are known, these four equations can be used to calculate estimates of shear force, friction force, and normal force to friction.
- Based on these force estimates, shear stress and coefficient of friction can be determined Using the force diagram.
- The following trigonometric relationships can be derived:

$$F = F_c \sin\alpha + F_t \cos\alpha$$
$$N = F_c \cos\alpha - F_t \sin\alpha$$
$$F_s = F_c \cos\phi - F_t \sin\phi$$
$$F_n = F_c \sin\phi + F_t \cos\phi$$

and

$$F_c = \frac{S t_o w \cos(\beta - \alpha)}{\sin\phi \cos(\phi + \beta - \alpha)} = \frac{F_s \cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha)}$$
$$F_t = \frac{S t_o w \sin(\beta - \alpha)}{\sin\phi \cos(\phi + \beta - \alpha)} = \frac{F_s \sin(\beta - \alpha)}{\cos(\phi + \beta - \alpha)}$$

where, S is shear stress

Merchant Circle: Force Analysis

THE MERCHANT EQUATION

- Merchant reasoned that, out of all the possible angles emanating from the cutting edge of the tool at which shear deformation could occur.
- There is one angle ϕ that predominates. This is the angle at which shear stress is just equal to the shear strength of the work material, and so shear deformation occurs at this angle.

$$\phi = 45 + \frac{\alpha}{2} - \frac{\beta}{2}$$

Now, let us try to do the force analysis. An equation can be derived to relate the four force components that cannot be measured to the two forces that can be measured. So, what cannot be measured? Fn cannot be measured, Fs cannot be measured, Fn cannot be measured, and F cannot be measured. This cannot be measured. What I can measure is only Fc and Ft.

Now, I have to connect this with respect to this. So, if the cutting force and the thrust force are known by some dynamometer, these four equations can be used to calculate or estimate the shear force, friction force, and normal force to friction. Based upon the force estimate, the shear stress and the coefficient of friction can be calculated using this force diagram.

Using trigonometry, we will try to figure out the relationship between F, N, Fs, Fn with respect to Fc and Ft.

$$F = F_c \sin\alpha + F_t \cos\alpha$$

$$N = F_c \cos\alpha - F_t \sin\alpha$$

$$F_s = F_c \cos\phi - F_t \sin\phi$$

$$F_n = F_c \sin\phi + F_t \cos\phi$$

$$F_c = \frac{St_o w\cos(\beta-\alpha)}{\sin\phi\cos(\phi+\beta-\alpha)} = \frac{F_s\cos(\beta-\alpha)}{\cos(\phi+\beta-\alpha)}$$

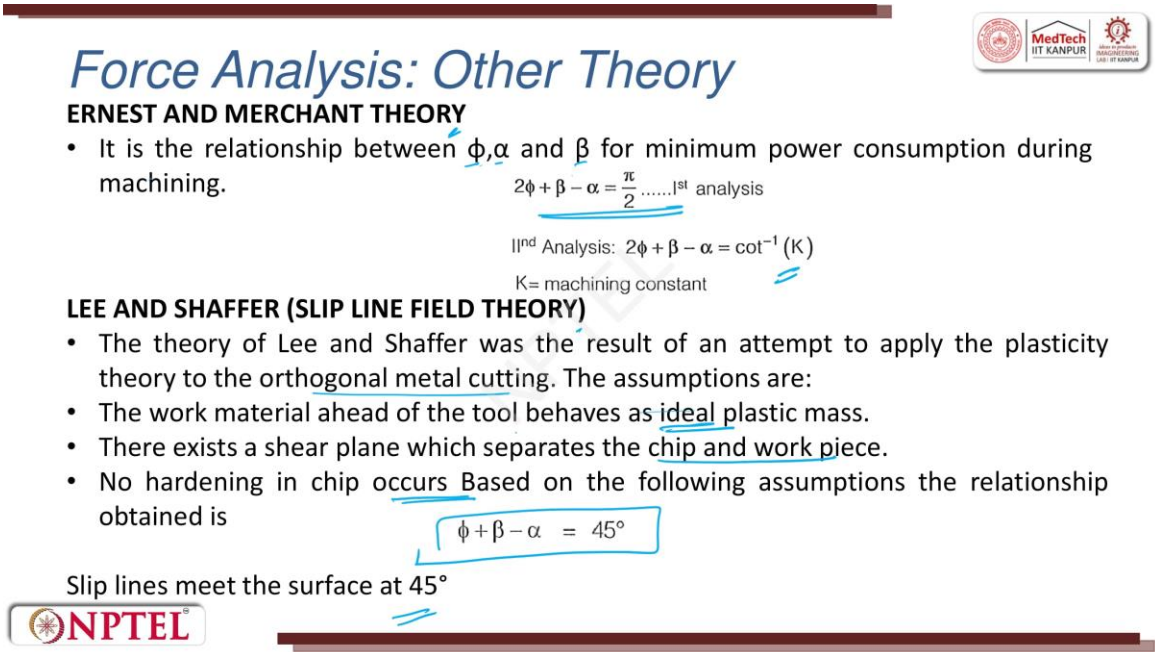
$$F_t = \frac{St_o w\sin(\beta-\alpha)}{\sin\phi\cos(\phi+\beta-\alpha)} = \frac{F_s\sin(\beta-\alpha)}{\cos(\phi+\beta-\alpha)}$$

Now, I have linked all of them by using the Merchant circle diagram. So, the Merchant circle equation can finally be written like this. The Merchant reasoned that out of all possible angles emanating from the cutting edge of the tool at which shear deformation could occur, there is one angle called Φ that predominates the shear plane. This is the angle at which the shear stress is just equal to the shear strength of the material. And so, shear deformation occurs at this angle.

$$\phi = 45 + \frac{\alpha}{2} - \frac{\beta}{2}$$

This is Merchant's circle equation. So, this is from orthogonal cutting. So, here it is very close to oblique. It has quite a lot of approximations, and by and large, by using the first principles, you can try to have a rough approximation of the forces.

So, that is why Merchant's circle equation and Merchant's circle diagram are very important while teaching metal cutting. There are advancements which were done by a few more researchers.



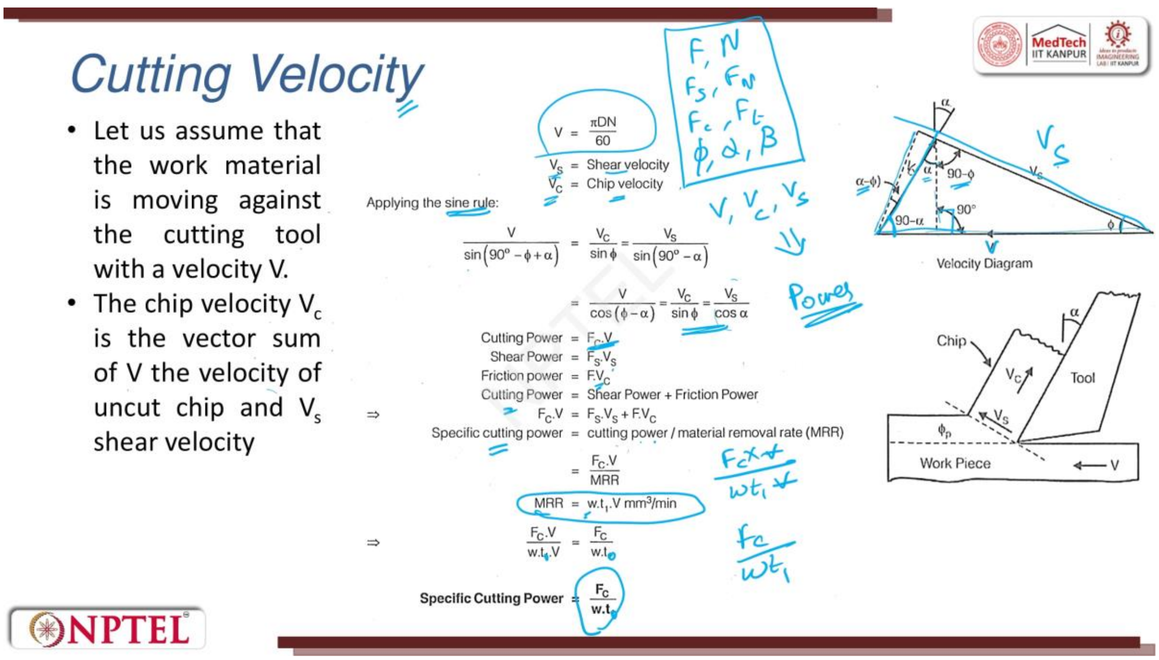
Ernest and Merchant—Ernest joined along with the Merchant theory or modified the Merchant theory—and then he brought in an equation like the relationship between the shear plane, rake angle, and friction angle for minimum power consumption should be written in this way, and then he did the second analysis. He presented it like this.

So, where K is the machining constant which depends on the tool material combination for K. So, the next advancement—see, the original value is here, the theoretical Merchant circle value is there. So, now Merchant circle—next came Ernest and Merchant's theory, then came Lee and Schaffer.

So, they are all trying to go closer to the original or to the experimental value. The theory of Lee and Shaffer was the result of an attempt to apply plasticity theory to orthogonal metal cutting. The assumptions were that the work material ahead of the tool behaves as an ideal plastic. So, here if you see, we assumed it as a material that is rigid and perfectly plastic. So, here he assumed it that it is an ideal plastic mass.

There exists a shear plane which separates the chip and the workpiece. No hardening in the chip occurs. Then, based on the assumption, he came up with this obtained, and the slip lines meet the surface at 45 degrees. These were the assumptions made. So, by and large, the important thing is you have to remember that there is a relationship between the shear plane, rake angle, and friction angle, which was expressed by Merchant and further fine-tuned by Ernest. Then, Lee and Shaffer, by changing the material behavior to an ideal plastic mass, came up with this relationship.

So, all these things give a relationship between the shear plane, friction angle, and rake angle. That is important for you.



Now, let us try to find out the relationship between cutting velocity and chip velocity. See, cutting velocity is nothing but v. When this v happens along the shear plane, it is called shear velocity, and when the chip moves, it is called chip velocity. So, let us assume that the work material is moving against the cutting tool with a velocity of v. What is v? πDN. 60, 100, depends upon a minute, second, whatever it is. The chip velocity Vc is the vector sum of v, the velocity of the uncut chip, and the shear plane.

So, if you see here, we are trying to plot the velocity diagram. So, the velocity diagram: this is v, and along the shear plane is Vs. So, this is Vs, velocity along the shear plane. This is a typical v = πDN. Now, we have to find out the relationship between v, Vs, and Vc. So, this is the chip velocity. Normal to Vs and V, we try to draw a normal, and that is called Vc. The shear plane angle is the angle between V and Vs. We already know the rake angle α.

So, when you draw a normal to VS which meets at V at 90 degrees, whatever you draw is called the rake angle. The angle between the normal and the shear velocity is 90 minus α. This is 90, this is 90 minus α, and this is α. Since this is α and this is 90 degrees, this angle is 90 minus α. So, since this is 90 minus α and we try to draw a normal, then that angle becomes rake minus 5.

So, applying the sine rule, V velocity is divided by sin minus 90 minus 5 plus α. We use the sine rule. So, this is equal to Vc by sin Φ and that is equal to Vs by sin 90 minus Φ. When we try to equate this, it becomes like this. V by cos Φ minus α is equal to Vc by sin Φ.

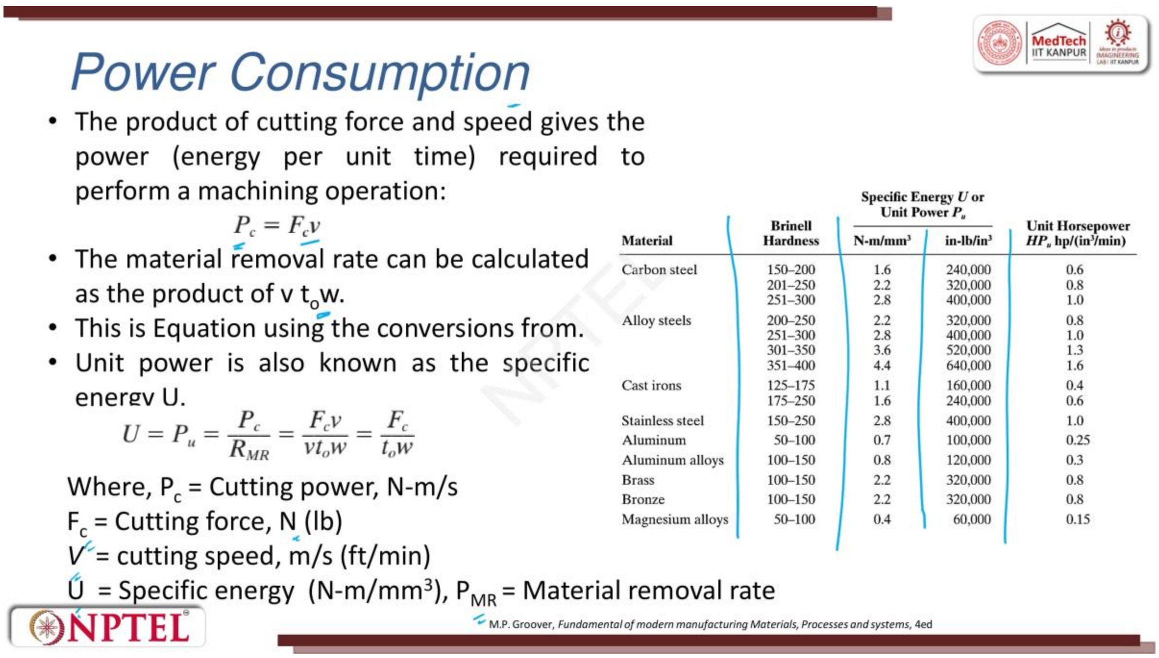
That is equal to Vs by cos α. So, now all these things—why is it important? Now, you have almost everything theoretically ready. What are they ready? FN, Fs, Fn, Fc, Ft, Φ, α, β. You have this at one side from the Merchant circle diagram.

Now, we have found out the relationship between V, Vc, and Vs. So, with all these combinations, you can try to calculate power. What is power? Ultimately, I have to find out what should be the minimum energy I apply such that I get the required output. So, cutting power can be figured out from Fc multiplied by V. Fc is the cutting force, which we can measure, multiplied by velocity.

The shear power can be found out by Fs multiplied by Vs. Vs can be figured out from here: Vs divided by cos α. We can try to figure it out. So, that tries to talk about the shear power. Friction power, if you want to do that, is nothing but F multiplied by Vc. So, the cutting power Fc multiplied by V is nothing but shear power plus friction power, which is Fc multiplied by V equals Fs multiplied by Vs plus F multiplied by Vc.

So, what is specific cutting power? Specific means it is always with respect to a unit. So, it is said as cutting power divided by unit material removal, or you try to put material removal so that you can try to figure out what is specific cutting power. Fc multiplied by V divided by material removal rate. So, now material removal rate can be figured out by the width of the chip T1 multiplied by cutting velocity.

So, the specific power will be Fc into V by W T1 into V. So, this VV goes off, so it is Fc by width into T1. So, this tries to give you the specific cutting power. Specific cutting for a unit amount of material, what is the power required is a specific cutting power. So, the power consumption is I have already dealt it is a product of FC into V. So, the material removal rate can be calculated as V into T naught into W. So here it will be T naught. Do not get confused. It will be T naught, T naught.



So, the equation can be written as unit power is equal to this divided by unit amount of material is this. So, we can try to calculate. Fc is given in Newton's, v is given in m/s, specific unit is given in Nm/mm^3. So, the power consumption is nothing but the mm^3. So, here you can see, I have given you various material, what are their hardness, what is the force, what is the unit power consumption, unit energy required for material removal.

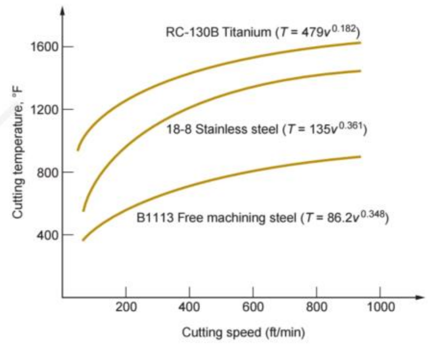
Cutting Temperature

- The equation can be used to predict the increase in temperature at the tool–chip interface during machining:

$$\Delta T = \frac{0.4U}{\rho C}\left(\frac{v t_o}{K}\right)^{0.333}$$

Where, ΔT= mean temperature rise at the tool–chip interface, C° (F°);
U= specific energy in the operation, N-m/mm^3 or J/mm^3 (in-lb/in^3); v = cutting speed, m/s (in/sec); t_o = chip thickness before the cut, m (in); ρ_C = volumetric specific heat of the work material, J/mm^3-C (in-lb/in^3-F); K = thermal diffusivity of the work material, m^2/s (in^2/sec).
Speed–temperature relationship to be of the following:

$$T = K v^m$$



M.P. Groover, *Fundamental of modern manufacturing Materials, Processes and systems*, 4ed

So, the next topic of discussion is going to be cutting temperature. As I told you cutting temperature is one of the very important phenomena because it is metal to metal cutting friction there and this friction deforms the workpiece softens the tool so you try to avoid it.

So, it is always good to find out what is the cutting temperature. The equation can be used to predict the increase in temperature at the tool tip is dT = 0.4U. What is U? U comes from a specific energy. Divided by ρ which is a material property and C is also a material property and v is a cutting velocity To is that uncut chip thickness divided by K, K is a constant to the power 0.33 this is relationship is got from empirical analysis. So, where delta T means the mean temperature rise from the room temperature to that then U is the specific cutting energy operation which we have seen, v is the cutting speed.

T is the chip thickness before cutting. PC is the volumetric specific heat of a given material. K is the thermal diffusivity. So, all these things are physical properties. It is the volumetric specific heat multiplied by the thermal diffusivity of the workpiece. Then, finally, we try to get a relationship as $T = Kv^m$.

Tool Wear

Tool wear is gradual process; created due to:

- High localized stresses at the tip of the tool
- High temperatures (especially along rake face)
- Sliding of the chip along the rake face
- Sliding of the tool along the newly cut workpiece

The rate of tool wear depends on

- Tool and workpiece materials
- Tool geometry - process parameters
- Cutting fluids characteristics of the machine tool

So, the final point of discussion is going to be tool wear. Because of friction, there is going to be deformation happening on the tool. So, now let us try to discuss tool wear. If tool wear happens, then the tool geometry changes.

If the tool geometry changes, the surface finish generated is not good, and the forces might go high. So, tool wear is a gradual phenomenon. Tool break can happen; tool wear can happen. Wear is a continuous phenomenon. Tool wear is a gradual process created due to high localized stresses at the tip of the tool.

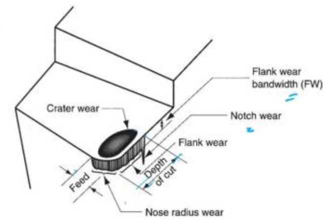
Here, there are very high temperatures. The sliding of the chip along the rake face produces friction, and the sliding of the tool along the newly cut workpiece also occurs. All these things lead to tool wear. The rate of tool wear depends upon the tool, workpiece material, tool geometry, process parameters, and the cutting fluid we use. So, these are the measures we take to reduce tool wear.

Tool Wear

Tool wear and the changes in tool geometry and they are classified as:

Crater wear

- It consists of a cavity in the rake face of the tool that forms and grows from the action of the chip sliding against the surface.
- High stresses and temperatures characterize the tool chip contact interface, contributing to the wearing action.
- The crater can be measured either by its depth or its area.



Flank wear

- It occurs on the flank, or relief face, of the tool.
- It results from rubbing between the newly generated work surface and the flank face adjacent to the cutting edge.
- Flank wear is measured by the width of the wear band, FW.
- This wear band is sometimes called the flank wear land

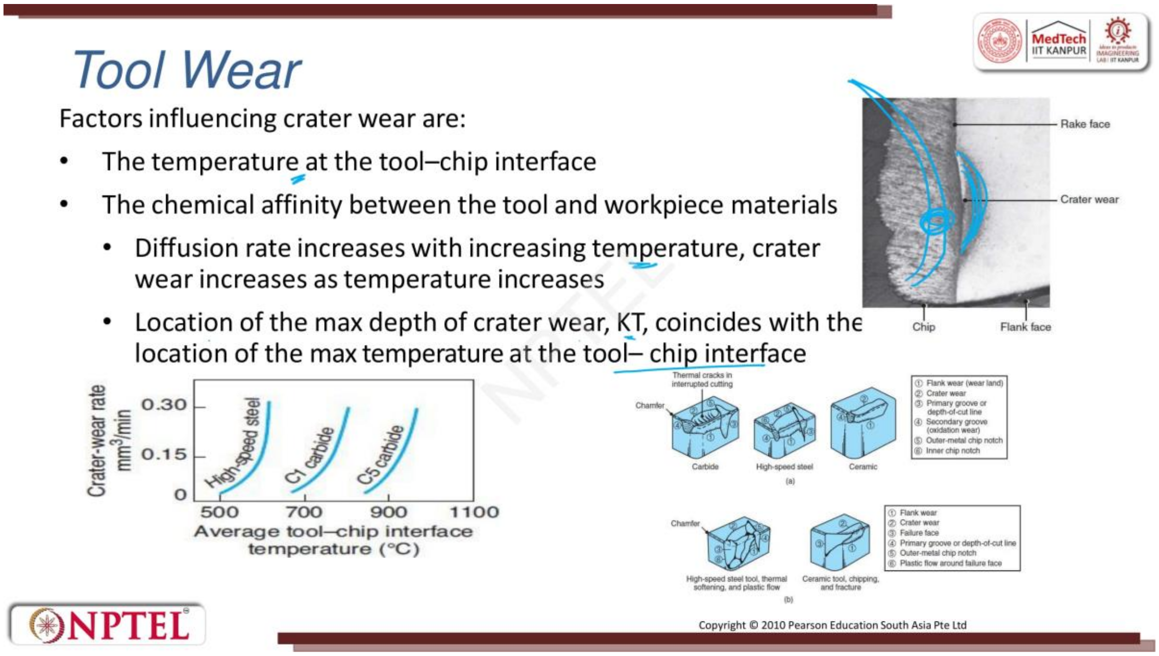
NPTEL

M.P. Groover, *Fundamental of modern manufacturing Materials, Processes and systems*, 4ed

Generally, in a tool, we have crater wear and flank wear. Crater wear happens along the rake face. Flank wear happens along the cutting edge. It consists of a cavity in the rake face of the tool that forms and grows from the action of the chip sliding against the surface. The high stress and temperature characteristics at the tool-chip interface contribute to wear action. The crater is very difficult to measure because it is erratic in nature, and its depth is also erratic.

So, we have to measure the depth to assess it. Generally, what we measure is the flank angle. The flank angle occurs along the relief face, flank, or relief face. So, here, as cutting happens, there is gradual wear. So, if you see here, I have linked it to the feed given and the depth of cut we provide with respect to machining—feed, depth of cut—and now what you do is try to figure out the amount of wear that has occurred.

So, we say flank wear, and then if there is a sharp dip it is called as notch wear. So, this is the nose radius. Now, you can try to see on the rake comes the crater on the cutting edge relief there comes the flank wear.



So, the factor influencing for crater wear can be temperature. This temperature leads to diffusion. So, heat is there. In heat treatment we saw there is a diffusion happening, right?

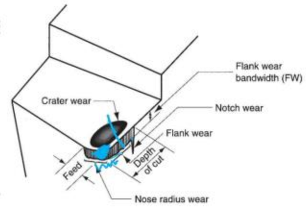
There is a diffusion which happens and because of this diffusion, there is a chemical difference and that leads to a wear. The chemical affinity between the tool and the workpiece material happens, the diffusion rate increases with increase in temperature which relates to the crater wear there is an increase. And then, the location of the maximum depth of crater wear KT coincides with the location of the maximum temperature of tool tip interface. So, what happens is, wherever there when the machining happens the chip goes like this.

So, here the temperature is maximum, the crater wear is also maximum. This is the chip. So, crater wear with respect to tool chip interface temperature we have just plotted it here.

Tool Wear

Nose wear

- As a consequence of the harder surface, wear is accelerated at this location.
- A second region of flank wear that can be identified is nos radius wear.
- This occurs on the nose radius leading into the end cutting edge



Notching plastic deformation of the tool tip

- An extreme condition of flank wear often appears on the cuttir edge at the location corresponding to the original surface of the work part. This is called notch wear.

Chipping

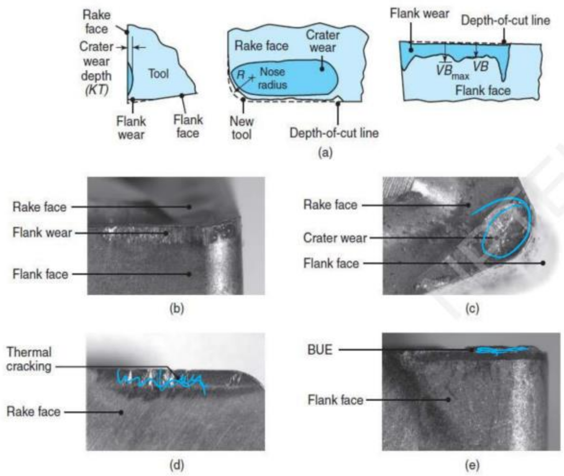
- Chipping may occur in a region of the tool where a small crack already exists.
- Two main causes of chipping: **Mechanical shock & Thermal fatigue**

M.P. Groover, *Fundamental of modern manufacturing Materials, Processes and systems*, 4ed

The nose wear which is also there, but it is very difficult to measure. So, as a consequence is of a harder surface the wear accelerates in at its location. The second region of flank wear can be identified is at the nose radius wear. So, flank nose crater. It is very difficult to measure, we always try to measure the average points and then we try to do it.

There is notching and plastic deformation which happens on the tool tip. Extreme conditions of the flank wear often appears on the cutting edge at the location corresponding to the original work piece. There can be a possibility of chipping of the tool also happens when the forces are very high.

Tool Wear



a) **Features of tool wear** in a turning operation. **VB**: indicates average flank wear
b) **Flank wear**
c) **Crater wear**
d) **Thermal cracking**
e) **Flank wear** and built-up edge (**BUE**)

So, here it tries to give you a lot of understanding. So, A refers to the feature of the tool wear in turning operation, B talks about flank wear, C talks about the crater wear, D talks about the thermal cracking which is formed on the flank and the E talks about built up edge. This is the built up edge on the top of the tool which is there.

Tool Wear: Mechanism

Abrasion

- This is a mechanical wearing action caused by hard particles in the work material gouging and removing small portions of the tool.
- This abrasive action occurs in both flank wear and crater wear; it is a significant cause of flank wear.

Adhesion

- When two metals are forced into contact under high pressure and temperature, adhesion (welding) occurs between them.
- These conditions are present between the chip and the rake face of the tool.
- As the chip flows across the tool, small particles of the tool adhere to the chip and are broken away from the surface, resulting in attrition of the surface.

Plastic deformation

- The cutting forces acting on the cutting edge at high temperature cause the edge to deform plastically, making it more vulnerable to abrasion of the tool surface. Plastic deformation contributes mainly to flank wear.

Tool Wear: Mechanism

Diffusion

- This is a process in which an exchange of atoms takes place across a close contact boundary between two materials.
- In the case of tool wear, diffusion occurs at the tool–chip boundary, causing the tool surface to become depleted of the atoms responsible for its hardness.
- As this process continues, the tool surface becomes more susceptible to abrasion and adhesion.
- Diffusion is believed to be a principal mechanism of crater wear.

Chemical reactions

- The high temperatures and clean surfaces at the tool–chip interface in machining at high speeds can result in chemical reactions, in particular, oxidation, on the rake face of the tool.
- The oxidized layer, being softer than the parent tool material, is sheared away, exposing new material to sustain the reaction process.

So, the mechanism generally can be abrasion, adhesion and plastic deformation. Abrasion is, with these hard particles when they are moving, hard particles built up edges they dissociate and they are hard particles between chip and the tool, where in which they try to create a scratch.

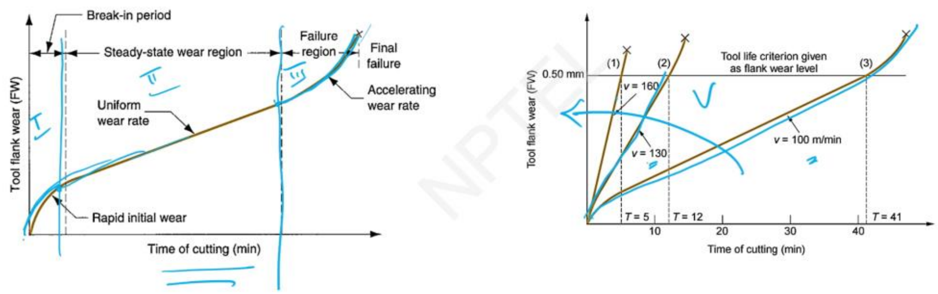
This scratch on acceleration tries to chip off, that is abrasion. Adhesion is, when there is a very high temperature between the chip and the tool, there is a thermal affinity happening and there is a diffusion happening. Because of this, there is a wear. So, when two metals are forced in contact with high pressure and temperature, adhesion occurs. This condition are present between the chip and the rake face and this is what I said.

The plastic deformation is because of the very high temperature which is there and when the chip is trying to move, the softening happens at the tool which leads to plastic deformation. Very high temperature leads to plastic deformation. Diffusion is the temperature between the tool and the workpiece is very high.

So, there is a transfer of atom from the chip to the workpiece, where there is a higher temperature, there a diffusion happens. So, this follows the Humery 3 rules, the atom gets diffused from the carbon, the carbon atom gets diffused from the steel into the tool material. So, by doing so, what happens is the workpiece becomes hard and brittle. The chemical reaction is almost the same with respect to diffusion.

Tool Life

- Tool life is defi ned as the length of cutting time that the tool can be used.
- Operating the tool until final catastrophic failure is one way of defining tool life.
- The general relationship of tool wear versus cutting time is shown



M.P. Groover, *Fundamental of modern manufacturing Materials, Processes and systems*, 4ed

Tool Life

within interval I:
The flank wear increases rapidly till point "a". Rapid increase of the wear is due to the unevenness of the newly sharpened edge is being quickly smoothed.

within interval II:
It increases at normal rate and termed as normal wear, and the slope of the wearing curve is dependent upon the cutting conditions such as speed, geometry, work piece material and coolant type.

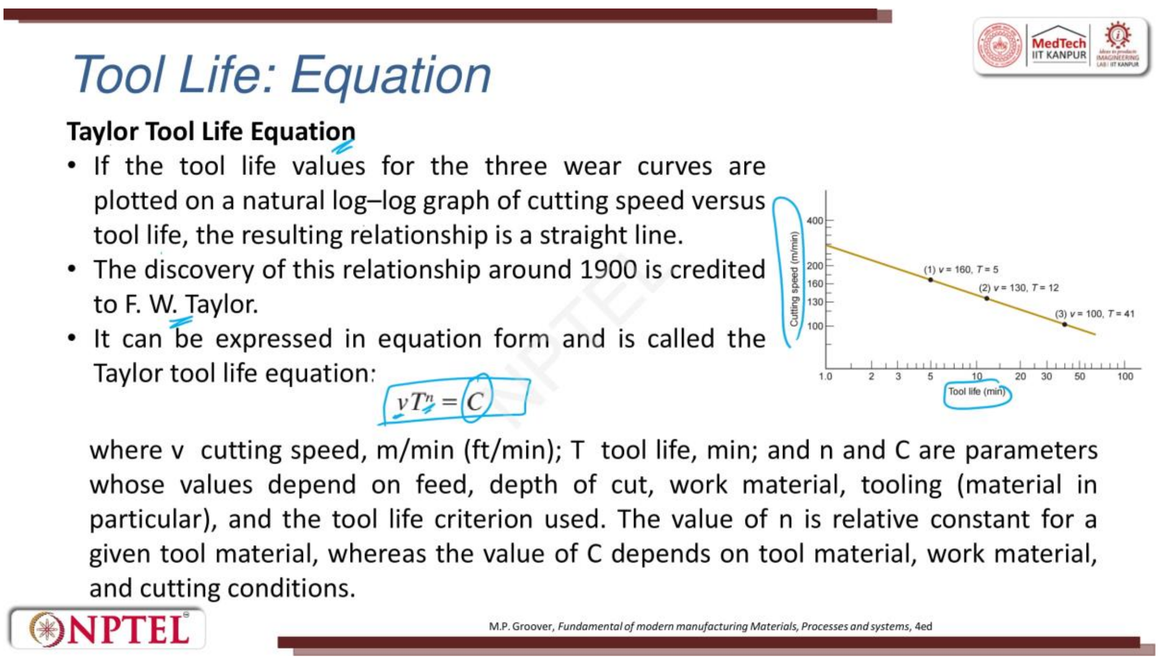
within interval III:
The flank wear increases rapidly till the cutting edge is completely damaged and any control is hardly possible. The reason is the appearance of the flank wear associated with the formation of thermal cracks and plastic deformation.

So, if we plot, the tool life is very important, like finding out the tool's cutting power. So, here we try to find out the tool life. The tool life is a gradual phenomenon. Tool life means finding out the tool wear.

Tool wear is a gradual phenomenon. I divide the plot into three. The initial one is called running-in wear. Then, it is called uniform wear. Then, it is called the failure region or sudden failure region.

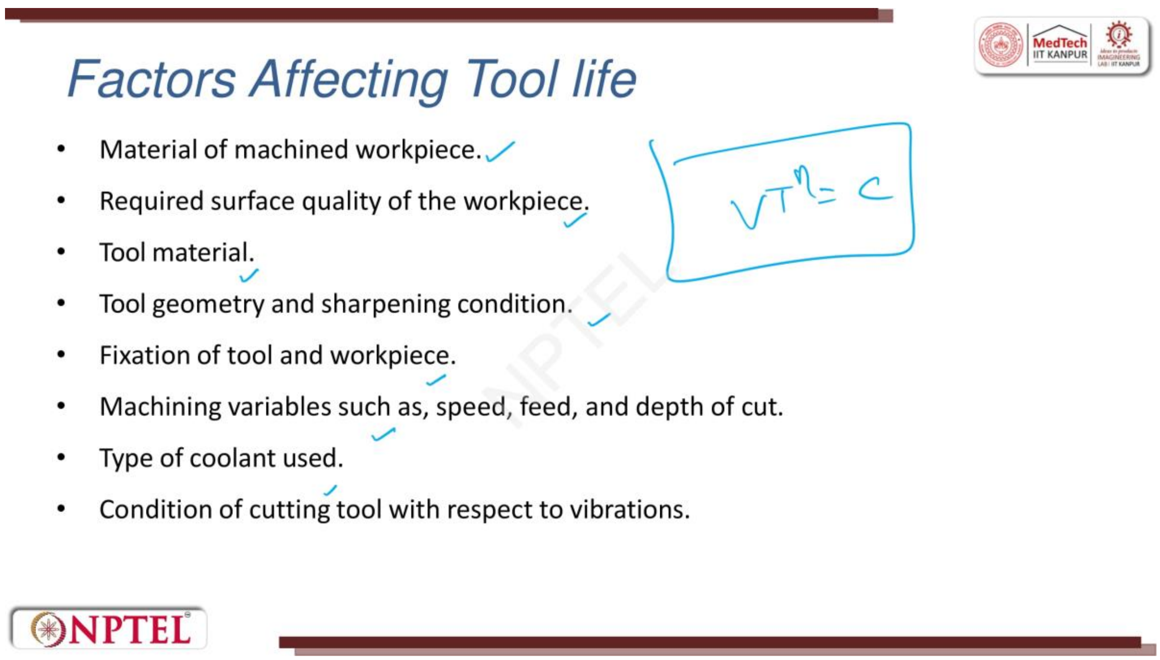
So, it is divided into three zones: zone 1, zone 2, and zone 3. Zone 1 is where the asperities on the tool get removed, and slowly the tool starts wearing. In zone 2, we try to have a uniform wear rate with respect to time, and once it reaches a limit, there is diffusion. So generally, what happens at this point is people will try to take the tool back and then try to grind it. They then bring the geometry back to the original, then they get into this zone. But once it goes into this zone, it is going to be a catastrophic failure.

So, zone 1 and zone 2 are comfortable. So, this is the tool flank wear with respect to time. So, here we try to see v = 100. At a cutting velocity, how is this curve 130, 180? When we go over to a higher cutting speed, what happens? The tool life reduces, the temperature goes very high, and all the wear phenomena happen. So, this tries to tell us that as and when the velocity increases, the tool life decreases. So, whatever I have discussed here, I have presented it in this slide.

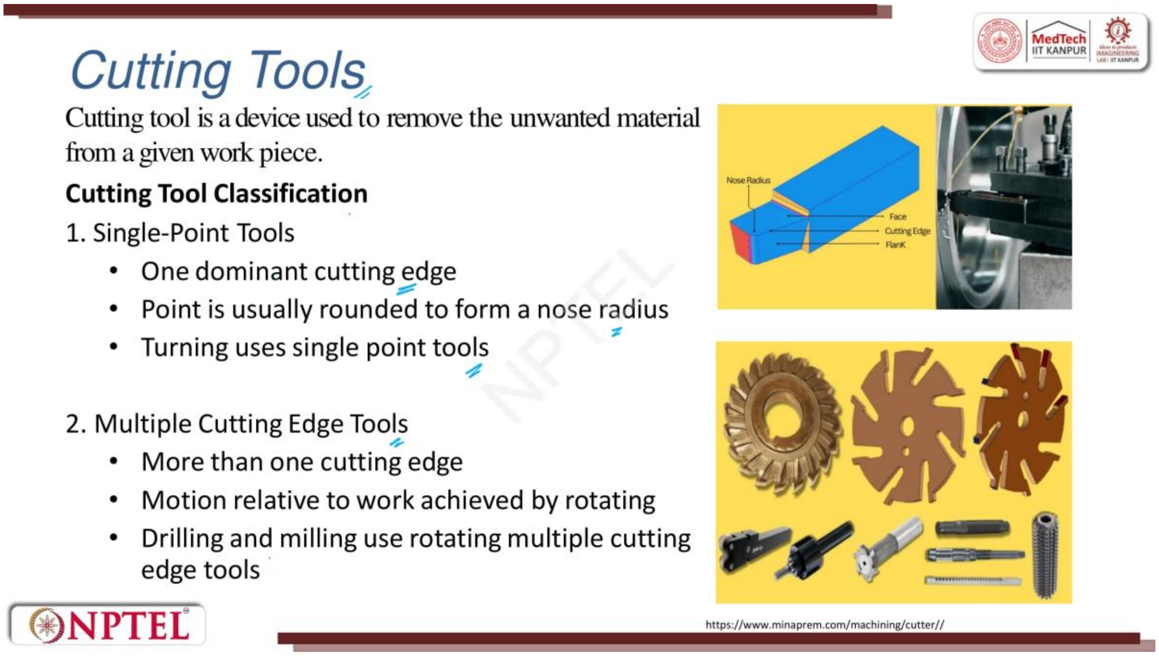


So, tool life equation: when I take the same thing, same plot, and I try to do a logarithmic plot. So, it is cutting speed versus tool life. I try to take the log value, and then I plot. It comes as a straight line. And the moment it comes as a straight line, I try to express an equation. So, with this equation, I can try to figure out at what velocity what will be the tool life time, and C is a constant which is between workpiece and tool. There is a constant which is already expressed. So, this equation was expressed by F. W. Taylor, or it is otherwise called Taylor's tool life equation. So, if the tool life value for the three wear curves are plotted on a natural log-log graph of cutting speed versus tool life, then we get a straight line.

So, the n value we get from the slope. So, with this, we can try to figure out what will be the life of the tool with respect to the cutting velocity for a given set of combination C.



So, the factors which affect tool life are material of machine, surface quality, tool material, geometry, tool machine variables, coolants, and cutting tools with respect to vibration. So, all these things are factors which affect $VT^n = C$, that is what we call Taylor's tool life equation.



So, now let us understand single-point cutting tool and multiple-point cutting tools. Single-point cutting tool: cutting tools can be classified into single-point and multiple-point. Single-point means where there is predominantly only one cutting edge.

The point is usually rounded to form a nose radius, and it is generally used in turning operations, turning, and boring. When there are more cutting edges, it is called multiple cutting edges. So, here motion relative to work is achieved by rotation. So, drilling and milling are multi-point cutting tools. Abrasive is also a multi-point cutting tool.

Cutting Tools: Classification

Sl.No	Single Point cutting tool	Multi Point cutting tool
01.	It contains only one main cutting edge in the cutter body.	It contains more than one (even up to hundreds) cutting edges in the cutter body.
02.	Material removal action at a time in a single pass	Simultaneously engage in cutting action in a pass
03.	material removal rate (MRR) and productivity are low.	It offers higher material removal rate (MRR) and productivity.

NPTEL

58

Cutting Tools: Classification

04.	Design and fabrication of single point cutting tools are easier.	Design and fabrication of multi point cutting tools are quite difficult.
05.	Rate of heat generation and subsequent rise in tool temperature is high.	Rate of heat generation and subsequent rise in tool temperature is low .
06.	Usually low feed rate and depth of cut is employed when machining is carried out with single point cutting tools.	Higher feed rate can be employed when machining is carried out with multi point cutting tool.
07.	Examples: Turning tool, shaping tool, planing tool, slotting tool, fly milling cutter, etc.	Examples: Milling cutter, hob, broach, grinding wheel, reamer, knurling tool, etc.

NPTEL

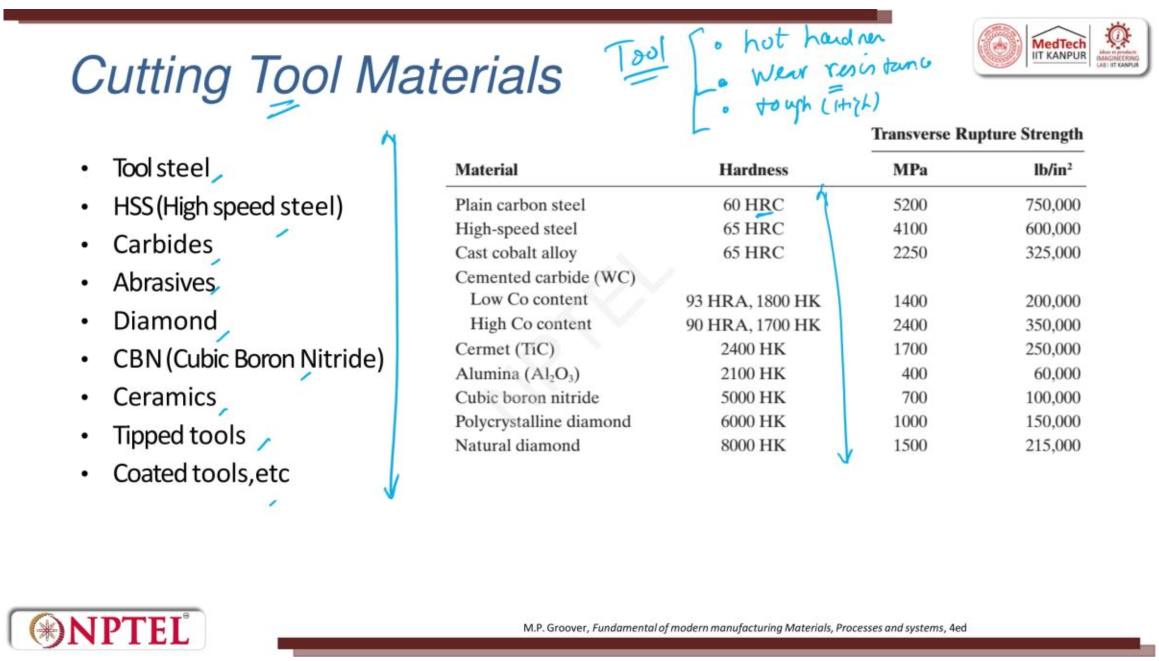
59

So, what is the classification of single-point and multiple-point cutting tools? It contains only one main cutting edge in the cutter body. It contains more than one cutting edge in the cutter body.

The material removal action at the time in a single pass involves simultaneously engaging in cutting. So, it has material removal. At a time in a single pass, here multiple edges will be present. Material removal rate and production rate are low here; it is high because, at any given point in time, two or more cutting edges will come in contact. Design and fabrication of a single-point cutting tool are easy; here, it is slightly difficult.

The rate of heat generated and the subsequent rise in tool temperature is very high in a single point. Since the heat is distributed, the heat generated is low. So, the tool wear is always low. Usually, a low feed rate and depth of cut are employed when machining is carried out with a single-point cutting tool. Here, we use a higher feed rate and a higher depth of cut.

So, under this classification of single-point tools, turning, shaping, planing, slotting, fly milling cutters, etc., boring comes into action. Here, milling, hobbing, broaching, grinding, reaming—all these things come into action. So, single-point and multiple-point classifications are given here.



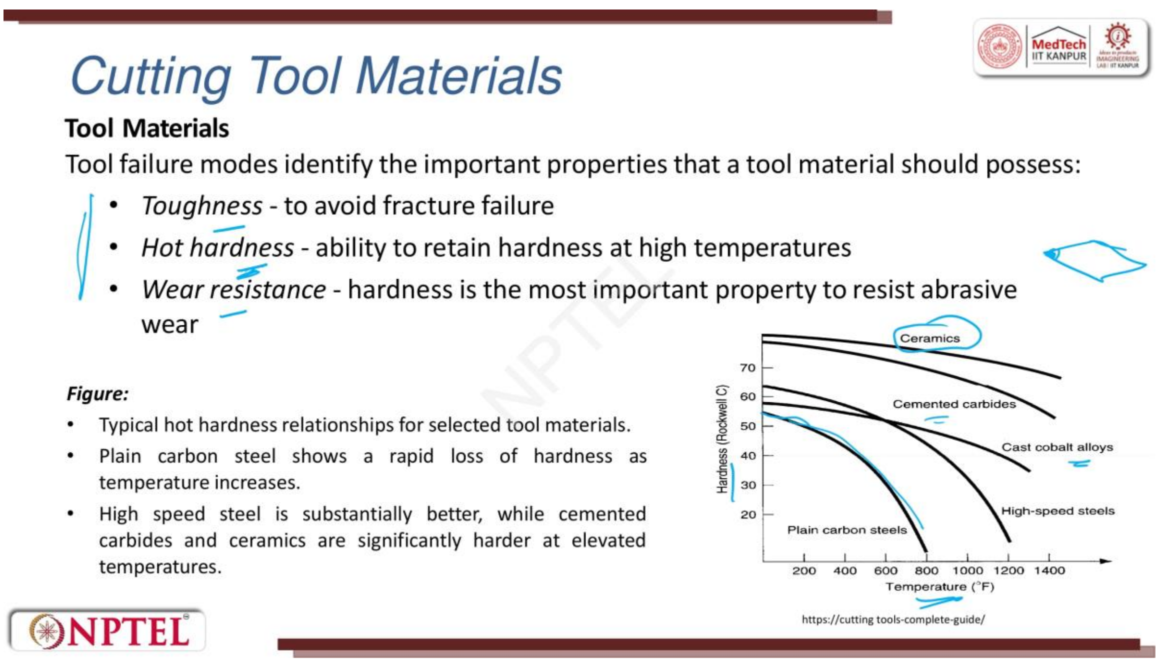
Material	Hardness	Transverse Rupture Strength MPa	Transverse Rupture Strength lb/in²
Plain carbon steel	60 HRC	5200	750,000
High-speed steel	65 HRC	4100	600,000
Cast cobalt alloy	65 HRC	2250	325,000
Cemented carbide (WC)			
Low Co content	93 HRA, 1800 HK	1400	200,000
High Co content	90 HRA, 1700 HK	2400	350,000
Cermet (TiC)	2400 HK	1700	250,000
Alumina (Al_2O_3)	2100 HK	400	60,000
Cubic boron nitride	5000 HK	700	100,000
Polycrystalline diamond	6000 HK	1000	150,000
Natural diamond	8000 HK	1500	215,000

There are various tool materials available. When we look at tool materials, we discussed single-point and multiple-point tools. When we examine tool materials, it is not just one material; there is a spectrum of materials available.

These include tool steel, high-speed steel, carbides (which are ceramic materials), abrasives, diamonds (both artificial and natural), and cubic boron nitride. So, ceramics, tool tips, and coated tools—these are all different types of tool materials available today. For example, plain carbon steel has a hardness of 60. When selecting a tool, the major properties it must have include high hot hardness. Hot hardness should be very high. It must also have high wear resistance.

Hot hardness is at a very high temperature; the hardness should be maintained. The wear resistance should also be very high. These are basic properties. So, hardness at room temperature is different from hot hardness. So, if you see, the hardness is put for varying materials.

So, you can try to understand what it is, and it also has to be tough. Because when there is vibration, the tool should not break. So, it has to have high toughness, high wear resistance, and high hot hardness. So, these three properties are very important for any given cutting tool.



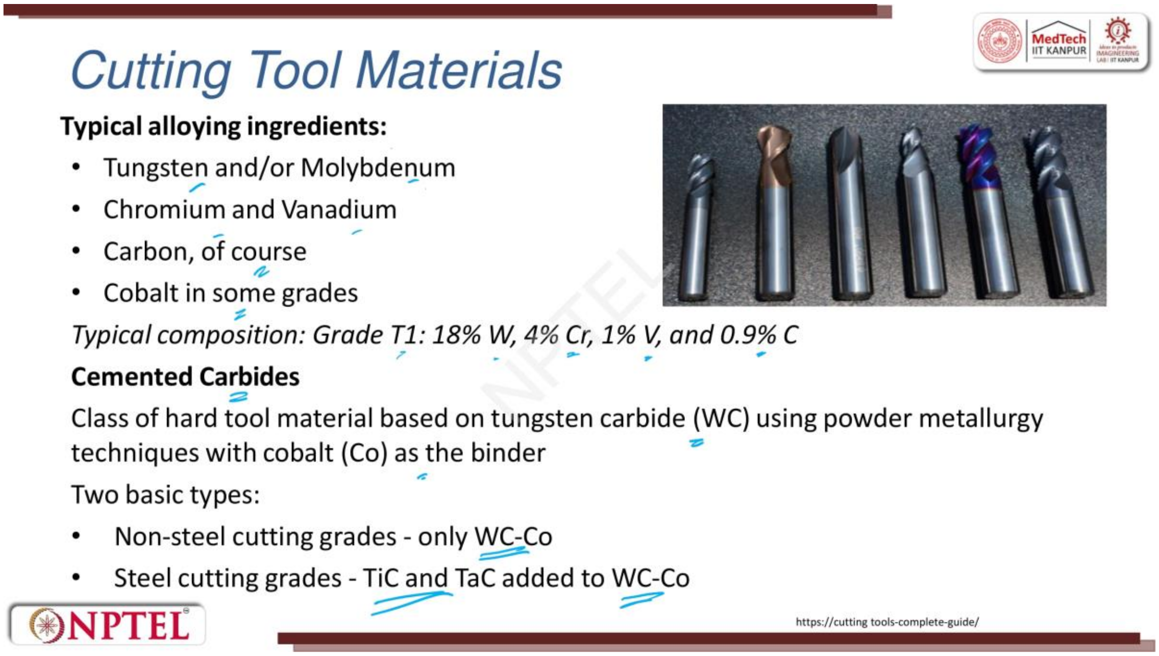
So, toughness, hardness, and wear resistance are the most important properties for any given tool material. So, you can see here there is a plot of hardness with respect to temperature; you see how the hardness property dips down. So, that is why we try to talk about a property called hot hardness.

So, you can see for cast cobalt alloy, then you can see for cemented carbide how the response is for ceramic. So, when it comes to ceramic, the toughness is very low. So, we try to use it as a tip.

So, this is a tool. Only this portion will be made out of ceramic, ok. So, the most important properties for a cutting tool are toughness, hot hardness and wear resistance property.

These are high speed steel tool material and these are the tools there are a display of tools what we show here. Here if you see the geometry of the tool is complex. So, high speed steel gives you a flexibility of defining the geometry and producing typical difficult geometries for the tool.

One of the most commonly used tool material is HSS. So, especially suited for applications involving complicated tool geometry such as drills, taps, mills and broaches we always use it. So, when we talk about tungsten carbide and molybdenum type. So, they are T-grades and M-grades which are there. So, in HSS itself we have T-grades and M-grades.



So, these are all typically alloyed ingredients. So, we have tungsten and molybdenum included, vanadium and chromium included, carbon of course and cobalt. So, these are all for tungsten carbide ok. So, I redo it here. Two basic types are which is defined by AISI.

So, tungsten type, which is said as T-grade HSS, and molybdenum is M-grade HSS. The typical alloys included in HSS are tungsten, molybdenum, chromium, vanadium, cobalt in some cases, and carbon, of course, is introduced into the material such that it can be harder than the workpiece, and you can try to define geometry. The typical composition for grade T1 is 18 percent W, 4 percent chromium, 1 percent vanadium, and 0.9 percent carbon. When we talk about tungsten carbide, the tungsten carbides are a class of hard tool materials based on tungsten carbide used in powder metallurgy techniques along with cobalt as a binder. So, there are two types here: only tungsten carbide and cobalt for non-steel cutting grades, which we use.

For steel-cutting grades, we have, along with this, the other alloys of titanium carbide and tantalum carbide added. So, when you add these alloying elements, it ensures that you retain hot hardness, wear resistance, and toughness.

Cutting Tool Materials

Cemented Carbides – General Properties

- High compressive strength but low-to-moderate tensile strength
- High hardness (90 to 95 HRA)
- Good hot hardness
- Good wear resistance. High thermal conductivity
- High elastic modulus - 600 x 10^3 MPa (90 x 10^6 lb/in^2)
- Toughness lower than high speed steel

Non-steel Cutting Carbide Grades

- Used for nonferrous metals and gray cast iron .Properties determined by grain size and cobalt content.
- As grain size increases, hardness and hot hardness decrease, but toughness increases
- As cobalt content increases, toughness improves with expense of hardness and wear resistance

https://cutting tools-complete-guide/

Cutting Tool Materials

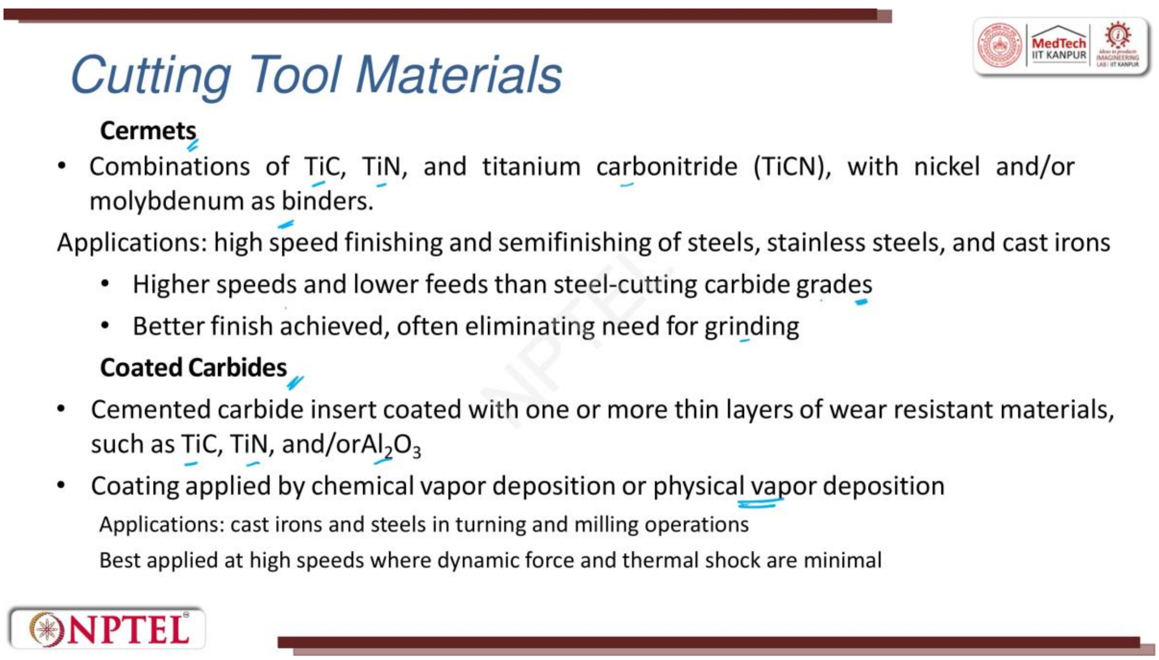
Steel Cutting Carbide Grades

- Used for low carbon, stainless, and other alloy steels
  - For these grades, TiC and/or TaC are substituted for some of the WC
  - This composition increases crater wear resistance for steel cutting, but adversely affects flank wear resistance for non-steel cutting applications

Cemented carbide general properties: it has high compressive strength but low to moderate tensile strength. So, toughness will be very low, high hardness will be there, greater hot hardness, greater wear resistance, E is very high, and the toughness is lower than HSS. That is why, if you see, all the HSS tools will be large; you will have a shank and other things.

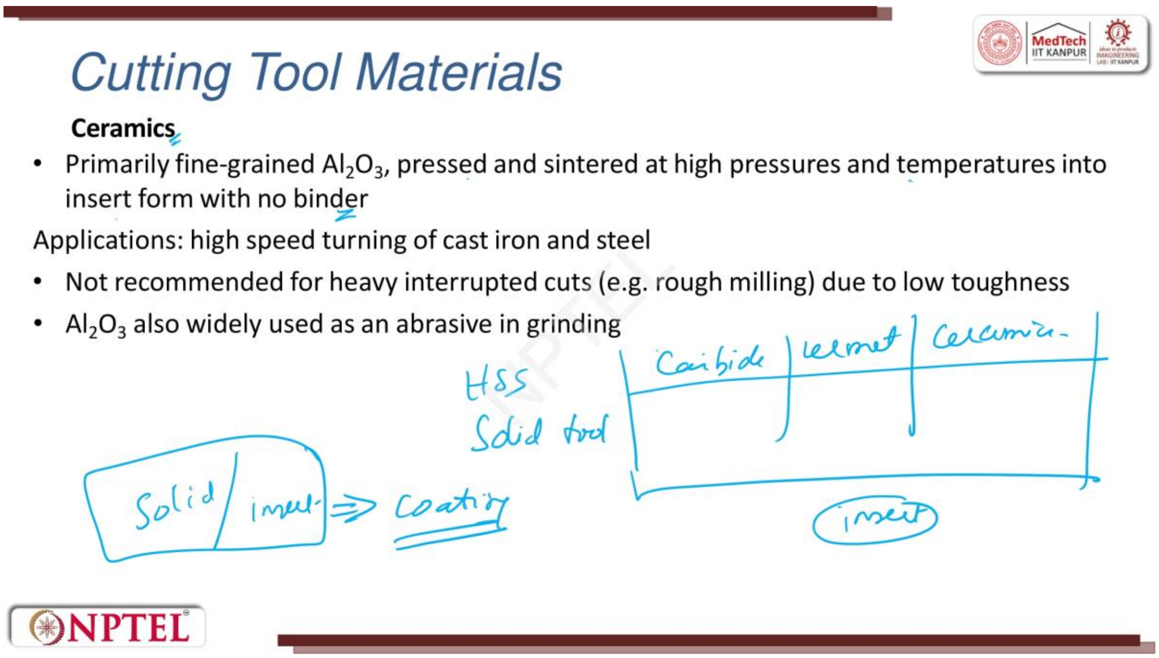
If you see tungsten carbide, these are all tool tips only made. So, only the cutting edge will be made, and this will be placed into a shank where there is toughness property. So, non-steel cutting grades are used for non-ferrous metals and gray cast iron. The properties determined by grain size and cobalt content are there. As the grain size increases, the toughness increases, and hot hardness decreases, right.

The hardness decreases, but hot hardness also decreases, while the toughness increases. So, we have to decide when we use a powder metallurgy route; tungsten carbide powder size is very important, as we said here. And the binder—because if you have only ceramic, you need a binder—cobalt is used as a binder, which also provides hot hardness and wear resistance properties. The steel-cutting carbide grades are titanium carbide and tantalum carbide, which are added. So, the composition increases the crater wear resistance for cutting steel.



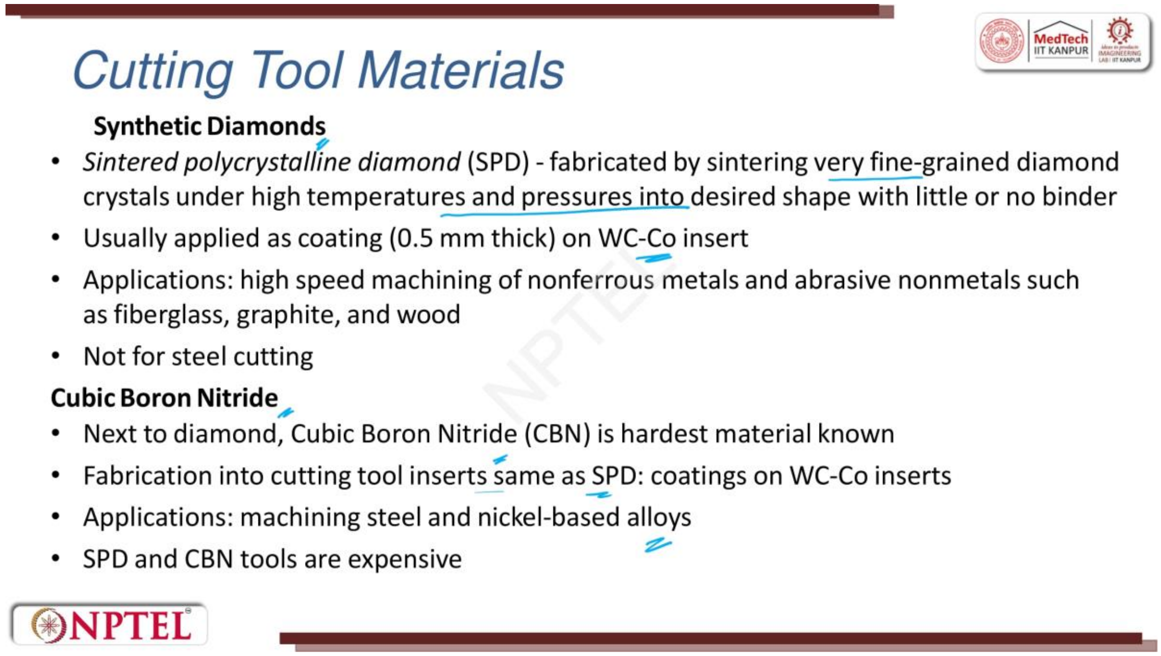
Cermet tools are also available. It is a combination of TiC, TiN, and TiCN with nickel or molybdenum as a binder. So, again, here it is an insert that is used for making it. So, friends, if you try to take solid tools, they will be HSS; all the other tools are inserts. Higher speed and lower feed can be used with steel-cutting grade, and a better finish can be achieved.

When we talk about coated carbide, even if you want to improve the resistance of your insert, we can apply a coating. So, a coating of TiC, TiN, or Al2O3 can be applied, or multiple layers can be given to enhance the properties, as shown here with coated carbides. Coating is applied by chemical vapor deposition or physical vapor deposition, which enhances the tool material properties.



Ceramics are on the higher end. So, HSS—we have solid tools, then we have tungsten carbides, then we have cermets, and then we have ceramics, okay?

So, these all are inserts. So, on top of a solid tool or a insert we can try to give a coating. The coating is only to avoid that thermal diffusion. Primarily fine grain Al2O3 pressed and sintered at high pressure and temperature is formed without a binder you can get it in ceramics. They are highly recommended for large depth of cut machining and exotic material machining.



Synthetic diamond is also used as a tip. So, now these all are, synthetic diamond is also a tip. Sintered polycarbide diamond fabricated by sintering very fine grain diamonds. Crystals under high temperature and pressure into a desired shape with little or no binder is done with synthetic diamond. Natural diamond, synthetic diamond.

Carbon, very high temperature, very high pressure what you get is a synthetic diamond. So, usually applied as coatings on this insert to get a better property. CBN is next to diamond, diamond is the hardest, next to the cubic boron nitrate which is the hardest material known. The fabrication into cutting tool inserts same as SPD is done here. It is application of nickel machining, titanium machining can happen by using CBN.

Applications of Metal Cutting

1. ***Automotive industry:*** Used for cutting and shaping metal parts for cars, trucks, and other vehicles.
2. ***Aerospace industry:*** Used for cutting and shaping metal components for aircraft, helicopters, and satellites.
3. ***Construction industry:*** Used for cutting and shaping metal components for buildings and structures, such as beams, girders, and columns.
4. ***Energy industry:*** Used for cutting and shaping metal components for the generation, storage, and distribution of energy, such as turbines, generators, and pipelines.
5. ***Medical industry:*** Used for cutting and shaping metal components for medical devices, such as orthopedic implants, surgical instruments, and dental implants.
6. ***Electronic industry:*** Used for cutting and shaping metal components for electronic devices, such as computers, smartphones, and other consumer electronics.
7. ***Consumer goods industry:*** Used for cutting and shaping metal components for household appliances, tools, and other consumer goods.

So, the application of metal cutting is found in various industries: automotive industries where there are complicated parts, aerospace industry, construction industry, energy industry where gears need to be made for wind turbines, medical industry where small plastic gears must be produced, dies must be created, electronic industry, and consumer product industry. Everywhere there is a complex process with a high depth of cut, we try to use the metal cutting process.

Recapitulate

- Introduction and Classification
- Cutting Tool Geometry: Single Point and Tool Designation
- Single Point Tool Geometry and Heat Dissipation: Chip Formation
- Chip Formation: Mechanism and chip type
- Chip formation: Mechanism
- Forces in metal cutting
- Merchant circle: Force analysis
- Cutting fluids
- Application
- Recapitulate

To recap, in this entire machining lecture, we have seen an introduction to machining and the classification of machining. We have seen the single-point cutting tool, the rake angle, flank angle, and then the six angles with nose radius. Then, chips—how does a chip form? What is the chip-forming mechanism?

What are all the forces involved in metal cutting? Then, we went into the Merchant circle diagram, cutting fluid requirements, and then we discussed tool materials.

Thank you very much.