Mathematical Modeling of Manufacturing Processes
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Lecture - 09
Force and Velocity Diagram - 1

So today we will discuss the other module of the Mathematical Modeling of Manufacturing Processes that is conventional machining process.

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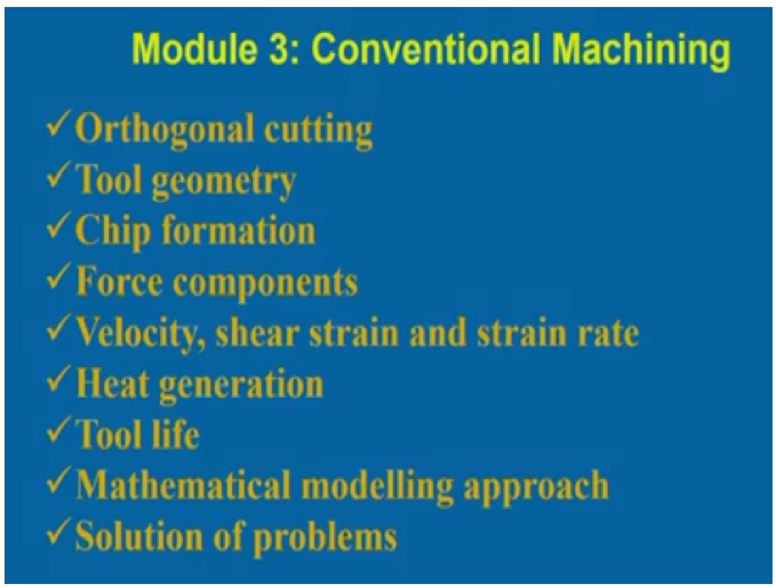

So in fundamental, we will try to describe the conventional machining process and the coverage of this module will be like that. First, we will try to focus on the orthogonal cutting process and we can say the orthogonal machining processes because the oblique cutting process is more complicated. So it will be easy to understand the relation between the different types of angles to estimate the force, estimate the shear stress generated.

All these are very conveniently better explained if we consider the orthogonal cutting process. Then, we will look into that different tool geometry, how we can specify when a particular cutting tool, which is involved in the machining process and of course after that chip formation, how chip formation, what are the different types of the chip formations normally and what are the favorable condition to produce different types of the chips.

Then how to estimate the force components, when the machining process in steady state conditions and we will try to estimate the velocity, shear stress, generate and of course then heat generation, equations and how can estimate the amount of the heat generated during the machining processes, then the estimation of the tool life using conventional processes. Then what are the mathematical modeling approach in this process, specifically conventional machining process and finally some solution of the different kinds of the problems.

So that will be the typical coverage of the conventional machining processes, but of course, this course is not intended or this module is not basically intended to explain different types of the machining processes. So rather in general in principle what are the mechanism or physical elements involved in machining process, conventional machining process. That I will try to explore in this module.

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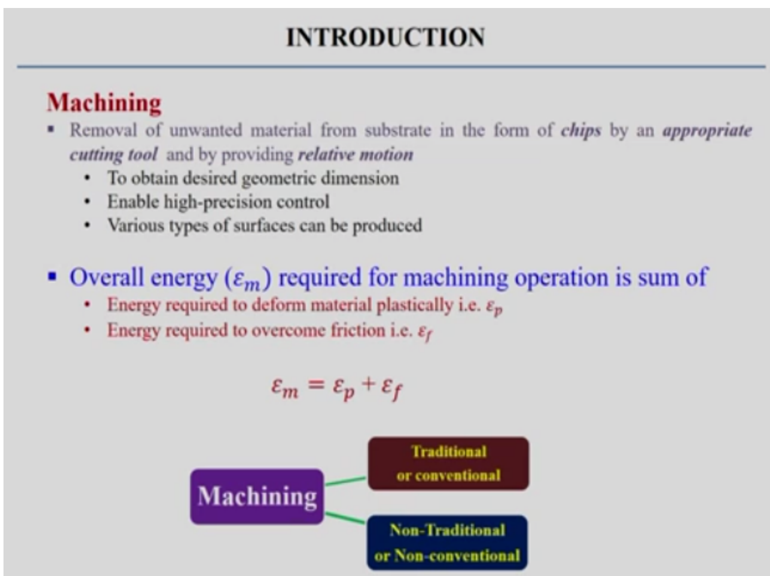

So machining at how, what is the purpose of machining in manufacturing processes. Normally, in machining process, we understand some removal of the material, so that we can get some desired shape and size and of course, that unwanted material that will try to subtract it from the basic material in the form of the chip and of course by using the appropriate cutting tool and definitely it is possible to remove the material.

If there must be some amount of the relative velocity between the work piece material and the cutting tool, which are used to remove the material. So in broad, we can say that what is the purpose, what is two of the specific geometric dimension by removing the unwanted material. Of course, high precision control is required if you try to get that desirable surface finish by removing the material and of course by following certain kind of the machining process.

And of course various type of the surface can be produced using the machining process because it depends what we put the relative motion between the tool and work piece material and it is possible to generate in such some kind of plane surface and in some machining process, it is possible to generate some kind of the cylindrical surface. So both, it is possible to generate in the machining processes.

But if you look into in principle, what is the overall energy requirement in case of machining processes. That is the sum of first is that, of course, energy required to deform material of plastically. So plastic deformation is involved and of course mostly is a particular plane, the setting deformation occurs and also each occurs. It needs to go through the plastic zone and of course, there is another part of the energy involved in machining process that is to overcome the frictional force.

They will try to explain at the plastically deformed material happens where there is energy required for frictional heat generation. So this is total if we say that in overall energy required consists of mainly the two components, one is to deform the material plastically, some amount of the energy required and of course to overcome or energy required to overcome the friction, that is we can say the epsilon f, so that indicates the total energy required in case of any kind of machining process.

Broadly you can divide the machining process in traditional or conventional machining process or the second one is the non-traditional or non-conventional machining process. We will try to find out the difference between the conventional and non-conventional machining processes.

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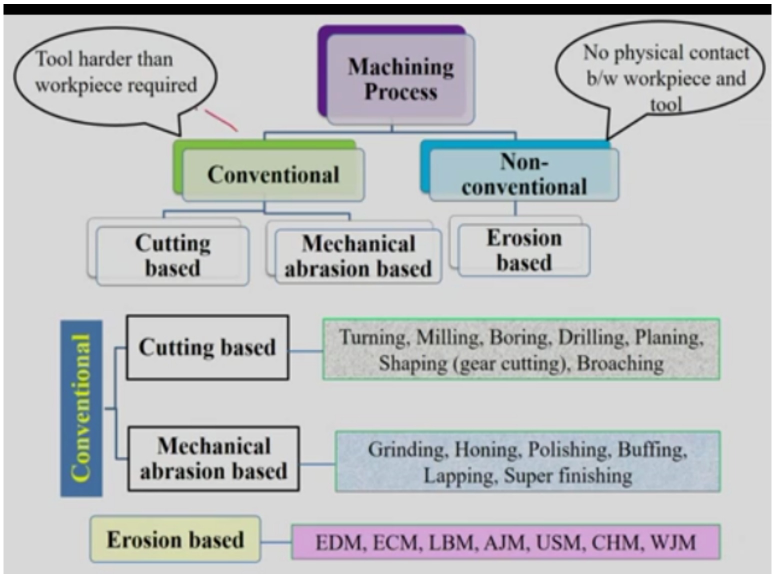

First, we the conventional machining process, what are the requirement? We need a tool actually the cutting tool to remove the material, but definitely when using the cutting tool that tool should be harder than as compared to the work piece material. So that is why some hardness difference must be there to remove the material and of course this is maybe more significant because there is change of the hardness with respect to temperature.

Of course in machining process, the involvement or due to the friction, there must be some kind of the heat generation and the temperature development and their hardness actually depends on the temperature. So we have to very carefully choose the hardness of the tool as compared to the work piece material. So that is the in principle that is the conventional machining process and non-conventional machining process, there is no such limitation that it is independent of the hardness of the tool.

And of course, second part is that not necessary to contact the work piece and tool in case of non-conventional machining process. That is the main difference, but definitely conventional machining process there must be contact between the work piece and the tool material. So in basic difference and what is the mechanism of the material in a conventional that is the cutting based, just cut the material and remove the material from the work piece.

Or mechanical abrasion based, that means we use abrasive particles. They are actually responsible to remove, to generate the chip when therein contact with the work piece material. Of course in conventional machining process, the most significant part is that it depends on the material removal rate, actually depends on to some. What is the relative motion is given between the two length of work piece material.

Non-conventional mechanism is basically erosion based. Erosion based that is erode the material, tools following different kind or different types of the principle. For example, in non-conventional machining process, we can see the electrode, such machining electrochemical machining. So electrochemical machining, so electrolyte is used to erode the material depending upon the principle of the electrolysis.

So that we use and even less of the machining processes also, it is high intensity, lesser we may use. So this electro diesel machining, electrochemical machining, laser beam machining, abrasive jet machining, ultrasonic machining, chemical machining and water jet machining, all are the non-conventional, all are categorized as non-conventional machining process and definitely and definitely we will discuss in the next module about the non-conventional machining processes.

Now we come back to that, in conventional machining processes, in cutting based, what are the different type of the machining processes we normally use. We will see and even in work options, we normally apply this kind of processes, turning process, wheeling process, drilling process, planning process, shaping process, and broaching. These are the typical machining processes. So the description of these and individual machining processes is beyond the scope of this module.

So in general these are the cutting based machining process and if you see the mechanical abrasion machining processes that are grinding, horning, polishing, buffing, lapping and super finishing. Actually, mechanical abrasion based machining process is normally used to bring the finishing operation. So definitely, when looked for the finishing operation, that material removal rate normally is very low in case of mechanical abrasion based.

If the machining process is used for the finishing purpose, to bring good finishing on the surface, the most focus on the surface finish of the component rather than what is the amount of the material removed per unit time. But in case of cutting based machining processes, normally the material removal rate is little bit higher as compared to the mechanical abrasion machining processes.

Now based on, but if you look into the turning, wheeling, drilling, these are the different types of the machining processes, but in principle the removal of the chief and cutting force estimation, all these things in principle, they are the same. They are the similar. Now in general, we will try to look into the physical aspect of the machining process.

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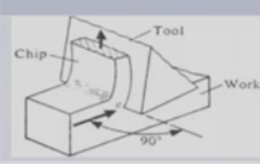
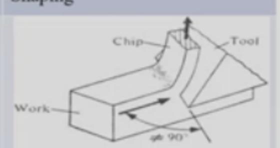
Parameter	Orthogonal Cutting	Oblique Cutting
Cutting edge (Tool)	Perpendicular to cutting speed	Inclined at inclination angle 'i' with normal to cutting speed
Cutting dimension	Two dimensional	Three dimensional
Chip flow	It occurs on the rake face of the tool with chip velocity perpendicular to the cutting edge	It occurs on the rake face of the tool at an angle ~ equal to i with the normal to the cutting edge in the plane of rake face
Cutting force	It acts along x and z directions only i.e. no cutting force along y direction	It acts along all three directions i.e. x, y, and z axes.
Examples	Sawing, Broaching	Turning, Milling, Drilling, Shaping
Diagram		

Before doing that idealization of this machining process is called the orthogonal cutting process. So orthogonal cutting process and oblique cutting process, the basic difference is that in orthogonal cutting process, if you see this figure, the orthogonal cutting process the cutting edge, this is the cutting tool and this is the cutting edge. So the cutting edge and velocity vector, they are perpendicular with respect to each other.

So that creates the situation of the orthogonal cutting process. Definitely the force component in orthogonal cutting process is basically 2 dimensional. So in particular plane, 2 components of the forces are there, but if some inclination angle is there, that means the velocity vector and the cutting edge are not perpendicular, then there are some inclination and it is not equal to 90 degrees. So this type of machining process is called the oblique cutting process.

In practical, most of the machining process, different types of the machining process, they follow the principle of the oblique cutting. So definitely an oblique cutting is 3 dimensional situation. So all the 3 different force components generate during the machining process. Now we can look into the different parameters and how the orthogonal cutting and oblique cutting process are different. So perpendicular to the cutting speed definitely to velocity vector.

Cutting edge is perpendicular to velocity vector and of course cutting edge having some inclination with respect to the cutting velocity vector. Cutting dimension, 2 dimensional in oblique cutting it is 3 dimensional. Chip flow, chip actually this is the cutting, this is work piece material and cutting tool is in contact. So this is the formation of the chip and chip will try to flow over the erect surface of the tool.

Of course, this erect chip flow is definitely perpendicular to the cutting edge in case of orthogonal cutting position, but it is not perpendicular in case of oblique cutting situation. So definitely cutting force 2 dimensional in case of oblique cutting it is 3 dimensional. Example are the broaching, sawing, this is the typical orthogonal situation, that normally in this metal machining processes, we can observe the orthogonal cutting situation.

But if you look into other processes turning, milling, drilling, shaping, all different types of the metal cutting process, we normally follow the oblique cutting situation. So now in terms of orthogonal cutting, we will try to explain further and we will try to establish the physical element involved in machining process.

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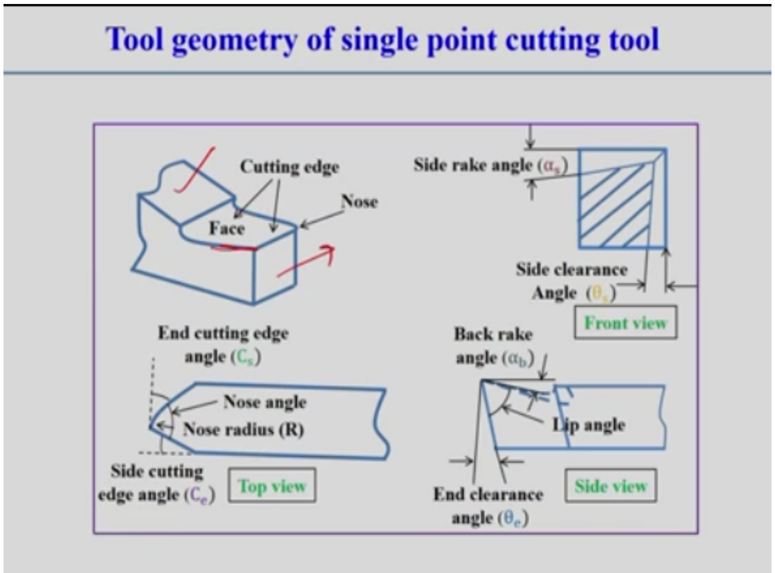

Now before doing that, we will try to look into the tool geometry of a single point cutting tool. In single point cutting tool, suppose this is the typical shape of a tool and of course it is 3 dimensional and if you look into different phase, different view, we can observe the different types of the angles, we measure to define the single point cutting tool. So of course single point cutting tool means the contact is in single point.

So apart from an over area, we assume this theoretically. Now if we assume this is a single point cutting tool and of course this is the phase and the cutting edge is this that is in contact and sorry, this is the cutting edge and this creates the, this is the nose and that is in contact with the chip. Now if you look into different view, first if you look into the front view, so if you look into from this side, in front view, if you see there is this angle, the side rake angle.

This is called the side rake angle and this is called the clearance angle, but it is called the side clearance angle. Now if you look into the top view from the top if you see, that this is in actual contact, in the nose radius and then some allowance is there that is end cutting edge angle and of course this angle we can define the side cutting edge angle and if you look into the side view, and in side view and if you look into the side view, so from this side, this is the rake phase.

And this called the back rake angle and this is called the end clearance angle. So if you look into different view, we can define the different angles. Actually by defining, if you see, we can observe there are 6 different types of angles. So by defining the angles, we can specify a particular cutting tool. Of course the sequence of this different angles and naming may be depend on the different types of the system.

If you follow different system, if you follow American system, British system, all these cases, the naming may be a little bit different, but I am not explaining the different type of the system. You can get in standard textbook. What we understand from here is that we define the side rake angle, back rake angle, two rake angles we define here. Then, side clearance angle, end clearance angle, 2 clearance angle are flank angle also you can say and the 2 cutting edge angle, end cutting edge angle and side cutting edge angle. So by defining all these values, we can specify a particular single point cutting tool.

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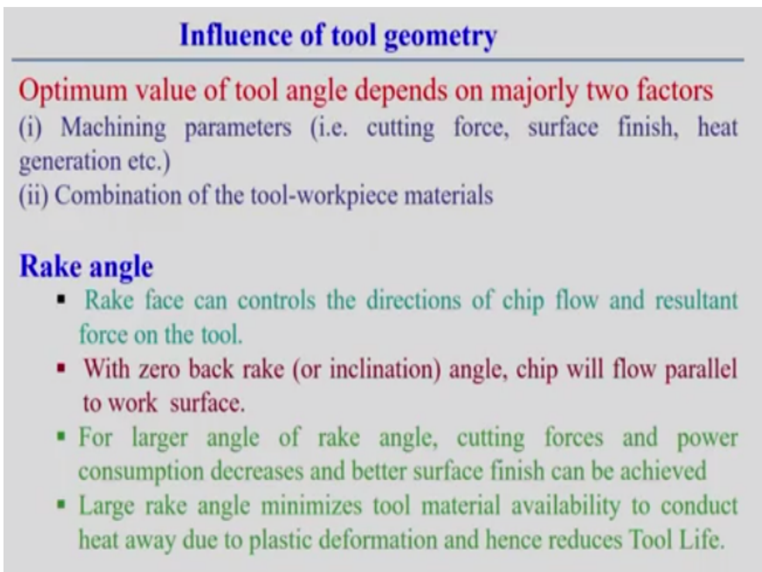

Now once we define the single point cutting tool, of course all these angles having some influence or maybe you can that how to decide the different tool geometry, specification of the tool geometry. In other way, how to define all these different type of angles. So to define all these types of angles, we need to understand how this angles or geometry and optimum tool angles basically influence on the different types of parameters in the machining process.

For example, optimum value, so we need to define the optimum value of the different tool angles. Optimum value of the different tool angles is measured on 2 factors. First factor is the machining parameter, so that machining parameter we understand that cutting situation, cutting force, surface finish, we need to achieve the surface finish, what is the amount of the heat generation, all decides the machining parameters.

Of course, second point is there, second factor is important to decide the optimum tool angle, that is the combination of the tool, material and the work piece material and the interaction between tool and the work material. Based on that we can decide what is the optimum value of this different types of the tool angles or how we can define the optimum tool geometry, we can decide, if you look into all these 2 different factors, machining parameters and materials point of view.

So but in general we can get some idea about how these angles influence the different parameters. For example, you start with the rake angle. So basically rake angle erect phase, rake angle is definitely define with respect to the rake phase, so over the rake phase, the heat control specifically how the chip flows, chip flow direction all these things are decided by the rake phase. Of course that chip flow also depends on the resultant force on the tool.

That also the deciding factor to decide the rake angle. For example, if with 0 rake angle or inclination with a 0 back rake angle or we can say 0 inclination angle, chip flow will be always parallel to the work piece surface. Of course, if some sort of inclination angle means is a 3 dimensional situation, oblique cutting situation, that is not necessary. This chip may not fall parallel to the work piece.

It can deviate to certain angle depending upon what are the inclination angle we define based on the chip can deviate from that with respect to the parallel to the work surface. Similarly, for larger angle of the rake angle cutting force and power consumption actually decreases. If the rake angle is too high, then cutting force reduces that means that is having some influence and when there is reduction of the cutting force, definitely power consumption will be reduced during the machining operation.

Other part is that better surface finish can be achieved if we increase the rake angle, but if we increase rake angle too much, then there may be other difficulties, so that means that minimizes the tool material availability. So that means, the heat actually weakens the tool material and of course that actually hampers the heat dissipation during the heat generation. So in other way heat conduction may not be appropriate if rake angle is too high.

So that, of course, if tool weakens, maybe area of the volume of the tool material reduces if we increase too much of rake angle, then plastic deformation, easily happens due to the application of the load. At the same time, heat actually reduces the life of the tool. So that means, too much of rake angle is not feasible at the same time if the rake angle is also very low, almost 0, that may not be the optimum condition.

So definitely some sort of rake is needed to define to get, to optimize all these parameters or optimize these 2 opposing fact between these 2. Similarly, clearance angle or flank angle sometimes you see.

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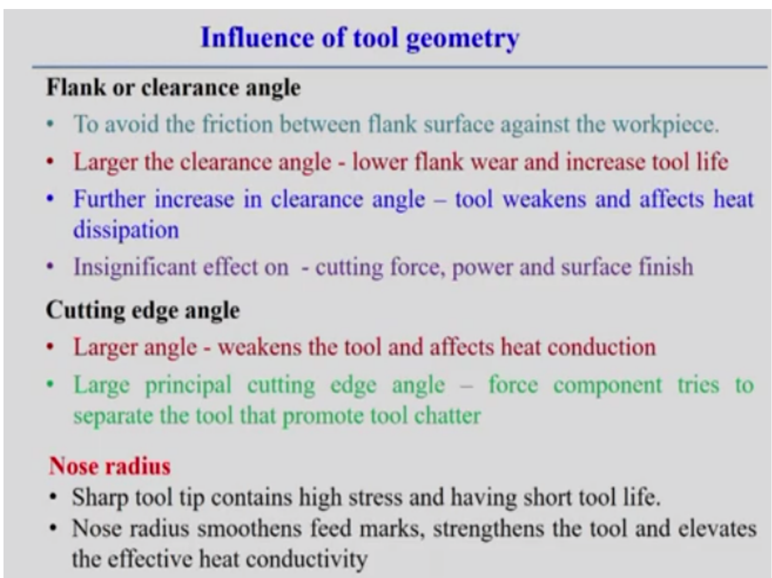

Clearance angle, we can see, that we can look to the figure also clearance angle. So that is the side clearance angle and this is the end clearance angle. So but what is the influence of the clearance angle. We can see the clearance angle is mainly provided to avoid the friction between the tool against the work piece surface. So flank surface against the work piece surface to avoid that some sort of clearance angle is required.

Now if larger the clearance angle, if clearance angle is very high, similarly it can reduce the flank wear and of course when there is a, when it reduces the flank wear, then it increases the tool life. But if it is too high, flank angle is too high or clearance angle is too much, that also weaken the tools and affects the heat dissipation, seen otherwise. So then, definitely some optimum value is required. Of course insignificant that again need to optimize this part.

But the clearance angle having some insignificant effect, not much impact on the cutting force, power requirement and the surface finish. So it is less influenced in all these aspects. So that means, if you compare the rake angle and the clearance angle, so rake angle is having more influence on the power consumption cutting poor surface finish, but clearance angle is having less influence on power consumption and surface.

But still we need to know some optimum clearance angle is needed to provide during the machining process. Similarly, you can look into the cutting edge angle also, what is the influence of the cutting edge angle? So cutting edge angle, if you see the cutting edge angle, the end cutting edge and side cutting edge angle, after looking that side cutting, cutting edge angle, so large angle if we put the cutting edge angle too high.

Then heat also weakens the tool and affects the heat conduction definitely and of course at the same time, if large principle cutting edge angle you provide, then force components try to separate out and that clears the situation or promote the tool chattering during the process. So some optimum cutting edge angle we need to provide during this process. So definitely cutting edge angle also clears some kind of clearance with the work place.

Apart from all these, 3 different types of the tool angles we need to define the nose radius, but what is the role of the nose radius, if you see the surface, definitely it will sharp nose tool tip that means it is a very sharp nose that we put, then it clears the high stress concentration at the contact point and of course when there is a high stress concentration, it actually loses the tool life. So definitely nose radius will need to provide some amount of the nose radius.

That actually, it smoothens the feed marks, because the nose radius to some extent influences the surface finish of the machine surface. So some push the nose radius, it smoothens the feed marks on the finished machine surface. At the same time, nose strengthens the tool and of course elevates the effective heat conductivity. So it influences effective heat conductivity. So it is not necessary or it is not desirable to use the sharp cutting tip.

So some sort of nose radius is needed to be provide to obtain the good surface finish and of course optimum strength of the tool and good conductivity of the tool, so some sort of nose radius will be defined.

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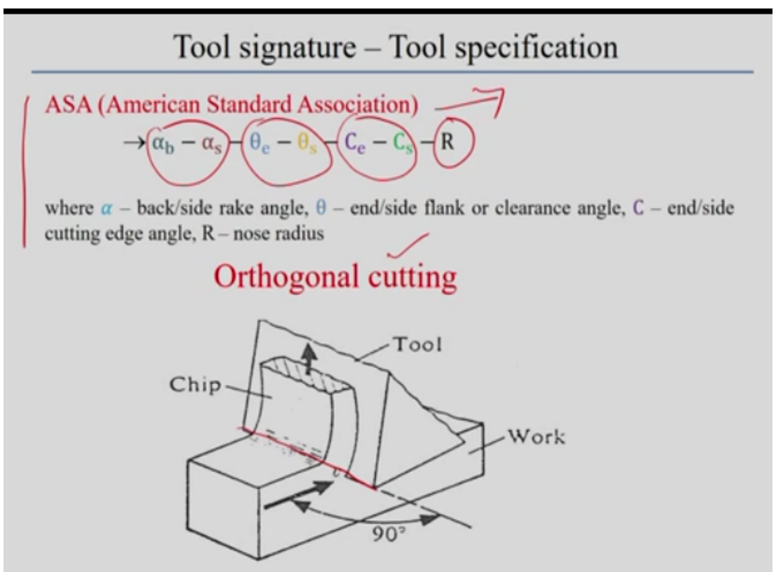

Of course, looking into this back rake angle and I think clearance angle and of course cutting edge angle, so then back rake angle, clearance angle, cutting edge angle, and of course nose radius, so this is called specifically the tool signature. There are 7 elements of tool signature, so 3 pairs of elements indicates three different types of the angles, rake angle, clearance angle, and cutting edge angle, and last one it indicates the nose radius.

So this sequence, it is according to the tool signature is according to the ASA system, American Standard Association system and based on that we define the tool signature, maybe in other system on the other standard system, the name of the tools, angles may be different. Now we come to that point, the orthogonal cutting situation because orthogonal cutting is more ideal situation to understand, to find the relation with different types of tool angles and estimate the forces.

So orthogonal cutting we have already defined. The situation cutting edge is perpendicular to the velocity vector, tool, work piece, velocity vector, or we can say relative velocity between tool and work piece, that actually define the orthogonal cutting situation. So in this case, this orthogonal cutting situation creates the two dimensional cutting process.

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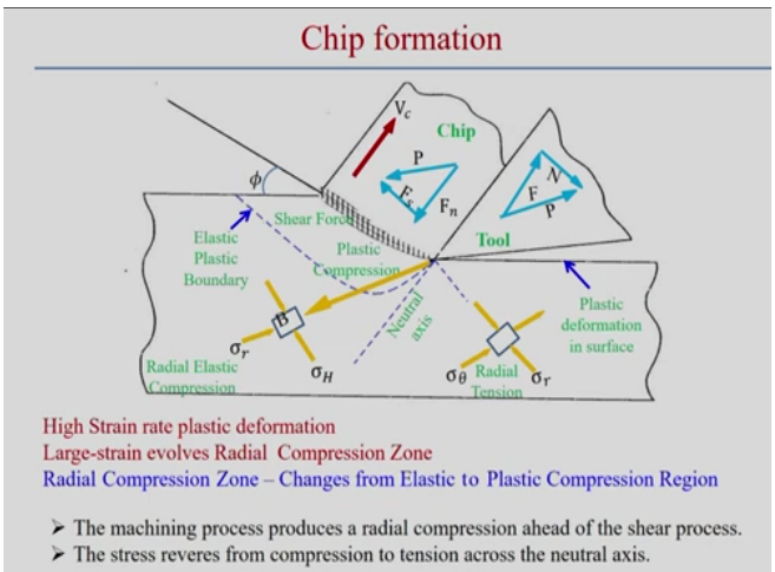

Now chip formation means, suppose this is a cutting tool. So relative motion between cutting tool and the work piece is moving these things, and then this cutting tool is cutting the work piece material and then it creates the chip and chip is actually by removing the extra material from the work piece in the formation of the chip and we can get that this is the machine surface. This is the typical elements of an orthogonal cutting process.

But in mechanism we can see that high strain rate, this process involves actually high strain rate plastic deformation, because the relative motion between the tool and the work piece becomes very high, so tool cuts on the surface. It is subject to some kind of high plastic deformation because it needs to overcome the elastic component and it should be plastically deformed. Once plastically deformed, the shearing happens.

The shear deformation happens in a particular zone, here. So that is the shear zone is specifically converted to the raw work piece to the deformed by shearing action and the chip can be formed here and chip is flown over the erect surface. Now high strain rate plastic deformation, this is involvement of this process. Then large strain evolves radial compression zone. So basically if you see that any application of the tool and the work piece is in contact, the shear force is acting here.

And of course this zone is plastic compression zone has happened and of course this is the elastic boundary and below that there is elastic deformation and beyond that there may be some kind of plastic deformation. Plastic compression normally happens in these zone, certain zone, but shearing happens here and chip is formed there correspondingly. Of course, now this part, we can see under compressive load, radial compressive zone and this radial compressive zone changes from elastic to plastic compression region.

So here the elastic compression zone, but when it comes here the plastic compression zone, it creates after cutting or removing the tool or removing the chip. So this machine process produces the radial compression ahead of the shear process. So here the radial compression is ahead of the shear process, but this stress reverses from compression to tension across the neutral axis, but here the radial tension actually happens instead of the compression.

So this zone, that means if you divide this zone, this is already material is removed by the cutting process. Now if you look into that what are the different forces normally acting in this process. If we see that when the tool, this is the tool forces acting, this is the P and chip flow here, so frictional force will be there. So some frictional force between the tool and chip and this is normal force. So this is friction force, this is normal force and this is the resultant force.

Similarly, if you look into the chip also, shear force is acting here and then the normal force is acting here and the resultant is basically force P and of course, chip flow with velocity Vc is shown at this time, the velocity. That velocity is parallel to the rake surface.

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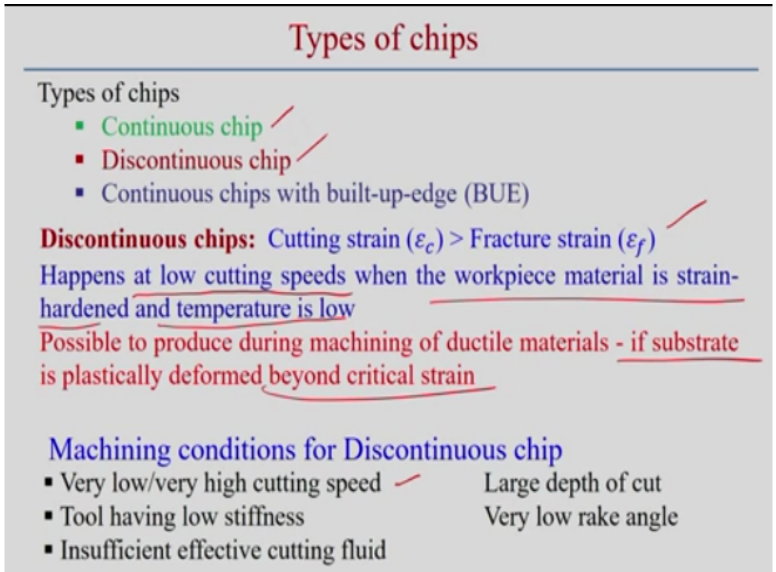

Now what are the different types of the chips normally formed in machining process. So types of chips, first is the continuous chip, discontinuous chip and the continuous chip with built-up edge. What are the different conditions to put different types of the chips? Discontinuous chips definitely discontinuous chips are produced, the chips actually breaks and there may not be continuous production of the chip. So theoretically chip breaks.

So in this case, definitely the cutting strength should cross the fracture strain. Then only it forms the discontinuous chip. What may be conditions? Basically at low cutting speed, if cutting speed is very low, then work piece material is strain hardened and of course the work piece material strain harden and temperature is very low. So if work piece material becomes strain harden, temperature is very low and cutting speed is not very high, very low that condition actually creates the situation for formation of the discontinuous chip.

Even in ductile material it is possible to discontinue the formation of the discontinuous chip. If the substrate is plastically deformed beyond the critical strain, so in that situation, in case of the ductile material this creates the discontinuous chip, but normally discontinuous chip is normally produced in case of the brittle material, because in case of brittle material, the fracture, the brittle material deform without much elongation.

So that may be the reason to produce the small, small chips and that is called the discontinuous chip during the machining processes. So if you look into that, what are the typical situation that prevents the formation of the discontinuous chip, irrespective of whether it is ductile material or the brittle material. First, either very low or very high cutting speed, but of course depending upon types of material whether it is ductile or brittle.

Second, tool having low stiffness, stiffness is very low in case. Then, insufficient effective cutting fluid. If we do not use a proper cutting fluid or maybe released cutting fluid even we do not use any, that also favors the formation of the discontinuous chip. Large depth of cut, so if depth of cut if you put very high, that also promotes the discontinuous chip and of course, low rake angle, so if rake angle is not very low rake.

Of course, we can see the negative rake angle also, then that also creates a situation of the formation of discontinuous chip.

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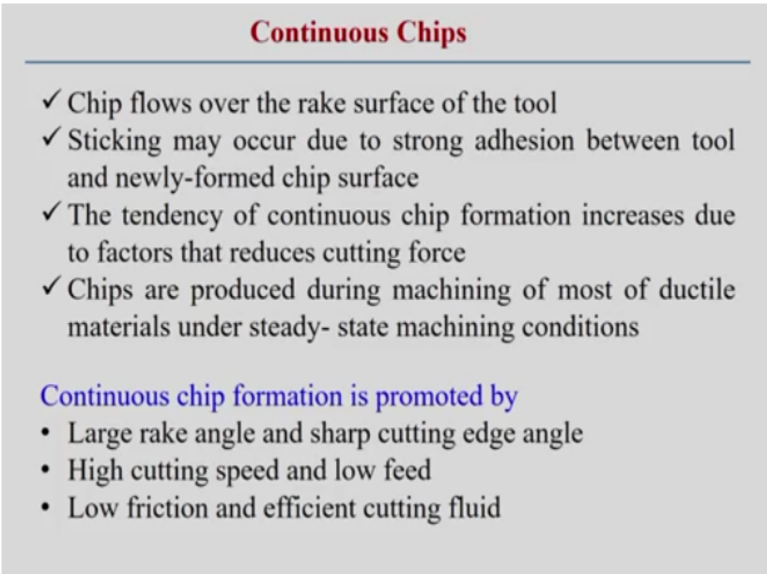

Continuous chip, of course in continuous chip, chips flow through the rake surface, but there may be the possibility of sticking of the chip with the tool, because strong adhesion between the tool and a newly formed chip surface and that is the possible. They may stick also and of course at some favorable condition is required for sticking, but in general tendency of the continuous chip formation actually increases due to the factors, which is responsible to reduce the cutting forces.

In that situation, that formation of the continuous chip formation actually chances is increased. Definitely most of the ductile material, they normally create a continuous chip, but in case of steady state machining conditions, but this machining that continuous chip will be promoted by formation of the larger rake angle. If rake angle is very large, that promotes the formation of the chip because if rake angle is very large, then drastic deformation may not be there.

Because finally, the chip will flow through over the rake phase and if rake angle is very high, maybe if you say rake angle equal to 0 degree, then before cutting of the work piece and after formation of the chips, that makes the angle almost 90 degree. So that gives large deformation happens in these cases. So that is why if higher rake angle, that promotes the continuous chip and of course sharp cutting edge promotes the continuous chip formation.

Very high cutting speed, but at the same time low feed that actually promotes the formation of the continuous chip and low friction and efficient cutting tool that gives the promotion of the continuous chip.

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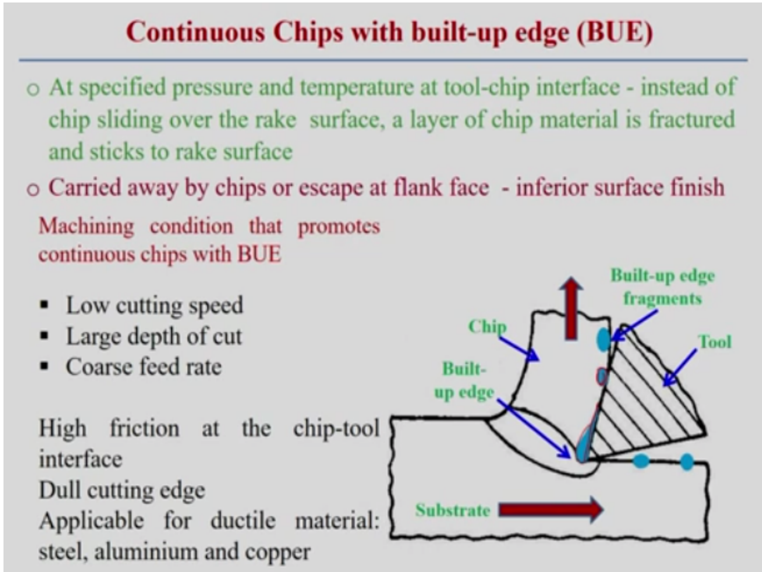

Now there is one situation, continuous chip with built-up edge. So they are specified that particular pressure and temperature that situation that what way the chip and tool interact, that instead of the chip sliding over that rake phase, there is a possibility of the chip chipping on the rake phase and of course a layer of the chip material is fracture and stick to the rake surfaces. So that kind of situation we can see that this kind of material is generated.

And that this small built-up edge actually forms, that will characteristic with the rake phase and occur then what finally breaks and adhere with the open that is already machine surface. So that fragment is present in the machine surface. This is called the built-up edge formation. Of course this is characterized by the chip or maybe this small fragments either characterized with the chip and some parts may stick to the rake face.

That actually creates the formation of the two layers and of course pierce the inferior surface finish, because some fragments may be part of the machine surface. So what are the condition that is responsible for formation of the built-up edge. So if it is cutting speed is low, depth of cut is very high and of course if heat, if you consider a very high feed rate, then that also creates a kind of condition of built-up edge formation.

Of course, built-up edge formation is not desirable because it affects the surface finish. So it is in machining process, we will try to focus on the formation of the continuous chip, for discontinuous chip, but without any built-up edge formation. So high friction at the chip and tool interface is responsible. Dull cutting edge that also may create the built-up edge formation and of course applicable for the ductile material, say the steel, aluminium and copper. There is chances of the formation of the built-up edge little bit more in these cases.

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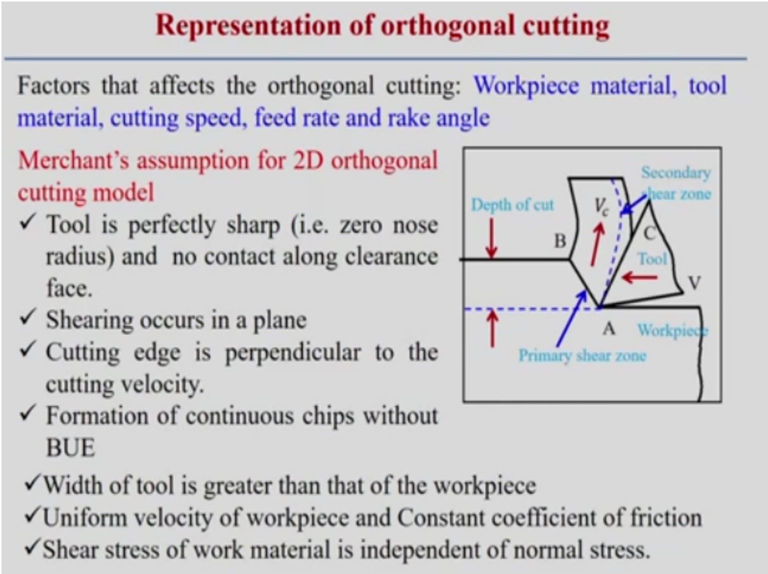

Now in orthogonal, we analysed the chip formation all these things, but what we look into the orthogonal cutting situation and how to represent the orthogonal cutting processes. First look into this figure here, which is an ideal figure here. So this is the work piece and there is a tool is moving or there is elective motion in machining processes, either motion is given to the tool, work piece can be kept as fixed or otherwise tool can be fixed and work piece can be given as in motion.

Such that there must be some relative motion between the tool and the work piece. So if you assume the relative motion, the velocity V, tool is moving with respect to velocity V and it is cutting the material and the shear plane, it is converted to the raw material to the chip and the chip is A and that clears the machine surface. So one tool moves in particular direction or we can keep tool fixed and work piece can move in this direction velocity V.

That also creates a similar situation. So what are the things that normally the uncut chip thickness then we define by the depth of cut here and chip. This is the chip velocity Vc moving and B we assume the tool velocity and this is called the primary shear zone. Shear deformation happening, of course, some shearing may also happen between this tool and chip, but that is a secondary zone. Now what are the factors that affects the orthogonal cutting.

We explain this orthogonal cutting situation in the 2 dimensional, maybe one plane we define all these parameters and we can analyse these things. Now what are the factors that affects the orthogonal cutting of push material, tool material, cutting speed, feed rate and rake angle, all actually particular combination of this thing. They gives us the situation of the orthogonal cutting.

Now when we try to explain the orthogonal cutting situation, we assume the Merchant's assumption 2D orthogonal cutting model. So if you look into that Merchant's assumption for the 2D orthogonal cutting, we can look into that. We assume that tool is perfectly sharp. That means there is no nose radius, no contact along clearance face. So there is no contact at the clearance face. There is no contact at the clearance face. All contact is not in the clearance face.

Shearing occurs not in a particular zone rather shearing occurs over a plane and that plane is this is plane and which is normal to this surface. Now cutting edge is perpendicular to the cutting velocity. Definitely, that is the condition for the orthogonal cutting and of course formation of continuous chips, we assume the formation of the continuous chip and without any built-up edge. That is the most ideal situation and width of the tool is greater than the work piece.

So width of the tool is greater than the work piece, that means total width of the tool edge such that it will cover the work piece thickness or we can say the work piece width also. Uniform velocity of the work piece and the constant coefficient of the friction. So uniform velocity of the work piece or we can say the elective velocity between either tool or between work piece and tool is that must be following no acceleration and constant coefficient of the friction.

Friction coefficient is not varying with respect to other parameters, specifically temperature and other surface conditions, but we assume the constant coefficient of the friction. Then shear stress of the work material is independent of the normal stress. So we assume the shear stress formation here, which is the shear stress is independent of the normal stress machining process. So with these assumptions, we can calculate different kind of forces in case of orthogonal cutting situation.

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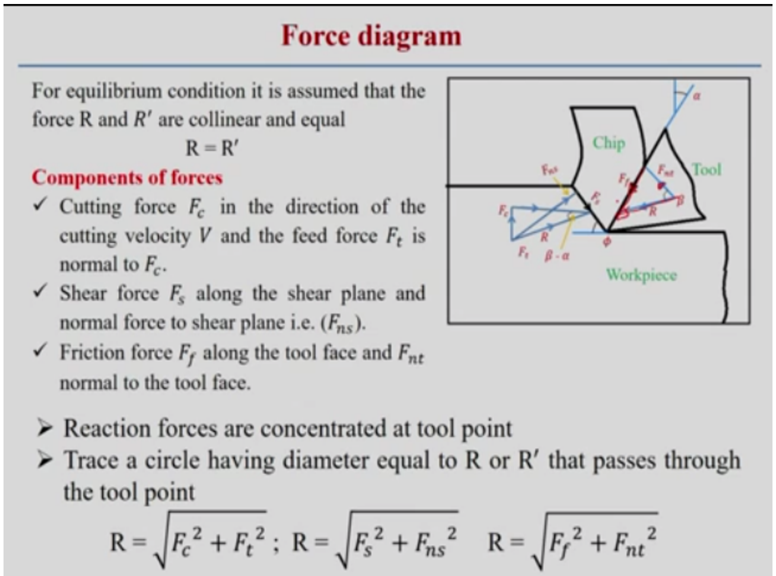

Now if you see, here from the tool site, this frictional force is there and this is the normal force and that this is a resultant force R. These 3 forces are acting. If you look into the body with respect to the tool, then from the work piece part we can see there is a shear force is acting here and Fs we define the shear force Fs on the shear plane, it is acting shear force and normal to that normal force and resultant of this is basically R, shear force and this.

The resultant of the shear force, it may be R, of course other part is that cutting force, which is acting just along the velocity vector, tool velocity, along the velocity its cutting force is acting and this is the other force normal to the cutting forces, such that it gives a resultant force. So that R in both site we can estimate for the tool site, on the work piece site and we can estimate this, all these forces are acting such that it is in equilibrium condition in steady state situation.

So for equilibrium conditions, we assume that the force R and R dot are collinear and they are equal. So R or R dot, if you assume that R dot is basically in this case is R dot and here in the tool site, we estimate the resultant force R, but here R=R dot during the steady state situation.

Now what are the different components of the forces in this process. Here you can see the cutting force Fc is in the direction of the cutting velocity V.

So you define in such that the cutting force, this is Fc is acting in the direction of the velocity V and the feed force, Ft is normal to Fc. So you can define Ft the force which is normal to cutting force, such that it creates a resultant force Rc. From that create the resultant force, at the same time the shear force also along the shear plane. So this is the shear plane. So shear force is acting on the shear plane, Fs and of course this is the force, that is the plane and the normal force to the shear plane.

This is the normal force to the shear plane Fns, normal force to the shear plane, such that the resultant is basically R dot. Now friction force is acting here between the tool and chip. Friction force Ff is acting along the tool face, then that because of the friction between the chip and tool and Fnt is the normal to the tool face. So basically if you see the friction force is acting Fs and that this is the normal force such that resultant is the force=R.

Here Fnt acting normal to the tool face, such that resultant will be R. Now we assume that equilibrium condition, maybe R should be equal to R dot. So if we define the different tool angles or maybe different angles or different other parameters, such that we can relate the different types of the forces in case of orthogonal cutting situation. Now reaction forces are connected at the tool point. So reaction forces is basically actually connected to the tool point.

If you assume that things and if the trace we define and circle having the diameter equal to R or R dot. Because R=R dot and with respect to the tool we define the diameter R and we can define one circle, such that resultant diameter of the circle is R and of course other point, when we draw the circle it passes through the tool point, this point basically cutting at this point and then we can estimate the different force components.

Such that R equal to, can be estimated resultant force equal to Fc square + Ft square. These are the two cutting components. Fc and Ft, we can see the cutting force and the feed force. R can also be estimated from, if you know the shear force and forces component acting normal to the shear plane. So these 2 components and R can also be estimated. Resultant force can be estimated in terms of friction force.

The friction force and force is normal to the tool face Fnt, the resultant force. There are different ways we can estimate the resultant forces R. Now in one, if you draw one circle and we can define all these different types of the forces here.

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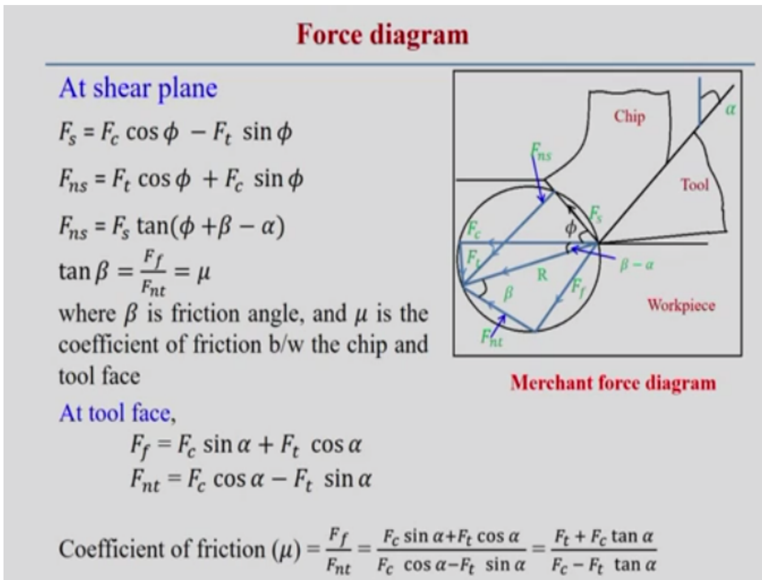

Now if you pass this surface force tag, we look into that. This is the tool a chip is flowing, this is the shear plane and we can draw. This is the resultant force R and we draw one circle, passes through the tool tip at this point. Now within that circle we can define the different force components and different angles also. So here this angle is shear angle. The shear angle can be defined such that the angle with respect to the shear plane and the cutting velocity vector with respect to that.

That is the shear angle. Then if this is shear angle, so then this corresponding the shear force and this is normal to the shear plane. This is the force, this continues such that it gives the resultant R. Similarly, this is the cutting force, which is acting along the velocity vector Fc and this is the feed force, which is normal to the cutting force, such that define Fc and Ft such that resultant equal to R and of course the friction force acting between these two.

We can place it, friction force is acting between the contact. We can place, this is the friction force and this is the corresponding normal to the face, which we have constructing here, we represent here, such that this and this is the normal force, so this is always 90 degree, such that a resultant equal to R. Now within the circle, we can represent all the force components and now if you define different angle, say this is the angle phi.

Now what is alpha? Alpha, this is the normal and this is the two rake face, this angle we define as alpha. Therefore, only define this angle alpha. If this is alpha, so this angle also alpha. Now if this is phi, then all the force components are G phi, so this angle is alpha. Now total is 90 degree and of course this between the normal force and resultant force are that is the angle of beta, is basically friction angle. So friction angle, we define the Coulomb's law of friction.

Between the reaction force, resultant force and the normal to the friction force. Between these 2 forces, the angle is defined as beta. If this is beta, so this angle is basically 90-beta angle. If this is 90-beta, this is alpha, so this angle will be 90-beta-alpha, so that corresponds to 90-90+beta-alpha. So this angle becomes beta-alpha, which is well defined here. Beta-alpha, this is angle phi cutting velocity and this is Ft and so all in terms, so here we define the 3 angles.

One is the shear angle, phi, shear angle is difference when it comes to the velocity vector phi. Shear angle, and then we define the angle beta is a friction angle. If you know the coefficient of friction, from there we can estimate what is the friction angle for a particular material and alpha is the rake angle. The rake angle in orthogonal cutting, we define only on the single rake angle and not 2 rake angles here.

So one rake angle, we can take normal rake angle. We can say that alpha equal to, I think it is defined here also, beta is the friction angle and mu is the coefficient of the friction such that, tan beta can be let mu equal to Ff/Fnt. We will discuss the relation between these forces and of course in this case and shear angle and alpha is the rake angle. So now if you define all these angle, now we can correlate the difference force components.

First we look into that part, that at shear plane what is happening in the shear plane. So Fs, Fs can be related with the cutting components Fc and Ft. Now Fc and Ft define the cutting force and these things, because we will try to relate morally the other force components with reference to the Fc and Ft, because experimentally we can measure these Fc and Ft by using the dynamometer, we can measure that force components.

So that is why it is desirable to, it is feasible to define that other force components in terms of the two components Fc and Ft. So let us try to look into that. Now here Fs=Fc cos phi maybe if you see, if this angle is phi, so this is 90, so this angle is 90-phi and of course this angle is 90-phi and from here we can find out, this is phi, this 90, so this is 90-phi, this is also 90-phi, this is 90 degrees, so this angle should be phi here.

Now Fc cos phi, so you can do that Fc cos phi is projected on this. It is something like that Fc cos phi, this value Fc cos phi and in terms of Ft sin phi, I think this is the value of the Ft sin phi. So now Fc cos phi-this Ft sin phi that actually represents the Fs. This is the first evaluation. Similarly, Fns in terms of that, it is Ft cos phi inters of Ft, these components and in terms of Fc, so Ft cos phi, first part and Fc sin phi.

This is Fc sin phi such that we can estimate these components, sin phi. So here you can estimate the Fc sin phi+Ft cos phi. Now Fns, now if you put that between Fs and Fns, so this angle if you know, that this angle is phi+beta-alpha, so this angle and we know the F tan phi tan=Fns. So basically this is Fns/Fs. So from here you can estimate this evaluation Fn is equal to this.

Now tan beta, we can easily estimate the tan beta in terms of friction force and that F tan beta in terms of the friction force Ff and of course in terms of the tan beta. It is easily estimated Ff/Fnt. From here you can estimate the tan beta and that is equal to the coefficients of the friction mu. If you know the mu, we can easily estimate. So beta equal to tan inverse mu. From here you can estimate the angle beta.

So now at the tool face, if you look into the tool face, so in terms of the Ff, friction force and Fnt, we can estimate in terms of Fc and Ft, similarly the Fc sin alpha+ this angle is alpha, so it corresponds to Ff is there, if you look into this corresponds to Fc sin alpha and Ft cos alpha. Similarly, Fnt Fc cos alpha and Ft sin alpha, from the diagram we can easily estimate these things.

From here also we can estimate the coefficient of friction in terms of other component that Ff/Fnt is the coefficient of the friction that we have already find here and if you put Ff and Fc value in terms of Fc and Ft, so that corresponds to that. Here you can see that Fc, Ft and alpha. So Fc and Ft is miserable quantity and alpha is basically that tool rake angle, which can be defined when to try to use in the specified tool.