Introduction to Machining and Machining Fluids
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Lecture – 03
Chapter-1 (b): Principles of Machining/Metal Cutting

Welcome to the Principles of Metal Cutting Section. We are now proceeding to somewhere interior to it how we study some of the basics of principles of metal cutting. Basically, if you see the metal cutting process is considered to be the severe plastic deformation process.

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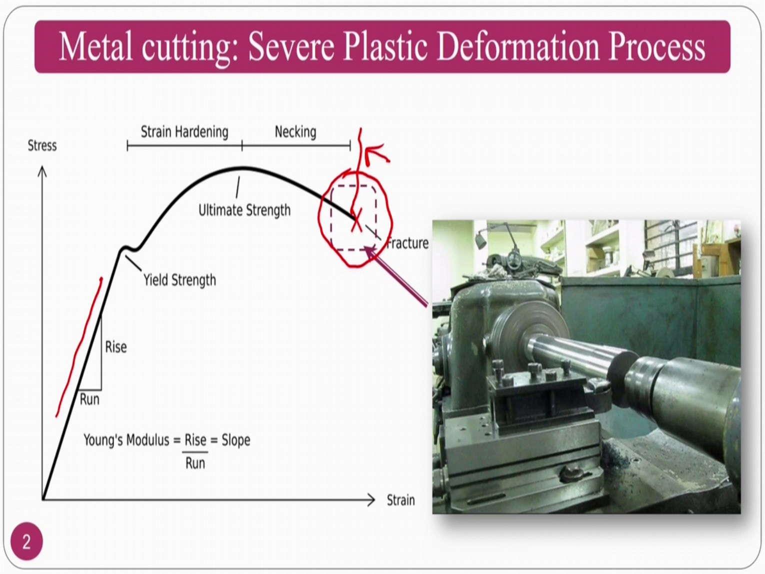

Normally, plastic deformation comes in the metal forming. However, the metal cutting is a subtractive process. If you see the manufacturing normally or introductorily you can divide into 3 or 4 sections, where one is the metal cutting metal forming advanced machining processes and joining processes and casting and also so on.

So, deformation comes under metal forming; however, this particular metal cutting process is considered to be the severe plastic deformation process. If you see the stress strain graph of a any ductile material normally here given is the might be steel basically, if you see the basic curve of the stress strain. If you see the metal cutting starts after the plastic deformation.

So, that is why here also deformation is taking plastic region, then the plastic upper yield point lower yield point and ultimate point then the fracture point comes. So, the metal cutting starts after this punch position ok. So, that is why this process is normally called as a severe plastic deformation region or de severe plastic deformation process ok.

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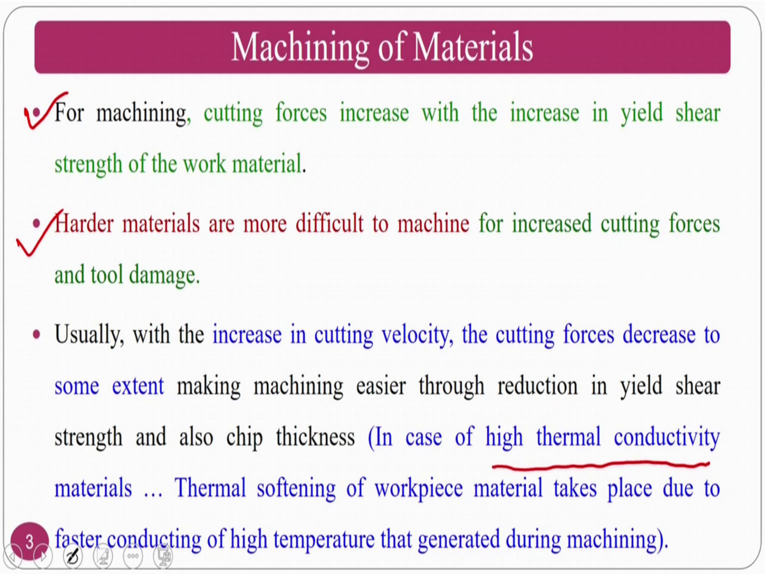

So, in the mechanics of machining you can study more about these deformations, what are the other things the mathematics behind it, and these are the courses already taught by some of the people and currently also some of the people are teaching. So, that comes in the completely mechanics, how the mechanics deals with this process and all those things.

Since this is a introductory so we can see; that how and what is the introduction part of this one. See the basic thing that one has to remember is; in a metal cutting operation the work piece should be softer than the tool material that is, the tool material should be much much harder than the work piece material ok

So, that can be thing, but at the same time if you are increasing the hardness of your work piece material it will become difficult and difficult because the hardness ratio that is, the hardness ratio is nothing but the tool hardness to the work piece hardness. If the hardness ratio is near or similar region then metal cutting will be slightly difficult. So, that is why the hardness ratio should be slightly higher. Normally, it can range from 3 to 5 to so on so on.

So, if the hardness ration is very high the forces and all those things also slightly lesser. The tools which can resist these forces is the resistance of this forces by the tools is slightly higher. So, that will be good cutting process.

The cutting forces increases with the increase in the yield strength of the material that work piece material. If you see the yield strength of the work piece material in the previous slide if the yield strength increases if you see the here yield strength of this any material increases.

If it goes higher what will happen the forces will be required will be very high. So, or it increases that is why, the metal cutting process is good if the materials yield strength is less, but if at all if I you want to machine the higher yield strength materials normally I have to choose appropriate tools whose harnesses are yield strength and other properties are much much higher; that is what ? That is what the first point says.

The second point harder materials difficult already explained you. If the work piece is much much harder there is a another concept called hard turning operations or hard machining operations, where it is difficult to machine because the tools are there are very low varieties of tools ranging from h s s to the diamond.

So, you have to choose among those. So, if you want to machine a CBN. You do not have any much alternatives because that CBN itself is a one of the hard materials. So, it will it is slightly difficult ok. So, for what I mean to say is; it is easy to machine the less harder materials. Usually with the increasing the cutting velocity the cutting forces reduces or decreases.

This is what I mean to say is; this is particular to those material if you see here in case of high thermal conductivity materials. What will happen? If the work piece material is assume that this is the work piece material the conductivity is very high in this one, what will happen? If I am cutting with the high velocity, that means that cutting velocity, what will happen? The work piece rotates very high speeds. If it is rotating with the high speed the temperature generation in the high velocity cutting or high-speed cutting will be very high. If the conductivity of this material is very high, what will happen? The temperature conducts at the fast rate.

So, thermal softening takes place ahead of or slightly ahead of the cutting tool. So, in that a circumstance the cutting forces reduces, that is what I mean to say. Now I just want to show you a video where machining of ductile and brittle materials can be shown.

You can in this video you can first see what is metal cutting and what is the ductile materials metal cutting and what is the brittle materials also in this video clearly shows that difference between a ductile material cutting and the brittle material cutting and all those things work piece material as we moved in the form a chips continuous chips are formed when

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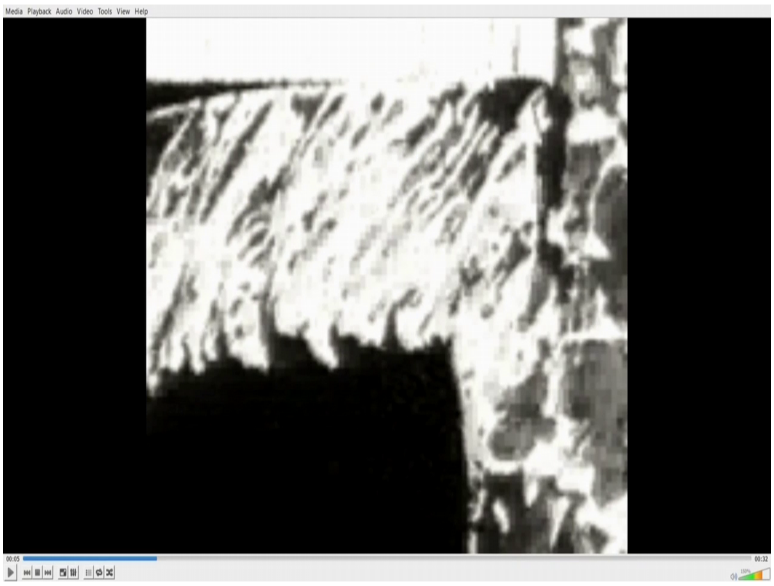

You can see here this is the continuous chips cutting ok. So, you can see there is no discontinued, but the thing you can see the only thing that you can observe here is on the bottom side, sa at the bottom side means if if you see that the top side normally this is the top side, this top side is tool in contact with the chip on the bottom side you can see the rough surface of the chip.

Cutting tool is in continuous contact with the pot especially when cutting that to materials such as (Refer Time: 07:59) or a (Refer Time: 08:01), but this continuous chip is around even in a continuous operation while turning when the material is.

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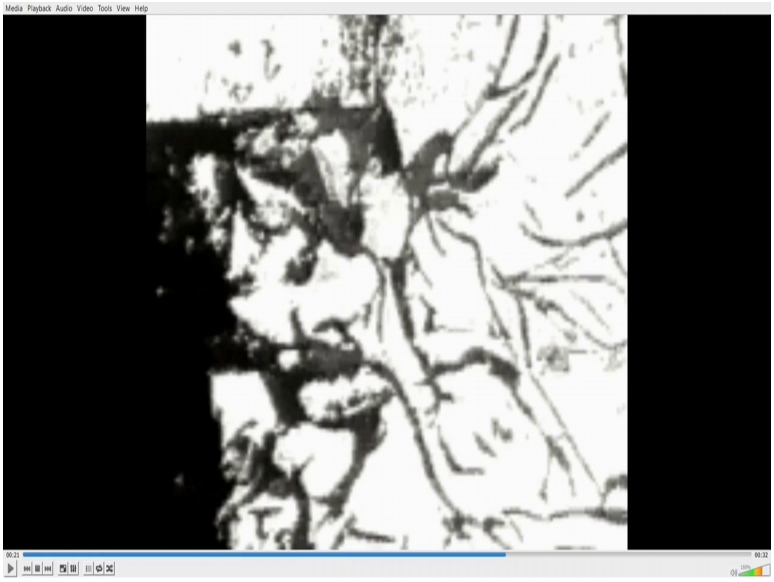

You can see here this is the brittle materials machining. The cutting tool is cutting the brittle material in this one the material removal is taking or the fracture is taking place ahead of slightly ahead of the cutting tool itself. Duct to enough to define continuous like a factures ahead of the cutting tool, just continuous chips are form when machining brittle materials like casted ion ok.

Just now we have seen the video; what is the difference between metal cutting of brittle materials and ductile materials. So now, we will see; what is the basics things that we have observed in the video.

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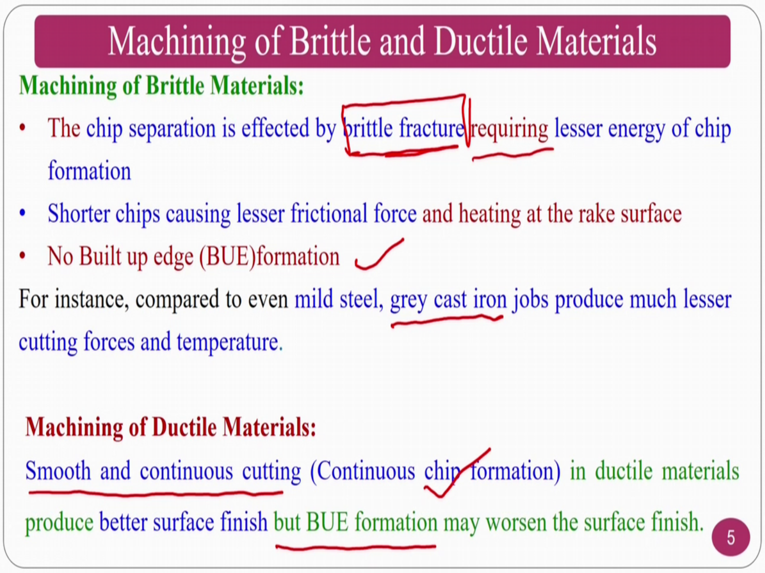

The machining of brittle materials normally chips operations takes place and affects brittle fracture ok. So, in brittle materials metal cutting the what will happen? Chips operation affect by the brittle fracture requiring less energy, normally this is subjected to some materials only like cast iron or something.

So, brittle fracture it is taking slightly ahead because of which there is no the chip flowing on the rake surface and all those things. So, the temperature generation is slightly less, because of which the point is partially valid that is less energy in the chip formation. The shorter chips causing the less frictional force because the continuous chips in the ductile materials causes lot of friction because it flows on the rake surface, which you can observe in the upcoming slides.

And there is no built up edge formation like you can see the built-up edge formation in the upcoming slides. So, normally the best material or the basic material for the introduction purpose you can say is cast iron is the one of the good examples, that o one can see as a brittle material machining. If you see the ductile machining it has a very good affect that is called smooth and continuous cutting process.

It is a smooth and continuous process because of which there is a heavy chance or 99 percent you will always get a continuous chip formation. If you have a continuous chip formation the cutting tool experiences uniform mode.

In a brittle materials whenever you see a brittle fracture, here in the brittle fracture what will happen? It is you cannot say that it is a discontinuous process, but in a nano scale or a micro scale you can say this is a slightly discontinuous process because it the particles will heat or the surface which is coming may heat. So, this is subjected to the papers to papers some of the papers they express this and the basic problem in the continuous process is built up edge formation, what is the built-up edge formation? And all those things you will see in the upcoming slides, which may affect the surface finish.

What is the problem is if the built-up edge formation takes place this forms on the surface of the work piece or; that means, that the work piece or the product that is coming out. So, it hampers or the worse make worse the surface finish.

At the same time continuous chips will entangle there in the machining region itself, which also may rub against the final product. This also causes the worsening of the surface finish.

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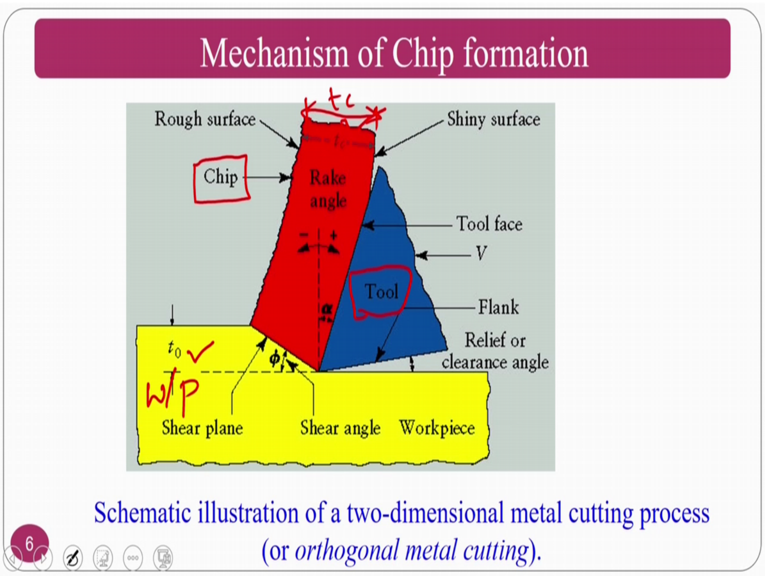

If you see the mechanics of chips formation, see the this is the work piece and this is the tool you can see here the tool and this is the chip ok.

So, this t naught the represents uncut thickness and the t c represents the chip thickness. Normally, red on red you cannot see this one this is called the chip thickness. And this is called the t naught chip uncut thickness, this is the normally the rake angle alpha stands for rake angle and phi stands for shearing angle and this is called the flank or clearance angles you can see clearance angles and all those things ok.

So, this is about the 2-dimensional metal cutting process normally it is called as a orthogonal metal cutting. Most of the cases we just simply assume our metal cutting process as a orthogonal metal cutting process and we proceed ok.

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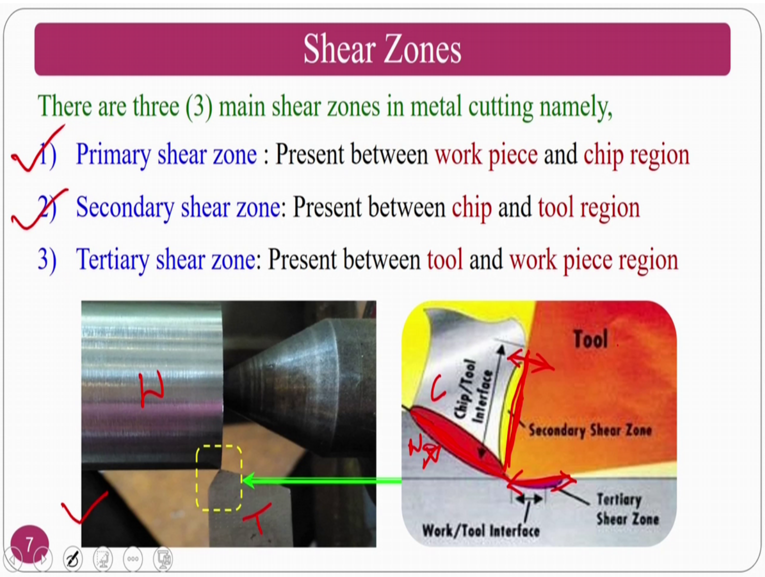

The shear zones there are the 3 main shear zones in this metal cutting process. If you see the metal cutting operation here this is taken from our own research papers. The metal cutting is wherever the metal cutting takes place you have a 3 shear zones. In the shear zones whenever we see there are 3 shear zones.

This is the picture that we have taken from our own research or just from our laboratory. So, if you see the metal cutting operation the tool this is the tool, this is a tool and this is the work piece. There are 3 shear zones one is the primary shear zone.

Normally primary shear zone if you see this is the primary shear zone, where work piece and chip in between it is along the direction of the shearing region. So, secondary shear zones is between chip and tool, this is nothing but secondary shear zone. The red one which I am already showing this is the primary shear zone this is the secondary shear zone and this is the tertiary shear zone. The tertiary zone is between the final product or the after machined work piece to the tool this is the tertiary shear zone.

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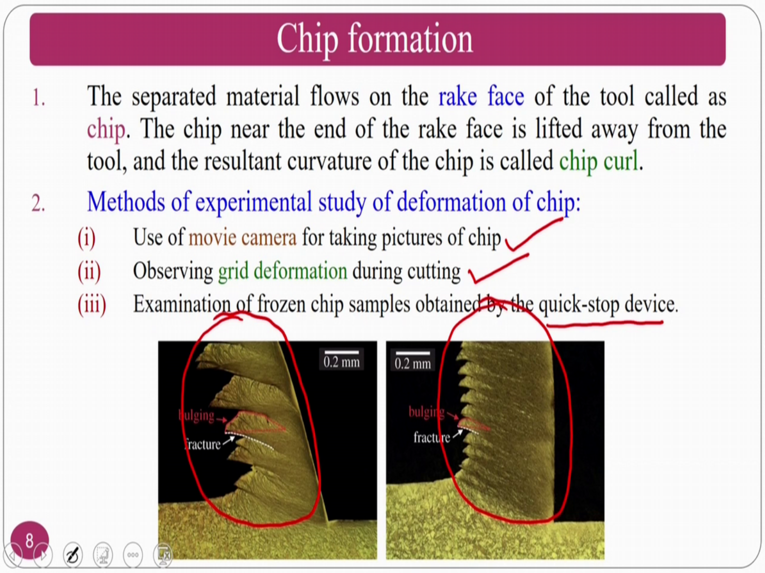

The chip formation normally the separated materials flow on the rake surface of the tool is called as a chip. This is the basically the chip that is flowing on the rake surface ok.

This is the chip and normally the chip can be measured or you can study this by using many things normally, one of the methods is moving camera technique and by giving the grids on the surface. What we can do is some of the techniques are there just you just do the gridding place the grids on the surface and you just move and you can study or some of the quick stop mechanisms also there.

You just quickly or this mechanism just stop it and at that position you can also study the deformation of chip process. This is about the chip formation

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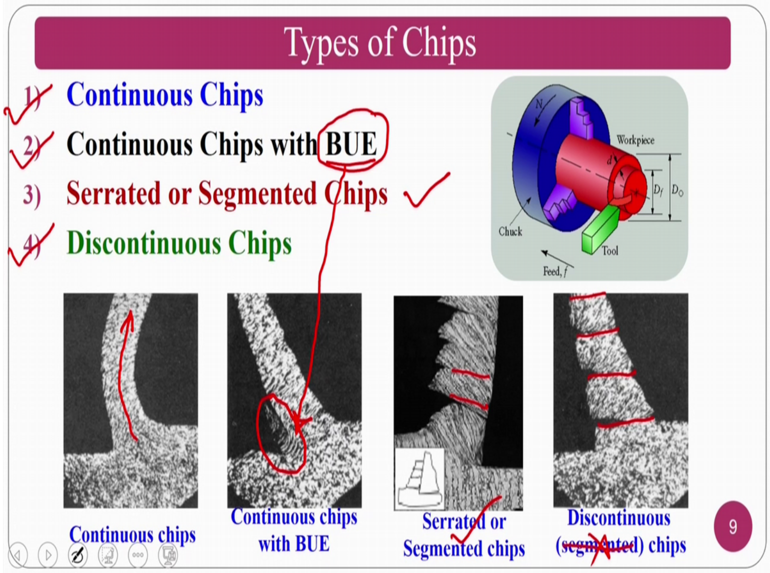

And the different types of chips. Basically, this is another basic study where you can see the 4 types. Normally some of the basic text books if you see they only deal with the 3, one is a continuous and continuous chips with built up edge and discontinuous.

And there is another one which is I am going to deal is serrated or segmented chips. So, there are 4 varieties. This is called the continuous there is no break or something it just moves continuously ok. So, this is called the continuous chip whenever you are machining a ductile material.

Whenever you are the second variety is the continuous chips with BUE. BUE stands for built up edge ok. So, the built-up edge you can observe clearly here. This is called the built-up edge formation ok. So, this will hamper partially the cutting process that is what.

And the third one is segmented or the serrated chips. So, there is a slight variation between the discontinuous chips and serrated chips. So, in the discontinuous chips normally in a schematic views they can show like there is a discontinuity between 2 this are the segments that; however, in the serrated chips you can see normally each and everything there is no this one, but; however, there is a discontinuity after sometime.

So, that is the slight difference normally in a older text books you may not find, but in a some of the research papers you may find this or some of the new text books you may find.

That there is a slight boundary between discontinuous this is wrong discontinuous and serrated chips. So, we will just deal what are the things that cause the continuous chips.

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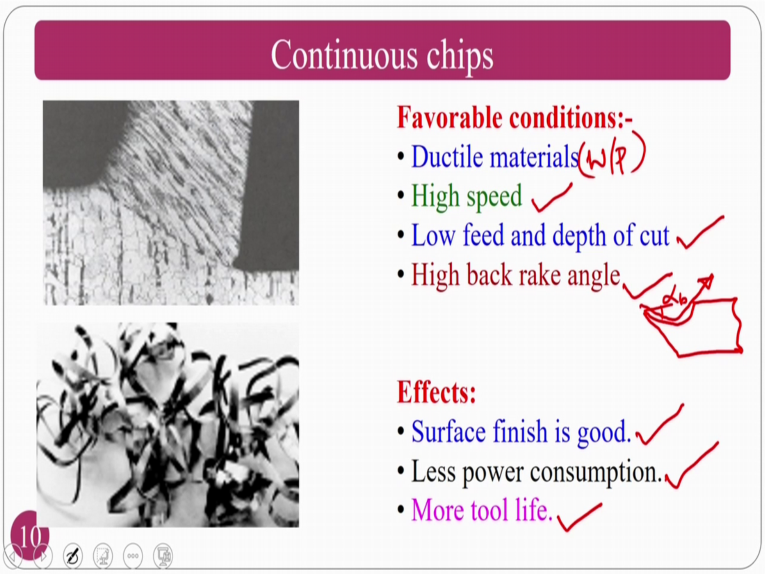

If you see the continuous chips favorable conditions. First and foremost is work piece should be the ductile material ok. If it is ductile materials smooth cutting will takes place and the cutting speed should be slightly higher that is high speed so that the continuity will takes place. At the same time low feed and depth of cut, if you have low speed and low depth of cut the cutting will be smoother and the forces experienced by the tool will be very less, at the same time our cutting edge will remain sharp for longer time and high back rake angle.

Normally back rake angle if your back rake angle is very high, assume that my single point cutting tool is like this. So, this is called my back-rake angle alpha b. So, if my angle is very as angle increase what will happen my chip flows smoothly on it.

So, that is what the beauty about this high rake angle, but the problem is or the good things is or bad things about this is surface finish will be very good; that means, the roughness is very low. So, you may get a good shiny product out of this one low power consumption because of the continuous cutting there is no intermittent or some other problems so less power is required and tool life is more. This are the advantage of a continuous chips machining, machining of ductile material which generates the continuous chips.

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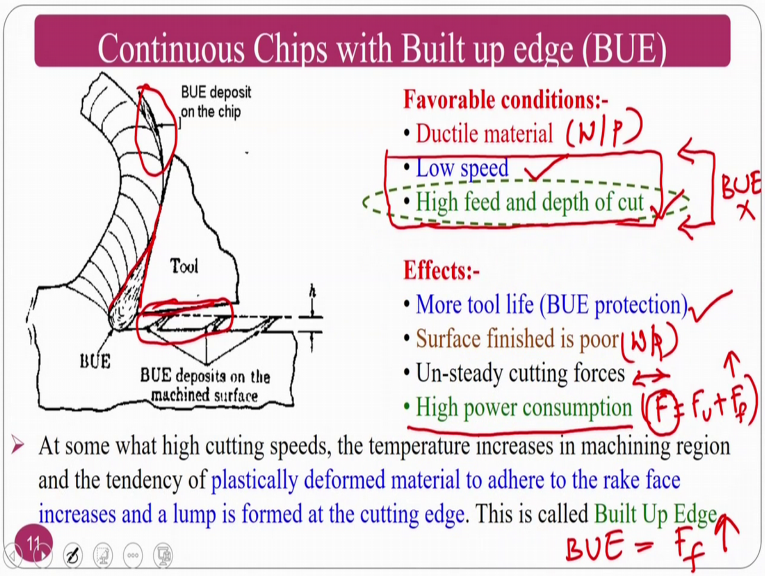

So, second thing is continuous chips with built up edge, here also the material that you do with the work piece e work piece material is ductile material, but the difference only with the machining conditions here that is, low speed in continuous you might have seen high speed and high feed and high depth of cut.

These are the 2 changes between continuous and continuous with BEU ok. If you put input these 2 conditions normally, what will happen? These built up edge formation takes place you can see a droplet type of thing this is nothing but the built-up edge.

After the built-up edge if you see if you are cutting continuously the built-up edge will also adhere on to the chip, which we do not bother about much because it would not come under the product because our product is this one whatever which we are getting here. So, this built up edge will deposit it is not going affect our product, but; however, it is going affect our tool rake surface. This is our tool rake surface; it may damage the tool rake surface, which may lead to the creator wear and all those things.

The other disadvantage of built up edge formation is this built up edge partially will adhere on to the product also. So, this may deteriorate the final product quality so that is why, we normally do not want this built up edge during the machining process. That is why, in order to impart we have to select these 2 conditions such a way that BUE should be minimum or BUE can be reduced.

So, the effects more tool life normally some of the papers they say that the built-up edge that is forming here. You can see the built-up edge forming here will protect the tool from the direct contact of the work piece in a nano range or a micro range; that means, there is a slight gap between the cutting tool as well as the work piece machining point ok, and the surface finish is poor the surface finish is poor.

Since, why I mean to say is; I was saying the more tool life because there is a gap this is the cutting point and this is the my cutting tool position or the point there is a gap, this is a gap. So, here my built-up edge is protecting my tool that is how the tool life is more.

The second point is surface finish and the work piece basically will be poor you can see surface finish is poor because we need a better surface finish for a good quality product. If the built-up edge fragments are welding or it has adhering to this work piece final product, then the surface quality will be very poor. So, which we may not like unsteady cutting forces because this is not a the built-up edge, the built-up edge which is forming here is looks like a semi solid or a liquid type of thing, because of which this is a solid this is also a solid and in between you have a liquid or semi solid there may be chance whenever this BUE goes off or BUE formation may be less.

At the same time BUE is going to the chip as well as BUE going to the final product because of which there is a fluctuation of the size of the BUE, because of which there may be the difference in the distance between my cutting point and my work piece real contact point, because of this there is a slight fluctuation and this may leads to unsteady cutting forces, but this may not be very huge, but there is a slight variation in the cutting forces.

High power consumption because built up edge helping the adhesion on the rake surface. If you see the built-up edge the built-up edge is adhering on the rake surface it is adhering on the final product also, because of which what will happen? The friction between my rake surface and the chip the friction between flank surface and the final product goes up.

So, if the frictional force goes up what will happen power consumption also goes up. If you see my required is force is F is required to useful cutting force plus un useful or the frictional, because of this built up edge formation what will happen? Our frictional force goes up; that means my required force goes up because this is increasing; that is why, the high-power consumption takes place. This is with comparison to continuous chips not that we required very high power or something. Just relatively to the continuous in a built-up edge we need slightly higher power ok. So, this is about this one.

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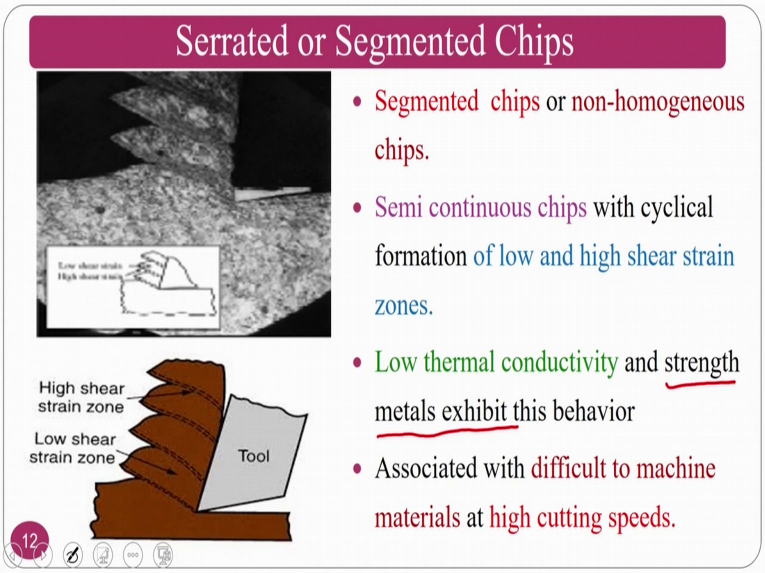

So, the third one is segmented or a serrated chips these are non-homogenous chips and the semi continuous chips. That there are discontinuous, but this are the semi continuous; that means, that you will neither it can be a continuous nor it can be a discontinuous in between that normally you will get.

So, low thermal conductivity and high strength exhibit this behavior. If your thermal conductivity is low and strength of this materials will be low then this behavior exhibits and associated to difficult to materials and high speeds.

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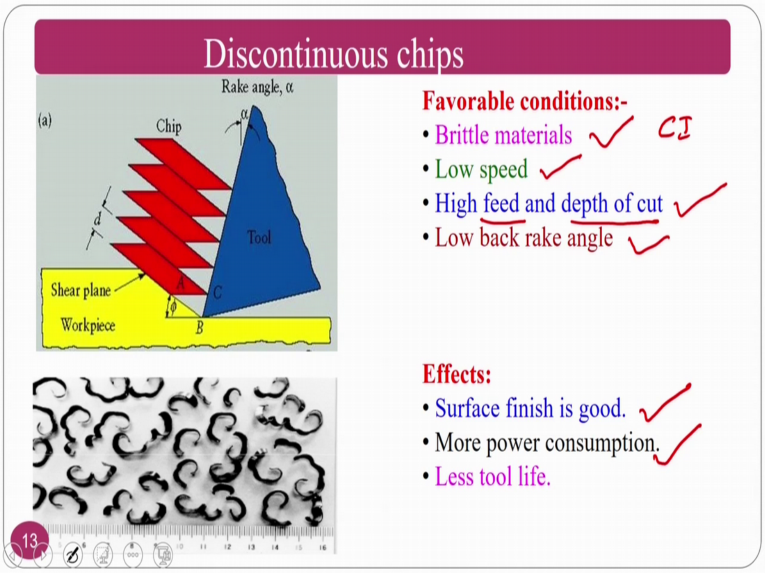

So, discontinuous chips normally discontinuous chips are very common in brittle materials like, machining of a silicon carbide or any other glass material or some other materials or for example, the common example is cast iron. If you are machining the cast iron normally you will get the discontinuous chips and the favorable machining conditions is low speed and high feed and high depth of cut and low back rake angle.

These are the things, what I mean to say is; if your speed is low your temperature generation is also low, if your high feed and high depth of cut what will happen in a cast iron whenever you do this one what will happen it will le lead to the particles type of chips; that is what, the discontinuous.

These are very good from the operator point of view or operator safety point of view in a continuous chips basically the chips entangle there itself. Once the assume that my cutting or the cutting tool chip comes, what will happen? This curls it there and there and it may touch the work piece and it may destroy it.

For that purpose, sometimes, the operator what he tries to do it he want to pull it out. So, that it would not affect or it would not damage the final product. In that circumstances it may hamper or it is slightly dangerous to the operator because it may the chip is very sharp and very hard.

So, handling the chip is very problematic in that conditions and it may hurt also. So, that is another problem. So, this is it in that particular point or for the operator safety whenever you are pulling that high temperature and sharp chips, this is very good discontinuous from that point.

So, effects the surface finish is very good because there is a discontinuous. So, there is no entangling of the chip on the final surface on it is not damaging. The more power consumption as I said, if you are having a discontinuous what will happen it may there is a micro or a nano reg level depend on your feed and depth of cut. So, there is a slight discontinuity in the work piece cutting region and the point or the line of the cutting of cutting tools.

So, there is a micro nano discontinuity will be there because of which power consumption will increase. If the power consumption increases or discontinuity is there what will happen? Every time it will touch in a micro nano piece, I am whatever I am showing is very high amplitude region, but the thing is that there is this one cutting edge will regularly goes and touch goes and touch; so that, the tool life may reduce this is about the discontinuous chips ok.

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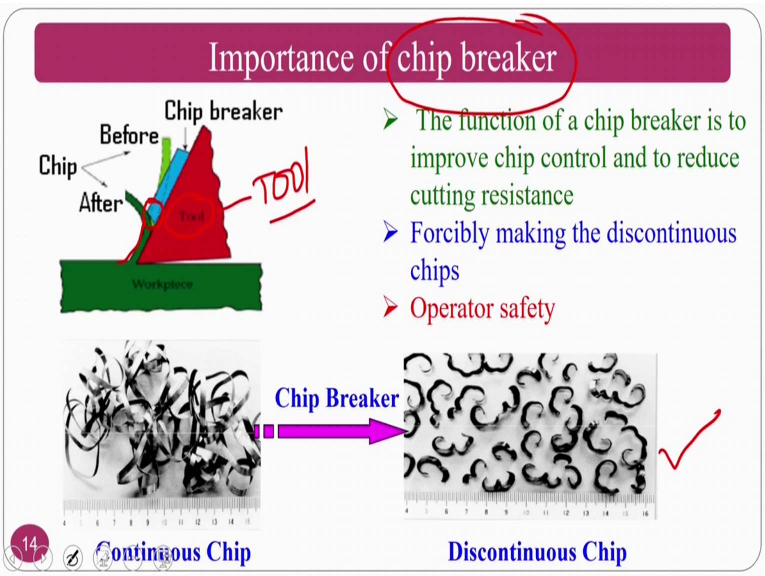

So, as I said from the operator point of view continuous chip is not good because it may hamper the operators hand and it is high temperature, for that purpose the researchers come out with some of the alternatives that is called one of the thing is nothing but the chip breakerm if you see the chip breaker ok. This is alternative just on the tool this the tool on the tool you just have a chip breaker, whenever the continuous chip flows on it will encounter here and breaks into the pieces.

So, that the beauty about this one is in a continuous process or the in a continuous chips your process is generating the continuous chips. So, your power consumption is low, you are getting a better surface finish. However, for the safety of the operator and to prevent the entanglement of the chips on the surface that is touching after machining because of that; if you can put a chip breaker you are converting in to the discontinuous chips. So, that is a beauty about it.

This chip breaker is helping us in producing the continuous chips, which reduces the force required indirectly power requirement and get the good surface finish. At the same time for the operators safety point of view and entanglement of this chip on the final product and destroying the surface roughness of the product we it is we are making the discontinuous chips. So, this is about chip breaker uses.

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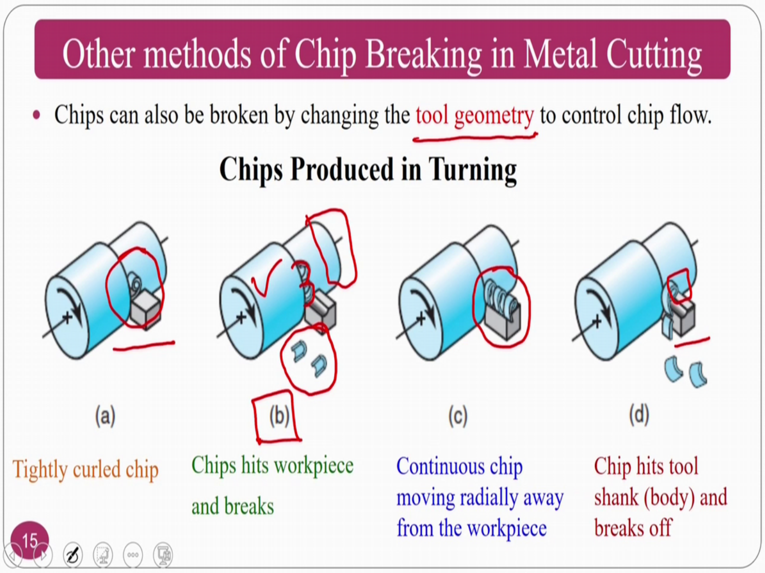

However, there are other methods also which can breaks the chip; that is nothing but chips can also be broken by the changing the tool geometry. If you can change the tool geometry you can also (Refer Time: 31:52). So, tightly curled chips this are you can see the tightly curled chips which are coming here, and chips with work pieces if you have a straight here.

If you see you have a straight; that means, normally whatever you are seeing a 0-rake angle. If you have a 0-rake angle normally curls are coming if you can generate some geometry on the rake surface you are going to get this is called chip hit the work piece and breaks. Normally, because of the slight geometry variation what will happen the chips are hitting the initial work piece and there are breaking.

So, in another case continuous chip moving radially away here also this is a geometry normally this is one of the geometry, if you can generate another one, but here also the chip hits the tool shank. Here instead of the in the figure b it is touching the initial work piece.

Here it is touching the tool shank; shank is nothing but this particular region and breaks off. So, this just you can play with the geometry of your tool, where the chip is moving. Normally, the chip moves on the rake surface; obviously. So, if you play some geometry on that one which can hit the initial work piece and it should not hit the final product, it should not hit my final product ok. It can hit my initial products which use to be machined and it another case you hit the shank of the tool and it can break.

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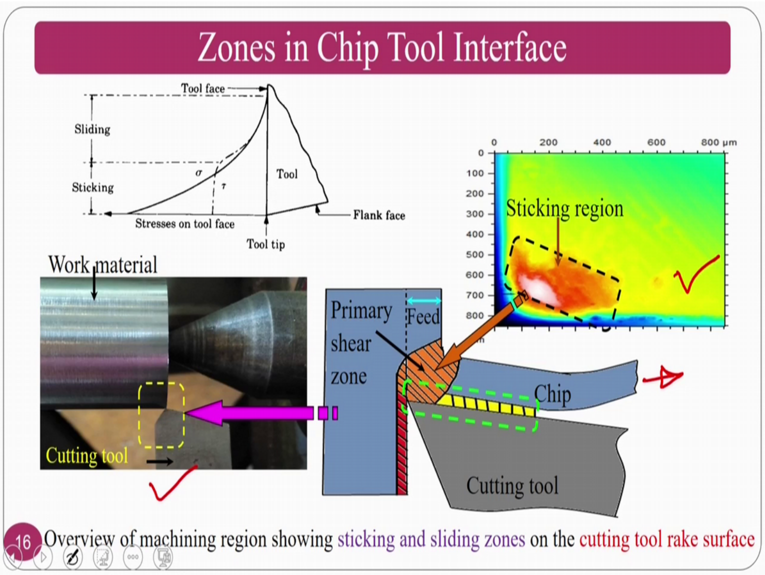

So, this are the 2 conditions. So, various zones in the chip tool interface region, which we have seen recently if you can change the geometry and you can enhance the chip breakability.

Similarly if you see this the beautiful schematic is done from the experimental point of view from our papers only. So, this is a work pieceful interface as you can see here. So, this is about the machining region and the chip in the schematic, if you see the chip is moving on my cutting tool. And because of which there is a sticking region and sliding region whatever the 3 dimensional normally whatever we are showing this picture is a 3 dimensional one, but we are seeing from top view so there is no third-dimension visibility here.

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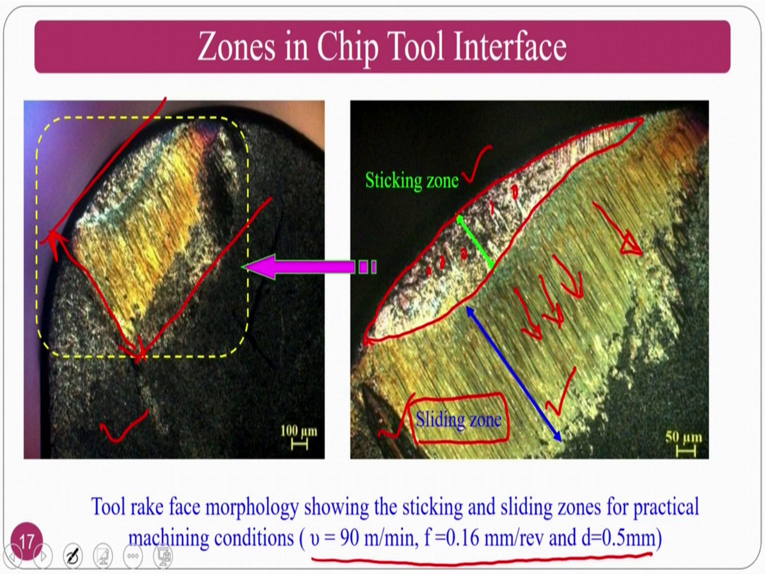

So, there are 2 regions one is sticking region and a sliding region. So, you can see this sticking zone and sliding zone. This is we have taken from our own laboratory experiments only for the demonstration purpose.

So, see normally some of the things can be explained by doing some of the experiments at the workshop or in our laboratory, then teach according to that will always give good feel. So, that is what the teaching is about. So, it is the combination you have to bring some of the research results to show better pictures. So, in that way if you see this pictures this is called chip tool interaction region.

Normally this con this is continuously is nothing but the chip tool interaction region, where you have a sticking zone this is sticking zone and this is called a sliding zone ok. You can see it is a sliding zone in a sticking zone you do not find the upbraiding marks these are the upbraiding marks.

You can see the chip is moving and it is upbraiding; that means, that this is a the chip is sliding in this direction and it creating it is own marks this is called a sliding region, which is shown by the blue arrow and the sticking region, because of the sticking nature predominantly you do not find the directional scratches or a you instead of that one you can see the material removal from the tool in the form of quarters or molten materials is gone out.

So, this is the a difference between the sticking zone and the sliding zone. For the given metal conditions this are the metal condition that we have given. In the metal cutting operation to demonstrate in a better way to you people for understanding what is sticking and what is sliding region, in practically how it looks like and all those things. That was the motive for us apart from oblige the similar works.

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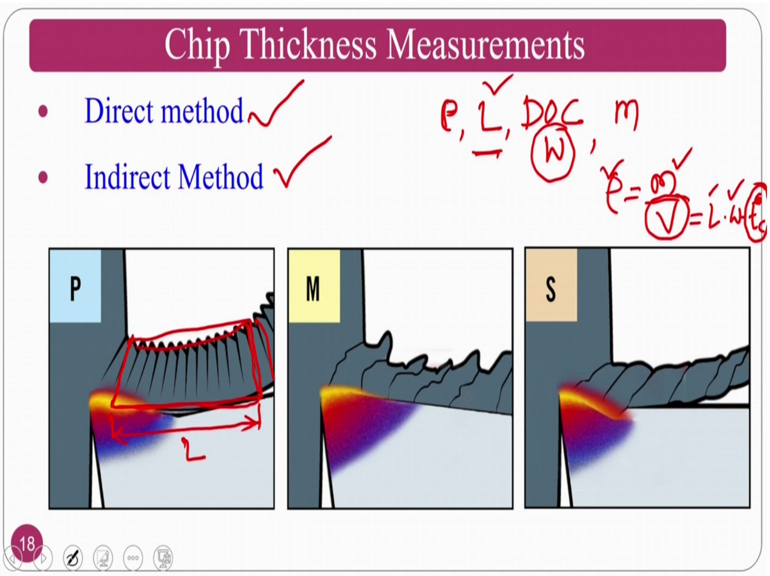

So, chip thickness measurements, normally chip thickness can be measured using direct method and indirect method. So, direct method normally you can take the micro meter or venire calibers and you can measure it, but you may not get the exact value because if you see this is the cutting tool and this is the chip. Normally, in a continuous chip or segmented chip you assume that this is a continuous chip or segmented chip or discontinuous chip what is the basic problem is one side it is the smooth cut this is the smooth cut and another side it is very rough.

So, if I put a venire calipers here and here, you may not get exact value because from point to point the thickness is varying. So, direct method is ok, but it may not give you exact value if you have a sophisticated equipment you may get it.

In the case of other chips also you can see there is slight variation on both sides. So, it may not be easy to get. So, the other method that you can rely on is. So, for example, if you are cutting a known material; so you know the density of the material, normally density of the material is known to you.

In a indirect method what I mean to say is you just take a chip from here to here. So, you can take the chip and you know the density of the material because the work piece material the density is constant, from here you can measure the length length of the chip. Since, there is a curve you can use the thread and you can measure the L.

And you know now you length also because you measured using a thread and just you put on the scale and you take the this curve is there, just put on the curve and the curve length you just make it straight to the thread then you put on the scale and you take the L. And you know the depth of cut, normally depth of cut is assumed to be the width which is not visible in this one. So, from the depth of cut you know the width of the ok.

And this is taken the length of the chip you already measured. The same thing can be taken on a common balance and you can measure the weight or the mass of that one. See you have already taken the chip out which having a length of L you just use common balance or the micro balance and measure the mass.

So, you want you know density equal to mass by volume, where you know the mass from the micro balance, density of a material is constant now the volume. If you see the volume you know already length and you know width of that. So, only the thick thickness is not there that is called length, width and thickness sorry. So, this is the thickness, so the two things so that you can measure the chip thickness. This is how indirect method works that is all about the today’s class.