Introduction to Mechanical Micro Machining
Prof. Ajay M Sidpara
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture – 10
Difference between macro and micro machining

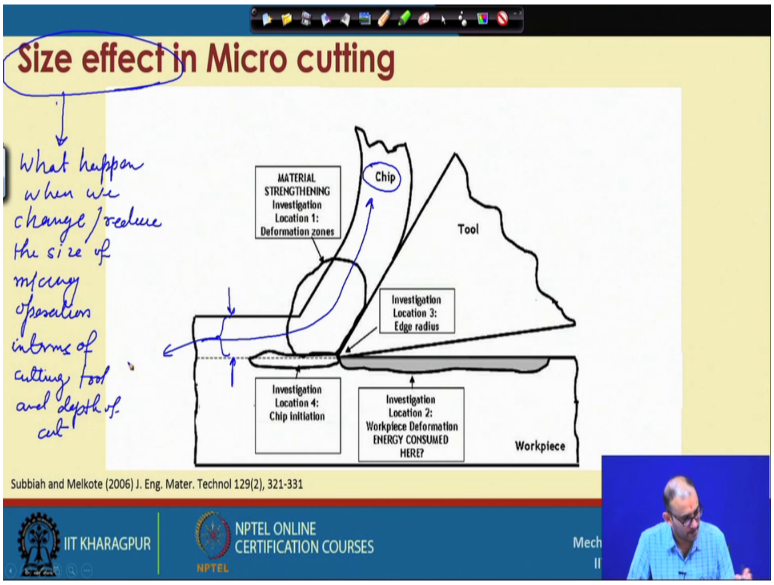
Good morning everybody and welcome to our course on Introduction to Micro Mechanical Machining processes. Till now what we have seen about the different type of classification then how this processor different are then other processes in the introduction part. And later on we have seen the different type of scaling (Refer Time: 00:34) that what we have to do when we want to do some changes into the system in terms of dimension. The whether it will be favorable not be favorable in terms of the different type of operation which we want to come out of the machine or some type of other components.

In that we have seen different examples some type of examples are living type of things and some of the manmade type of things and we have also seen different field like a fluid mechanics point of view in terms of the bulking bar or in terms of applied mechanics point of view, that what happens when you change the size of the component of size of the different element and how this will change depending on the loading and deformation and different type of other things, but till now we have not touched upon the processes which we are going to discuss that is micro mechanical machining.

So, now from this class we are looking into the different type of mechanism what is going to happen when you scale down the process; that means, suppose you are using a big tool like a 10 millimeter of end milling cutter and you directly go down to the 500 micron of end milling cutter with the same specification or geometry. Then what is going to happen to the material, what is going to happen with the tool whether tool will remove the material or it will not able to remove the material, what type of systems you require and; that means, now we go to the particular zone of the cutting tool and work piece material that is called interface.

Now, let us see that what things will be difficult or with what things will be different when you do machining at micro scale. So, today is our topic is the difference between the macro and micro machining processes.

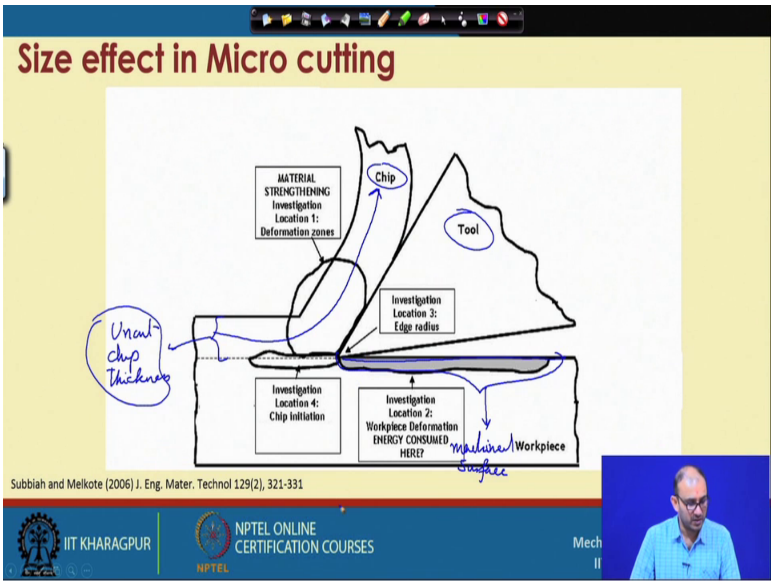
(Refer Slide Time: 02:21)



Now, first thing comes in our mind is the size effect, now what is the side effect. Now side effect is something like this. So, this will tell you that what happens happen when we change or reduce size of machining operation in terms of cutting tool and depth of cut, right.

So, here we will see about that now we have this particular diagram and this is well known diagram and this is the chip which is coming out from the work piece. So, this is the way it is going in this direction and this one is called uncut chip thickness.

(Refer Slide Time: 03:53)

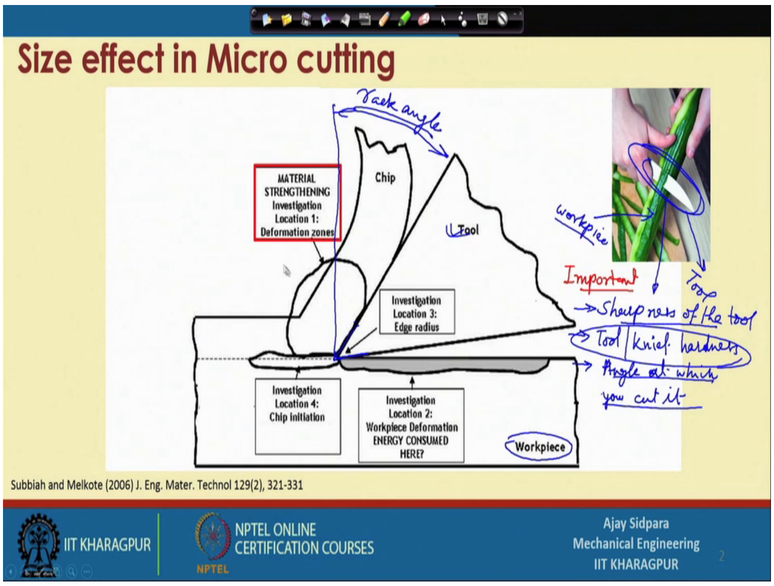


So, this is the chip is going in this direction this part is called the uncut chip thickness and this particular part this is called machinery surface right and this is the tool which is one known and this is the chip.

Now, this diagram is well known because we know every aspect about this part that when the tool interacts with the work piece at a particular uncut chip thickness depth that is called depth of cut at that time some material will remove in terms of chips and then you can get the machine surface at this location, but what is important here to understand that this is at the normal scale what we are discussing now, but now if you see that if you reduce the size of the cutting tool right now you consider this one is a very big cutting tool with a cutting edge radius around; 1 millimeter or maybe 500 micron or 100 micron, but if you continue in doing machining at a micro scale then this size will be very very small in that case.

So, let us see that; what are the different location by which; we have to pay more attention, so that we can get some useful information in terms of machining at micro scale. Now here we have I have shown one example of a normal cutting of a well-known to us.

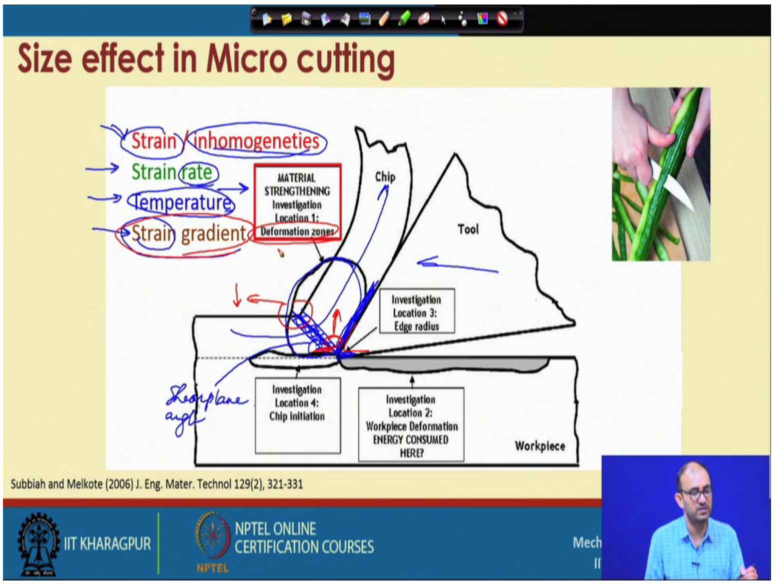
(Refer Slide Time: 05:25)



Now, here what we are doing that we are cutting one vegetable here and what is important thing is this is the tool and this is the work piece. Now from here what is important thing to get this then cut is the sharpness of the tool right let me write this thing here what is important this is the one thing another thing that tool hardness or we can write knife hardness, then angle at which you cut it and some other parameters let us first focus on these parameters.

So, sharpness of the tool is importance. So, how much is the sharp of this tool that is important than hardness is important because of we know that hardness of the tool should be much higher than the hardness of the work piece and third one is the angle at which we are cutting. So, we consider this one as a rake angle right. So, now, let us see that; what are the things where we have to pay more attention. So, first thing is the deformation zone and so let me clear this thing.

(Refer Slide Time: 07:39)



So, this is the first thing now what is that zone. So, this is the zone at which our material is going to deform.

So, what are the things here important? So, first thing is the strain or in homogeneities. So, that is in here. So, because suppose we know all material as little bit amount of defect; defect in term of some type of porosity is there some type of other things are there inclusions are also there. So, this are what is consider as a in homogeneities second thing is a strain rate the at which rate you are getting the deformation.

So, that is called with respect to time you are getting some deformation in the work piece third one is the temperature because we know that it is a physical process that there is a physical contact between the tool and work piece both (Refer Time: 08:27) relative motion this is going in this direction and this one is going in this direction. So, this is the contact area where the friction will occur up to this area.

So, temperature is; obviously, going to be increased in this location and what is the effect of temperature increase that will also important and the; another is the strain gradient. What is the strain gradient that we know that this is the shear plane and this the shear plane angle, but we know that plan is not actually plan, but it is a one type of band completely so it as area not the line. So, this is the 1 particular shear band in which the deformation is going to occur. So, strain is not actually the uniform at this particular area some location has a higher strain rate and some location as a lower strain rate. So, have to understand that what is going to happen when you cutting at a micro scale to this strain gradient.

So, if you see the where initial contact is here at this location. So, most probably so this are the location where the strain rate will be very very high at this location and this location and this is the location it is far from the deformation zone; that means, the contact from the work piece and the tool.

So, here the strain will be comparatively less in this particular case. So, in that case because in normal machining operation our chip thickness is very large and that time we do not mostly consider in this particular, but there is always exit the strain gradient of a different-different location.

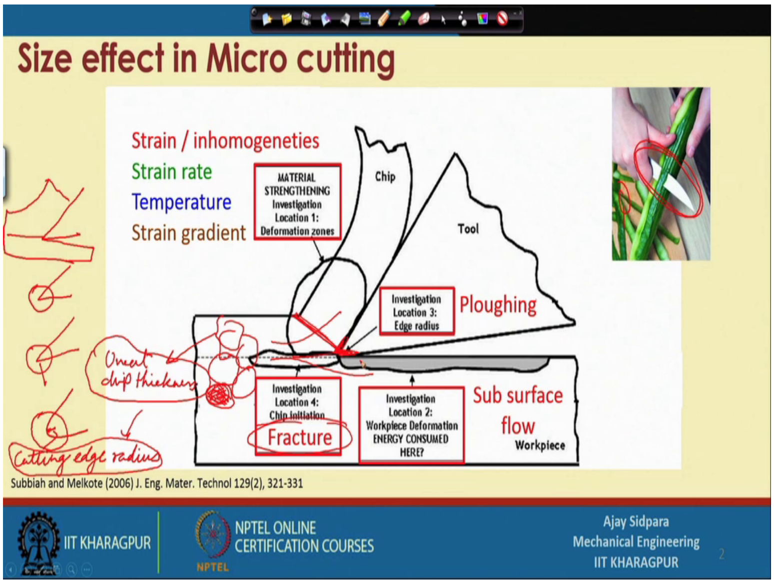
So, this is what is happen or what we have to understand at this location is the; what is going to happen in the deformation zone when you reduce the size of the machining process. Then the second one is the work piece because now we know that we have done some machining here and our object is to get this surface this is the surface which we want to get out of this particular row material. So, now, our objective is that we have to find out the; what is going to happen at this material.

So, our depth of cut is this much, but if you do machining at a micro scale it is not probably always possible to remove this much amount of material. So, what is the depth of cut you will not get the same amount of material at this side some material will make squeeze at this location and your end up with the moving of this material inside this particular finished component?

So, here we will see some of the example that at which particular condition this is going to happen. So, here the depth of cut will not be able to come out as a chip continuous some material will also penetrate or a; some material also go beyond this particular line and it will become a part of the machine surface.

So, here another thing is that once you do machining at that time we will be there be any changing in the property of this material or not. So, this is also important to study here. So, this is the location 2 where we have to do investigation in terms of the difference between micro and micro machining operation.

(Refer Slide Time: 11:42)



And subsurface flow that is what I am just now told you and third discussion location is the edge radius.

Now, we know that each and every tool our general diagram is this one that we show always we put the tool something like this and then we show them that this is the chip which is removed and this is the work piece and this is the machine component. So, we always tend to give the tool something like this, but if you magnify this particular area nothing is sharp perfectly sharp is not possible to make. So, if you magnify this area you will find that there is always one radius. So, this is called cutting edge radius cutting edge radius.

So, this is very important to understand that what is going to happen with this one, because we know in this particular case the if the our tool is very sharp it is very easy to remove the material, but if you see this particular thing that what is going to happen with this particular edge what will happen if this is not sharp; sharp, it is actually relative term because here we know that we are working at a very very small scale. So, whatever be the sharpness we have to compare it with the uncut chip thickness uncut chip thickness.

So, relative we have to say than what is the radius of this cutting edge with respect to the depth of cut or we can say the uncut chip thickness. So, that will decide that in which particular fashion the material will be removed and it may be considered as a ploughing also because you may not be able to remove material as a chip, but it may come as a plot material and then you have do some reworking to make sure that ploughing will not occur in the later stage.

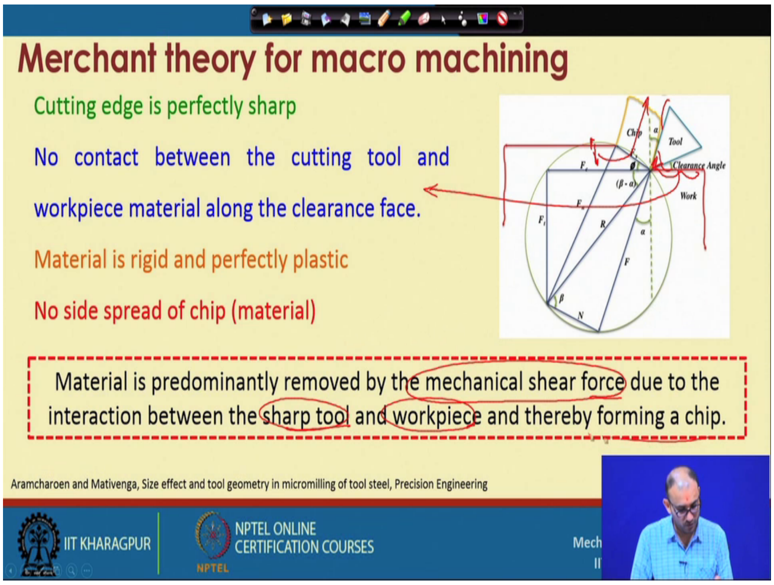
So, this is the third location in which we have to pay some attention and this is the chip initiation that is also important, because we know that in this particular case if you see that when you want to remove some material what we have do that this is the chip whatever is coming from here this are the chip in terms of our routine operation and here what is important then how to initiate the chip because chip initiation occurs at some particular defects because suppose you material has something here.

So, this are the grains located here there are some porosities available here some inclusions is also there some additional foreign material is available is it is alloy then there are different hardness hard face are available in that. So, this are the different-different type of defects we can see.

So, whenever y our tool edge or cutting edge encounter this defect it is easy to remove material, but we know that micro scale encountering of this defect is very less the probability is very less in that case. So, we have seen that in which case our material will be efficiently removed in in terms of chips. So, here fracture is also one important thing the chip initiations and because if it is a brittle material then you will get correct propagation if it is a ductile material, then you will get the different type of ploughing or the chip removal or the shear deformation or a plastic flow rate from these particular part.

So, these are the 4 different investigation locations where we have to understand how these things are different than the conventional machining processes.

(Refer Slide Time: 15:20)



Now, let us see about the merchant theory this is well known we have already seen this thing in conventional machining or the cutting tool or machine tool courses here what we are doing the merchant theory is based on lot of assumptions. So, first assumption was the cutting edge is very very sharp because merchant theory we are using to calculate the different cutting forces out of this forces some forces will measure experimentally and some of them we measure theoretical based on the scaling of this particular force diagram.

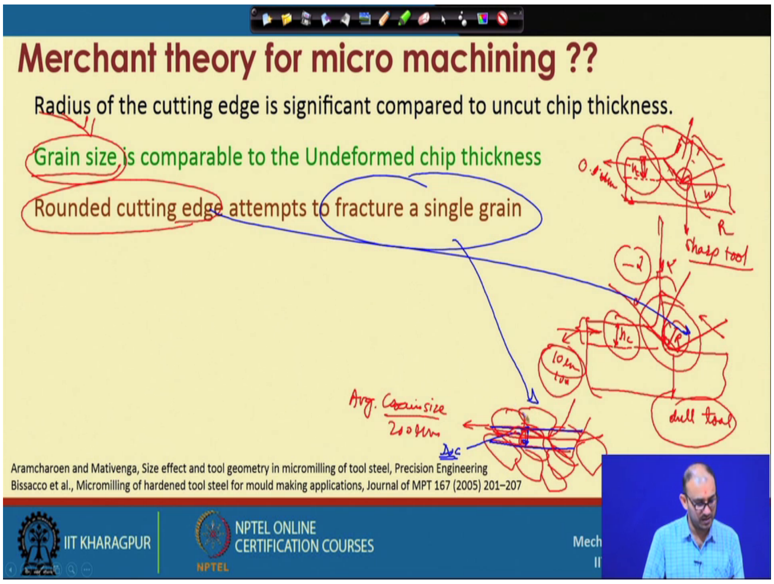
So, before we do that merchant as noted or told us some of the assumption that what are the assumption based on this particular theory works perfectly and there is no contact between the cutting tool and the clearance face of the work piece. So, this tool contact is here at this location only, but no contact here. So, this is the particular thing tool edge is very very sharp because that is what is going to happen in a different context when you talk about the micro machining then material is rigid and perfectly plastic even though it is like that if you do micro machining at that particular scale the material will not behave like that we will see those things in details and the no side spread of the chip of the material.

So, it is that whatever is the depth of cut whatever is this here. So, whatever is this depth of cut this whole material will come out as a chip?

So, there is no any side flows; that means, material is not moving in this side or the other side of the tool that is the front of this page and the behind of this page. So, what is finally, it was told that material is predominantly removed by the mechanical shear force. So, mechanical shear force is given by the tool due to the interaction between the sharp tool that is the first thing and the work piece and thereby it forms a chip. So, that is what merchant theory tells us when you do calculation of this different type of forces by using this merchant theory.

Now, let us understand that what is happening in the micro machine. So, can we use the same theory for the micro machining?

(Refer Slide Time: 17:40)



So, now there are lot of problems which are difficult to fit into the merchant theory first thing is the radius of the cutting edge is significant compared to the uncut chip thickness? Then the grain size is comparable to the un-deformed chip thickness rounded cutting edge attempts to fracture a single grain. So, now, let us see one by one. So, radius of the cutting edge significant compared to uncut chip thickness. Now if you see the conventional machining we consider something like this and this is our chip and this is the. So, this is chip which is coming out this is the tool this is the work piece this is the shear deformation zone let me give little more part this is the diagram.

Now, here if you see this particular cutting edge we have seen that there is always radius exists at this location. So, let us call it is a r and this is let us call as a h h c right. So, this is in terms of the conventional machining, but if you we know that we have to magnify this area to understand that what is going to happen in that normal in micro machining case.

So, now, let us say that this is the actual case of the cutting tool and now our chip will be something like this this is the machinery surface this is the bottom part and this is the chip now our R is something like this this is our r and this is our h c. Now many times what happen that whatever is R is there sometimes we have to cut a very small amount of material because the process is very very slow and because of that we have to also understand that tool life is also very short if your depth of cut is very very large?

So, generally we work with a very very small h c may be starting from 10 micron to hundred micron of type of things at that time your h will be your R will be also very very. So, now, if you consider this particular diagram in this comparison of these 2 thing now if you see this one is considered as a dull tool dull tool and this one is considered as sharp tool that is in terms of dimension, but if you consider this one is a micro scale it is also dull tool, but here our uncut chip thickness is very very small and that is the reason that comparison with this uncut chip thickness our tool is dull.

So, now, the material removal deform deformation occurs in a different-different way your shear zone will complete different. So, now, this one is a alpha what are we are talking about the rake angle, but there is always another effective rake angle is different that we will see it will be negative part because your deformation zone shifts from one location to another location.

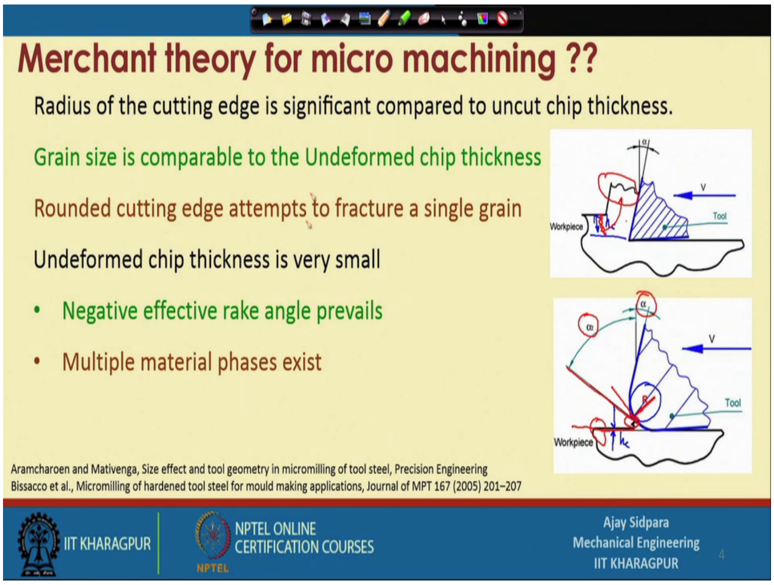
So, this is what is happening in this this particular part now coming to the grain size. Now say suppose your material is something like this and grain size is considered the hundreds of it is a 200s of average grain is 200 of micron grain size now you are cutting a material and you consider depth of cut is 50 micron. So, this is your depth of cut 50 micron depth of cut and if this is the depth of cut then what we can say that your Un-deformed chip thickness is comparable with the Grain size when you say the average let us we write average because whole grain when you are writing something like this all grain are not the same size. So, this is called average grain size.

So, here what is the problem that when you do machining in this particular scale you have to sometime cut the grain also, but that is not happening in this case because our uncut chip thickness is very very large it is may be in terms of the 0.5 millimeter to whatever is the capacity of the machine even you can start with the 100 micron also 100 micron to in terms of millimeter also you can go in this case very easily in conventional machining, but here we do not talk about the millimeter size because our material thickness is or things which we want to remove it as very very small thickness we do not want to remove more material from the work piece because of the scaling of the part.

So, here this is important the sometimes the grain we have to cut and that is difficult compared to the cutting through the boundary it is very easy to pass through it then round at cutting edge attempts to fracture a single grain. So, that is what is happening here because if this is the case and you are using a sharp tool then it is there a chance that it will cut down the material because you have a velocity and you have a sharpness also both the things. So, it can pierce very easily, but now we know that our tool is dull that is comparison which means relatively comparison between the uncut chip thickness and the cutting edge radius.

So, you are rounding cutting edge which is here that is cutting the rounded cutting edge is this one and this is cutting or it is a fracturing a single grain this is the grain. So, at that time now do you do not have sharpness, but you have a possibility of cutting the grain so that it even more difficult in micro machining case.

(Refer Slide Time: 23:50)



Now, this is what is happening in our normal case that we consider the tool is very very sharp and this is our work piece material and this is our rake angle and this is the velocity of the tool. Now this is what is happening in our micro cutting operation that, now we consider that there is always same radius exit and now if you see this one is the h h c and now here this one is h c.

So, now, you can understand the how much is the difference and another the important difference is this one. So, your chip is this one is your chip now if you see this particular your chip is located at this location.

Now, you understand that when chip flows it flows over the rake face, but now or rake face is this one, but it is flowing flow starts from the cutting edge radius some portion of that and then it is starting flowing in this direction. So, your effective rake angle is this one this is the effective rake angle and this is the nominal rake angle which we think that it has the tool with this particular cutting rake angle, but that is not happening when you do machining at this particular scale.

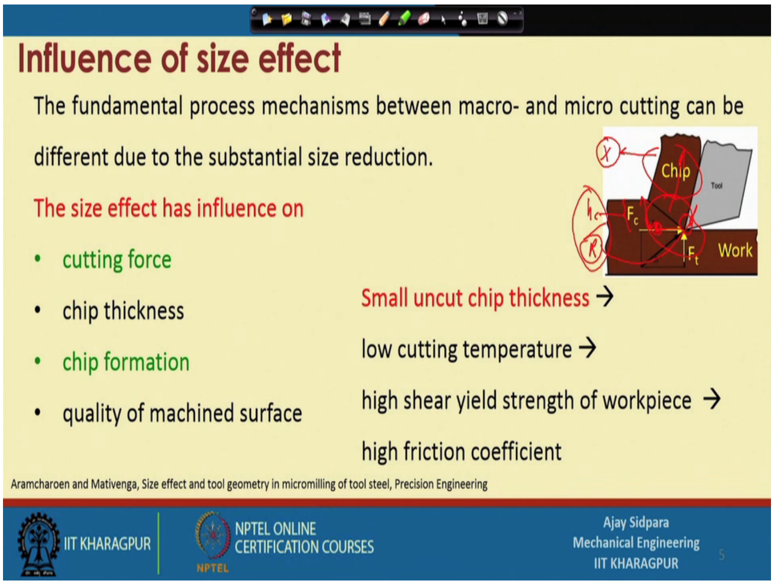
So, un-deformed chip thickness is very very small that is what is shown here negative effect rake angle prevails. So, this is called negative rake angle this is the effective negative rake angle because our nominal rake angle is this one, but when you do machining at a micro scale you are end up with this angle. So, your actual angle is this one and that is considered the negative rake angle.

Multiple material phases exist because now when you are cutting a material at a such a small scale you do not consider this one material as a homogeneous, because here what happens that there are lot of grains may be coming out as a chip, but here what is happening the single grain it may come across this thing. So, grains are oriented in a different-different direction. So, you have to find out that particular grain boundary.

So, that your material removal become very easy multiple phase exist because when you magnify this material or the particular surface of the material you may encounter different type of defects inclusions is also there porosities also there different phases exist. So, your tool encounter different-different material property even a single cut. So, some material is soft. So, tool will purely or it will easily cut that material, but certainly some hard inclusion come comes again the tool then tool has to provide more force to remove that material.

So, tool forces are also variable within a single cut and those things are completely different than the other things where we apply the merchant theory. So, there are limitations of using merchant theory for the micro machining operation and that is the reason that we have to do lot of trial and error experiments to get the required data of the force measurement and the machining conditions.

(Refer Slide Time: 26:52)



So, now how the what is the effect of size effect influence of size effect on the different type size effect means when you scale down the tool when you scale down the uncut chip thickness what is going to happen with the surface or what is going to happen with the tool also. So, in this case now the fundamental process mechanisms between the macro and micro can be different due to the substantial size reduction this is the normal conventional diagram whether chip is removing this is cutting force this is the thrust force and this is the work piece.

Now, size effect influence on the cutting force now first one is the cutting force here. So, now, if your chip thickness is small in this case your cutting force will be small because we know that we do not want to remove more material, but that again depends on what is the dia or radius of the cutting tool edge second one is the chip thickness because we know that our chip thickness is going to be very very small. So, there is a large variation in the chip thickness in the conventional machining in the micro machining process chip formation is also an issue, because if you do machining at a; this particular small scale there is a chance that you may not get the chip at all. So, this chip removal is not a guarantee here.

So, that everything depends on the; what is the ratio of this h c divided by R. So, this is the h c and this R is here this is the uncut chip thickness of the cutting edge radius of the tool. So, everything depends on this that which particular instance will make you or will give you one particular chip or it may not give anything in that case and the quality of the machined surface. Now we know that if chip formation occurs at that time we can get the machine quality much better because that is whatever we are getting it is as per our dimension, but if there is a variation between these 2 then you may not get the chip completely, but some material actually start propagating inside or it will squeeze through the work piece and it may deform the different type of properties which are important on the machine component.

So, what is happening with the uncut chip thickness small? So, if it is a small then the lower cutting temperature because we know that if the uncut depth of cut is very large or the uncut chip thickness is very large we are going to have very very large fiction here as well temperature rise. So, if the temperature is rised here what is the advantage of rising without temperature the temperature raise will be, somewhere here in this case some material most of the temperature will go with the chip temperature will also actually propagated ahead of the material which is just ahead of the tool. So, this material becomes little bit soft and this soft material when come into contact with that tool your tool need not to give more amount of force is to cut down this particular tool.

So, that is the advantage of having the higher cutting uncut chip thickness, but that is not happening. So, our cutting temperature is very very low and it will not help into removal of the material in by softening the part. So, if that is happening then your higher it will result in the high shear yield strength of the material because your material is getting to soften and; that means, you have to provide more amount of force to cut the material. And then you are end up with the high friction coefficient because now you are F t will increase and that is the reason you rubbing will be very very high in this particular case.

So, now, these are the different different influence of the machining zone. So, that we have to understand that at which particular ratio of this h c by R so that we can get the efficient material removal. So, let me finish this talk here and we will continue from this particular lecture in the next slides.

Thank you very much.