Introduction to Mechanical Micro Machining
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Lecture - 11
Difference between macro and micro machining (Contd.)

Good morning everybody, and let us go through our course on Introduction to Mechanical Micro Machining Processes. In the last class, we have started a new topic that is the Difference between the Micro and the Macro Machining operation. And we have seen some of the thing that, what is going to happen when you cut a material at the micro scale. And there is one now new term that came across, that was called the size effect.

So, the size effect is something defined like this that if you reduce the size of any process or any components, how the things will differ, make a difference in terms of the process mechanics or in terms of the operation of a particular component. And, we have seen that there are different components or the different parameters which will affect the machining processes something like a uncut chip thickness and cutting edge radius and there are different material properties also play important role when you cut a material at a micro scale. So, now, let us continue with the same class.

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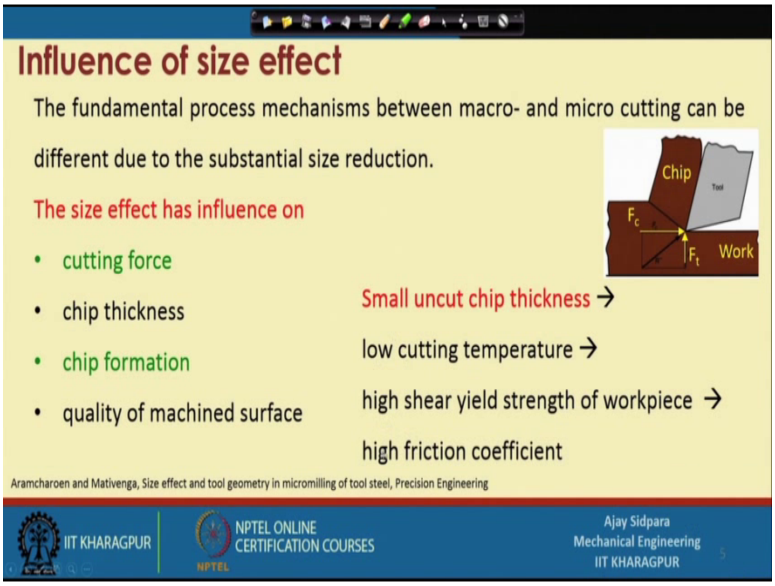

So, in the last class, we have seen this particular graph or particular diagram that where the size effect has influence on these different types of parameters. Now, let us see this thing that small cutting, edge cutting uncut chip thickness has the effect on the low cutting temperature, because the low cutting temperature the material yield strength is very high and it results in the high friction coefficient.

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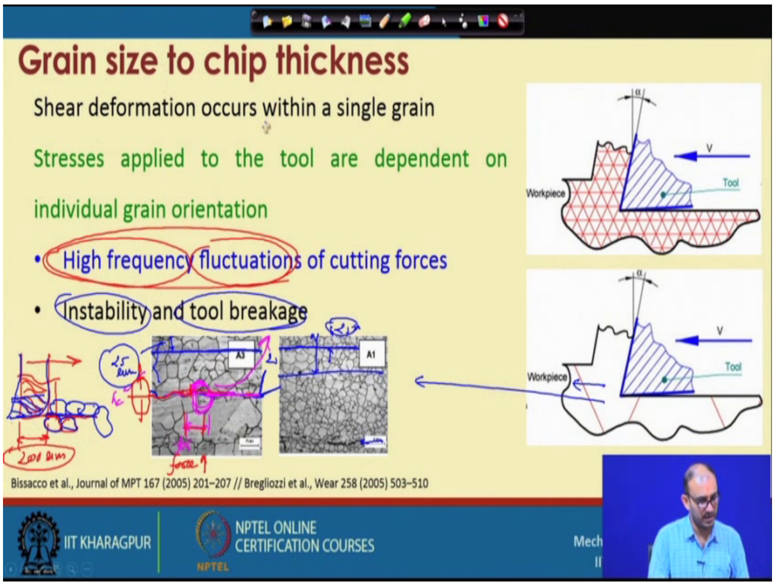

Now, let us see what is the effect grain size to the chip thickness, that we have seen in earlier slide that there is a effect of the grain size also. So, now, this is the diagram which is the conventional machining operation. Now, what is happening here that this is our tool and this is the uncut chip thickness, so, let us note it down here. So, this is uncut chip thickness that is h c and this is your cutting edge radius, but right now it is difficult because it is very start, but still let us put something like this is called R.

So, now, here if you see h c by R, this one is very large than one because h c is very large compared to the R. So, it removes the material very efficiently and this is your rake angle. Now, consider this particular thing whatever this triangle is showing. So, this is called the grain size, this is a single grain. So, this is in case of the conventional machine. So, your objective this figure is to show that your h c is many times higher than the R and you are efficiently getting one chip which is flowing over the rake phase of the cutting tool and this is the same diagram here. Only difference here is this particular grain.

So, if you see the we have not given any type of difference in the cutting tool alpha is also same, work piece motion is also same in this case and we have also not changed the h c. Now, h c is also same here. So, this is the h c; only one thing has changed here, that is, this particular grain. Now, if you see this is the one grain, but that one grain is become very large here in this case because our depth of cut is very small relatively.

So, now what is happening here in this case? Now, when you are cutting a material at a micro scale you are actually removing many layers of the grain. So, this is the 1 layer, 2 layer, it may be more than 2 or may be more than 10 also. So, when you do cutting in a macro machining or the conventional machining. But, when you do the same thing at this particular scale where h c is in terms of tens of micron and this is in terms of hundreds of micron, then each and every grain orientation property of this grain defect inside of this grain play important role in the removal of the material.

So, here in this particular case your tool is going to cut the grain. So, this particular part of this grain will come as a chip and this become the work piece; because, it is going below the cutting tool. So, in this case whatever energy we have to spend for cutting this material will be very high, because you have to cut the grain you will not encounter the grain boundary. Because, when you are cutting it at a micro macro scale or conventional machining you will easily get the boundary by which your grain will be separated out. So, you do not need to cut the grain, but here this type of probability is very less. So, many a time you have to do cutting of the grain.

So, what is this thing, shear deformation occurs in a single grain. So, that is what is happening here in this particular case. Stress is applies to the tool are dependent on the individual grain orientation. So, now, in order here is very ideal situation that all grains are oriented and put together in a very particular fashion, but that is not going to happen this type of particular fashion will not be available when you do actually cutting of a different material.

So, now, see these are the 2 different examples. So, here this is the small grain size and here, it is comparatively large grain size. Now, let us consider this thing at this particular example, that macro machining. So, macro machining will not make much difference because anyhow your cut will be very large. It may pass because here it is in 25 micron this much this scale is a 25 micron. So, if you consider 25 this one is the 50 micron. So, let us consider this is the 50 micron.

So, when you cut a 50 micron is a depth of cut, this is called h c; at the time there are many layers, comparatively less, but you may get at least 1 or 2 layers of the grain which will come out as a chip. And, that will be more easy in this particular case because in this particular case your h c will be this much, same h c, you will encounter many types of grains. So, getting that particular boundary is very easy in this particular case, but now, if you use these particular processes here. Now, let us consider depth of cut is very small. So, what is 25 micron is there, so, let us cut this 25 micron and same way it is here, this is also 25 micron and we are using micro machining operation for cutting this particular material.

Now, coming to this first one; so now, even if you are cutting 25 micron depth of cut still you are able to get the small amount of high probability of getting the grain bound because size of the grain is even smaller than what we have seen. So, here it is 5 microns. So, this dimension is a 5 micron. So, you consider 25 micron means it will be something like this. So, this will be the 25 micron. So, in this particular case also you can also easily remove the material, but here if you do the same thing here at this particular now what is going to happen here that you have to cut the grain here, getting a boundary very difficult. So, what is problem because of this? So, the first thing is the high frequency fluctuations in the cutting forces.

Now, why it is going to happen? Now, consider this particular part, now here if you see this boundary; this boundary has a very linear part. So, now, consider your tool is located here at this location. So, in this particular case will pass though this boundary. So, this whole thing will come out as a chip, but only there is a one problem that there is a one grain. So, this grain you have to cut because this grain is coming as a one of the some of the grain here some part the grain is below the material and some of the grain is located within this h c.

So, now when your tool is moving in this direction it is finding a grain boundary. So, as soon as it initiate the crack or initiate the particular shearing at that time whole thing will move very easily, but as soon as encounter this particular grain now this whole grain is come into picture and then because of that now you have to cut the grain. So, suddenly you have to apply more amount of forces to cut down this thing because now you are not getting a boundary. That is only way your tool will jump in this direction that depends on the stiffness of your machine tool, that we will discuss in more detail in the component of the machine tool. But, right now we had considered the machine tool stiffness is very high. So, in that particular case it will not jump over this part, but it will cut the grain here.

So, as soon as your grain cutting is your forces will be very high in these cases. So, here force will be high here for cutting this much amount of material. As soon as your passing this grain then again you are getting a grain boundary here, so, it will be very easier. And by chance, second instance you again encounter one grain which is half on the uncut chip thickness and half into this and again you have to apply more force. So, within a single cut, your cutting tool is encountering different orientation and different part of this part. So, sometimes it has to give more amount of force to material, sometime less. So, that is the reason that you are ending with the high frequency fluctuation because we are going at a very high speed that is the reason of the high frequency and fluctuation is because of the sometimes you need high force sometimes you need a low less force.

And, because of that, what is happening that it is instability and the tool breakage because we know that our tool diameter is very small. So, if you will consider the tool our tool is something like this. So, this is our end mill cutter consider and this diameter you consider 200 micron. Now, when the tool diameter is very small your effective length of the cutting length is also very small because you cannot have very long hangover on this part. And, now when you are cutting this part now it is consider as a moving this direction and you are getting a one particular boundary here. So, this are the grains located here. Let us consider, so, this are the grain located here. So, it is very easy to remove the material and now consider there is one grain here at this location.

So, when it is moving in this direction, at that time suddenly the grain is coming. So, at that time you will get instability suddenly you have to apply more amount of force. So, either your tool will bend a little bit in this direction or it will break from this location that depends on what is the rpm, what is your federate you are providing for cutting this particular part. So, you are getting instability. Instability means it may bend, but it will not break. It will continue with a machining of that and tool breakage; that means, whatever forces you are providing that forces are enough to break this particular slender tool, that is, micro tool. So, these are the problem when you are talking about the grain size with the chip thickness.

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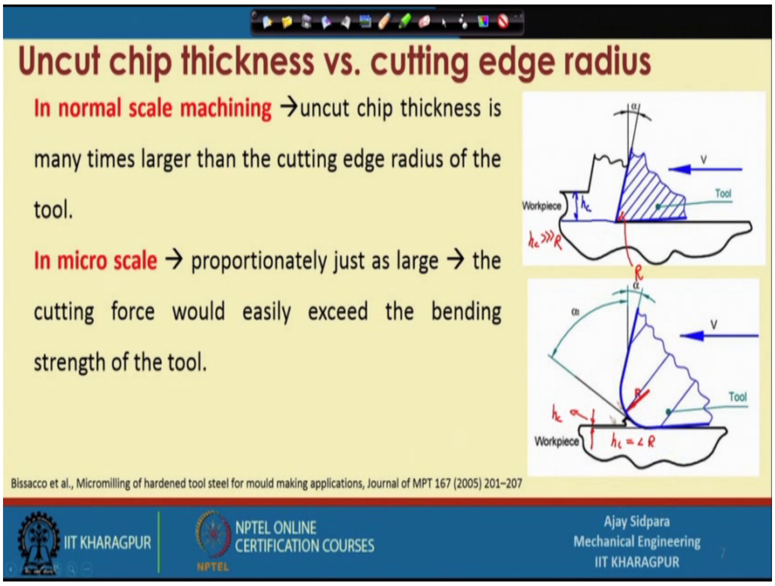

Then, coming to very important parameter; that is, uncut chip thickness versus cutting edge radius. So, now, in macro scale or normal machining we have seen that uncut chip thickness is many times larger than the cutting edge radius of the cutting tool. So, this figure we have seen that is what was here? So, it is very easy to remove material many things are there. So, this is our uncut chip thickness, h c and you will get small R here, let us consider this is the R. So, this here you can write h c is many times bigger than R. But, in micro scale proportionality is just as large or sometimes it is very small compare to this part. So, this is what is happening in our micro machining. So, now, h c is this one which is even very difficult to see also this is h c and R is very large that we have given here. So, in this case it is h c is equal to or sometimes smaller than the R.

So, what is because of that cutting force would easily exceed the bending strength of the cutting tool, that we have seen in the last slide that now you have to apply more amount of forces; because, your chip thickness is very small uncut chip thickness and your cutting edge radius is very large in this case. So, you are loading on the tool will be very large because we know if you want to cut the material with a blunt tool, you will have to apply more amount of forces and if it is the sharp the force will be very less that happens in any type of cutting.

So, if a blunt tool you are using then your force requirement or the amount of force you require to cut the material will be very large and it ends up in the removal of the breakage of the cutting tool.

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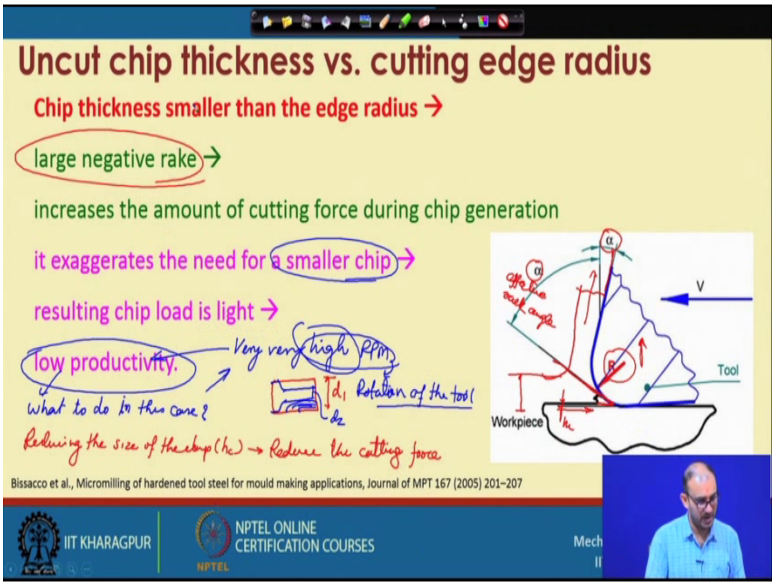

Now, what is happening? In this, particular chip thickness is smaller than the cutting edge radius. So, we know that there is a large cutting negative rake angle happens. So, that large weight at which location we are considering, now, suppose this is a cutting edge. So, now, the chip moving material is moving in this direction and your shear plain maybe somewhere here, this is your shear plain and this your chip. So, in ideal case or in macro machining what is going what is the scenario that your chip will flow in this direction and your uncut chip thickness will be something like this and it will be easy to remove the material, but that is not the case here, because of our h c is very small here this is h c and your R is very large here in this case.

So, your material deformation occurs at a location. So, your rake angle it is calculated from this location now, not from this location. Because, the some part of cutting edge it will behave as a rake face of the cutting tool and then you have to calculate this is the effective rake angle and this is the rake angle of the cutting tool. So, now, there is a large cutting negative rake angle that is what is here, this particular part. That increase the amount of cutting forces due to during the chip generation because now your blunt tool is coming into action your cutting forces will be very large in this particular case that we have seen also. It exaggerates the need for the smaller chip.

Now, we know that if you reduce the size of the cutting tool, size of the chip, so, reducing the size of the chip that is h c we can reduce the cutting force right. So, in this particular case we know that we are ending with the negative rake angle. So, forces will be very high. So, to counter existing what we have to do, we have to reduce the size of the chip. So, smaller chip is required to go through it and will depend that will result in light chip load. So, the chip load will be very light in this particular case, now we have reduced that thing now problem is that case, but there is a problem in the low productivity; because we have if you reduce the uncut chip thickness if you want to remove very large amount of material then you have to go through many amount of many passes in that case.

So, now suppose your let us use the turning operation. So, now, this is initial diameter is d 1 and then you want to reduce it to d 2. Now, this is your d 2 and this is amount of material you want to remove. So, if you reduce your particular chip load, smaller the chip you want to reduce then what is going to happen that you have to do many cutting here, maybe 3-4 pass to reach to this diameter, but if you use the very large amount of chip then within 1 pass or 2 pass you can cut the same amount of material. So, your productivity is very low in this particular case if you follow this path.

So, there is one way to encounter this thing that you have to increase the RPM. So, what to do in this case? So, here what we have to do? We have to need very high RPM for the rotation of the tool. If you give high RPM then what you can do you increase feed rate because you are able to remove more amount of material by this particular operation. So, high RPM is very important to get the high productivity. If you do not do with this thing then you end up with the low productivity because you have to save the tool also and you have to also get the work piece in a proper geometry as per the required dimension.

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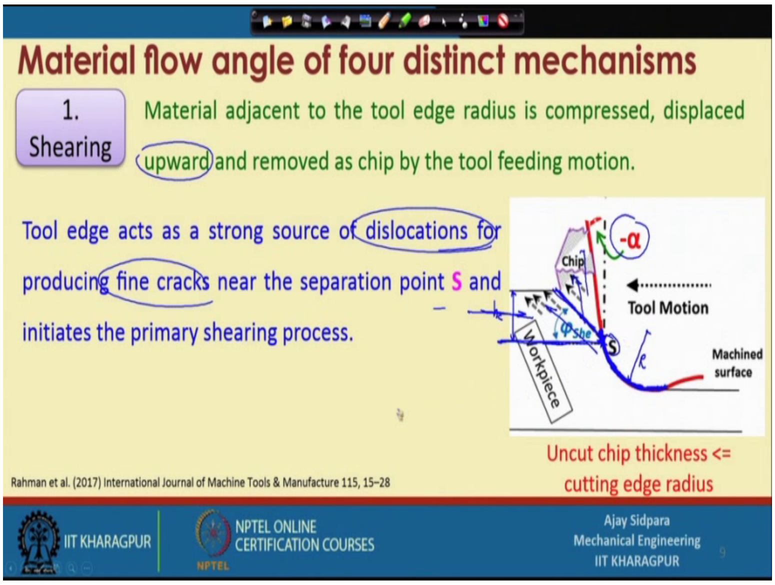

So, there are different types of mechanism when at which the material will flow over the rake phase. So, let us go through it. So, first one is the shearing operation. So, now, here we know that we are end up with the negative rake angle. So, in this case let us start that at which particular negative rake angle you are getting the chip and at which angle you are you are not getting chip at all. So, now, first example is condition where the uncut chip thickness is equal to or little bit smaller than the cutting edge radius. So, this is the uncut chip thickness, this is what it is showing here. So, this is h c and let us give something here, this is the h c then let us consider this as the R and this is the negative rake angle which is happening because of this part. So, here if this is the case then what are the chances of getting a chip out of this particular operation?

So, let us see, what the condition is or what is happening in this case. So, first thing is that material adjacent to the adjacent to the cutting edge radius is compressed. So, now whatever the material is coming from here, in this direction, that is, opposite to the tool motion, material adjacent to the tool edge radius is compressed. So, this is the cutting edge tool radius that let myself give some different colour, whatever is this here. So, this is the all thing is a cutting edge radius this one. So, material adjacent to the tool edge radius is compressed. So, when you are getting this particular time some of the materials compress displaced upward. So, this is the material.

So, this thing is going in this direction, but your material is also flowing in this case. So, some of this will displace in upward direction and removed by the chip as the tool feeding motion. So, if you continue in this direction. So, it will create one particular plain that is shear plane, above of this particular thing your chip will be remove and some of the material whatever is that that will come as it will again encounter in the next process. So, if you continue this motion in this direction some of the material which remove, but some of the material will take some time and after second instance or third instance it will come out as a chip.

So, tool acts as a strong source of the dislocations. So, this is the particular tool edge. So, this tool edge because; obviously, that tool is the only thing which is sharper compared to other location. Even it is a blunt looking like here, but it is completely sharper in the other edges around the tool. So, this will create as a, behave as a one of the source of the dislocation through which it will create a one fine crack. So, this fine crack will start from this particular point. So, this is one arbitrary point that we have found that this particular things. So, consider this the layer uncut chip region in this particular line and then it will create initiate a primary shearing processes. So, this is a way it will. So, this is a shear angle and this your shear plane and yours in this particular point.

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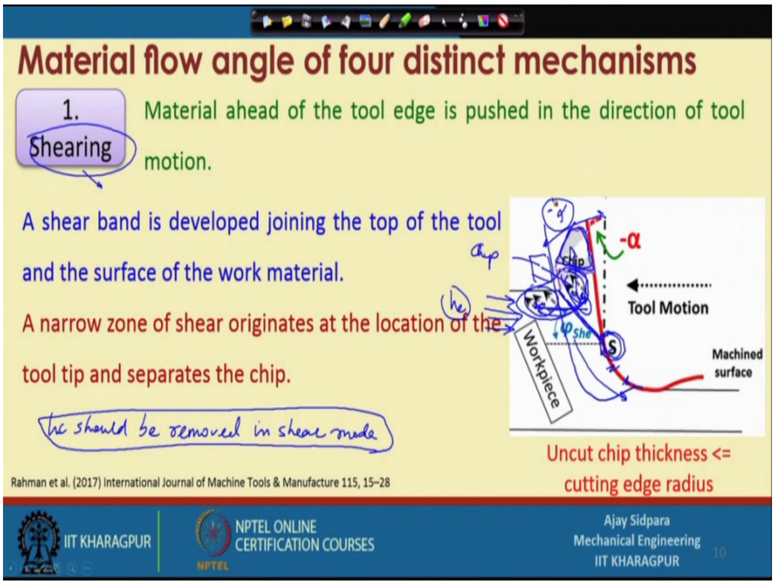

So, let us continue further in this. So, now, here in this case what happened? The material ahead of the tool is pushed in the direction of the tool motion. So, material is coming in this direction and this your tool is moving in this direction. So, material ahead of the tool S, this is your tool S that we have seen in the last slide also. So, this is the tool S, it pushed against the direction of the tool motion. So, this is the direction. So, these are the material work piece is coming from this direction whatever is the material which consider which is in the zone of h c that is going to push in this direction, because now it is not the sharp your phase that is your rake phase on the negative side. If it is in this direction, then the flow of material is in this direction, it is very facilitated. But, it is not in this case. So, now, shear band is developed joining the top of the tool and the surface of the work material here. So, now, this is a shear band.

This is the one shear plain it will generate because it is not located very easily because everything depends on what is the depth of cut, what is the feed attributes you are moving the work piece, what is the RPM of the cutting tool and everything depend on that. So, if you will find one location where you will get shear band developed in this case. So, this will be a very little amount of area given on here by which you can get the something done as a chip.

So, a narrow zone of a shear originates at the location of the tool tip and separates chip. So, now, we know that this old material is going inside the this old material whatever is here this old things here in this case all things is pushing towards the motion of the tool, but your material is continuously moving in this direction.

So, because of that the chip you are getting one particular instant at which will generate a shear band and some material will come out as a chip now see the chip location is this one still some material is here in this case. So, in the next instant when you continue you this operation your tool somewhere here. So, this is the second instance of tool. So, whatever is this material, this material will become a chip here and then this particular material come to this particular plane. So, in this case if you continue in such fashion, at that time you will get a more amount material as a chip and then remaining material may go inside the material also. So, it will continuously do a sequential machining in terms of this operation that is some part become h c then this particular part portion will take place of the chip and remaining portion will come to this place.

In that case, you can get the material removed by means of shearing. So, shearing is the important thing because we want shearing happen for all the things for h c is that. So, want that h c should be removed in shear mode. So, this is what is important in this case. So, everything depends on where we are located this S here, because if S is located somewhere here you will not get this also.

So, that thing we will discuss in the next class because now we have to shift the S in such a way in downward position so that alpha become more and more large in this particular case. So, that thing we will discuss in the next class and let us stop from this slide.

Thank you very much.