**Introduction to Mechanical Micro Machining**
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**Lecture - 14**
**Difference between macro and micro machining (Contd.)**

Good morning everybody, and welcome to our course on introduction to micro machining processes. In the last class, we have seen some of the aspect of micro machining, and that was related to the how the size effect affects the different type of mechanism during material removal. And we have seen that how the cutting edge angle of cutting tool that effect the different types of phenomena. That we have seen that one of them is a shearing that is what is required in the machining, second one was the extrusion, in that some of the material is moved as a chip and some of the remaining part will be become a part of the machine surface.

Third one was the rubbing of the surface and 4th one was the plowing. And we have also seen that plowing and rubbing should be avoided so that you can get the required geometry or the required machine surface without any problem. And then we have seen some of the phenomena of the ductal machining that when defects are present in the raw material, then there is a chance that the material.
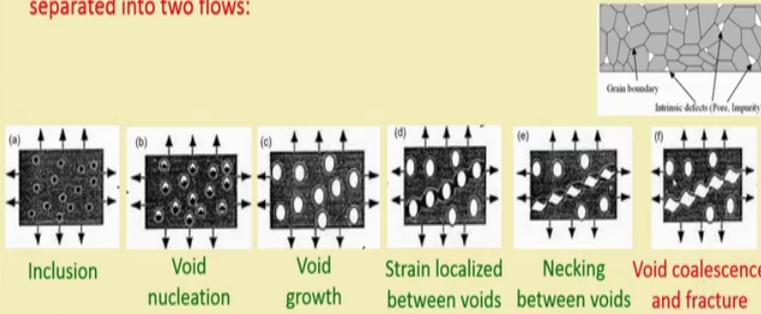
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Yes.

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And we have seen in the last lecture also that we need some defects.
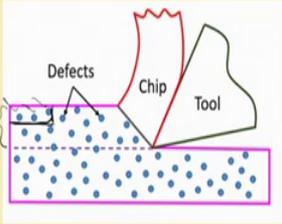
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So, that material can be removed very easily where the propagation of the crake will pass through this different type of materials. And that is very easy to explain in this particular slides yes, and we have seen the what are the different defects available that is mostly the pore impurities, and some type of other pore elements also.

And these are the different stages through which the material get fractured starting from the inclusion, and then it will pass through this different steps.

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And then we have seen that what is the effect of the presence of this defect during the material removal, and we have found that if the defect levels are very high, it can easily remove the material, but we know that we are removing material at micro scale. So, that is the reason that our uncut chip thickness will be very, very small this is the right now what is available, but our uncut chip thickness will be very, very small in this case. And that is the reason the number of the defects will be very, very less and that creates a problem in the machining.

So, you need a very, very high amount of forces. And we have seen the material resists plastic deformation much more strongly than expected due to less defects. And what is happening because of that? We are working with a small hc; that is the small amount very small value of the uncut chip thickness that is hc here. And what happens because of this that deformation will happen at a small scale that is what is showing here.

And when deformation is small scale we know that the tool will encounter less amount of defects. And that is the problem with the material removal and because of that you are end up with the high material strength of this because material will behavioral like a more ideal ideal material without any defects, and that is the reason you are getting a very, very high strength of the material at the micro scale machining.

Now, what is the effect of blunt tool? Because till now we have seen some of the examples, that where we are talking about the cutting edge radius of the cutting tool, where we have seen then it is not ideally sharp cutting tool and we always have some radius that is called cutting edge radius.

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So, what will happened because of the blunt tool? Causes some pushing of the material, that this diagram we have seen, that pushing of the material happens in different different reactions. So, there are different way way locations, let us identify those locations first. So, let us put this one is the one. So, that is called immediately ahead of the cutting edge into the chip.

So now this is our the chip flow. So, when this is the material now if you see from the side u, then our tool is here. Let us right now consider as a sharp tool. And this is our chip, and this is our material, this is our uncut chip thickness, and this is our machine surface.

Now when it is removing the material, this is the tool this is the work piece. So, this is immediately ahead of the cutting edge into the chip. So, whatever this portion is there, this portion will be here. So, and when it continues at the time, some of this part will come out does a chip while some them will be moving here and there that we will see here in the next 2 3 topics, right.

So, what happens because of that? First is some of the material will go ahead into the chip second is the into the machine surface. Now this is also the machine surface location. Now in the last class we have also seen this particular thing that some of the materials will move ahead into this particular location that is because of the location of this particular point d and because of this blunt tool.

So, whatever it is hc is there some of the portion of this hc will go as a chip and some of them will again become a part of the machine surface. So, these are the 2 things, and possibly to the sides also that we have seen in this particular diagram.

So now we can see that this whatever material is in this particular location, whatever we are looking at this part. So, this is at the front zone, and we know that our tool is moving in this direction. So, ultimately when tool approaches in this direction whatever material is present ahead of the tool that will be consider as a chip also, because at the end this whole material will be scooped out by the tool, but part of this material again become the machine surface some of them will go to the side and some of them go to this sides also.

So, this material will not play major role, but what is happening to this particular material that will be very interesting to understand by these 2 example. The some of the material become part of the workpiece surface. So, machine surface some of the material will go. So, ultimately you are not effectively removing the material. And possibly, from the to the sides. So, this slide is the again the plowing material. So, you are just plowing the material from these side. So, your surface will be a something like this, this is the cut zone, and these are the material which is tilde up on the both the sides because of this plowing effect, correct?

Now let us see the what are the different type of examples with respect to the material and the machining parameters.

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So, first one is the grain size to the chip thickness. So, material cannot be treated as isotropic, and homogenous like in the conventional micro machining. So now, this is the example. Now what this figure tells us. The this one is R and this one is d. So, this one is consider hc what we are just nomenclaching it hc, and this one is the R that is the cutting-edge radius. And this is our conventional machining. And we can see here that these are the small small grains.

This are not actually small, but because of the scale of this macro machining with the conventional machining, it looks like a very, very small in this case. And we consider our cutting is radius is R, and our R is much better than or much larger than the uncut chip thickness. And these whole material come out as a chip and our alpha that is the right angle is also positive. So, no probably means this case. And you can also clear see here that there are many layers of grains here that will come out as a chip.

So, machining through this grain boundary is very easy to performing these particular case. Size effects also effect the plastic behavior by creating the geometrical constraints obstruct, dislocations to initiate. And slide now consider this examples. This is the same thing, but at a micro cutting at micro level. Now many things are changed here, first thing is the R is note smaller than the d. So, it you consider R equal to d or R is bigger than d. So, in that case our sharpness of the tool also play important role load here. So, our now we have to put R here there, what is this R? So, this R may be equal to hc, hc or it is bigger than hc in this case.

So now our effective right angle is negative in this case. And our material removal will be different. Now if you see the grain size here you have seen here that there are many grains which are is which are coming out as a chip, but that is not happening here. Now you can see that if you draw one line through this particular line, then you can see the this whole grain is going to cut when this tool will approach to this particular grain. And other then there some of the grains are individually orientated and located randomly at different different location, and because of that you have to create a lot of amount of energy here to remove that material or to fracture this particular grain.

So, what size effect tells us? The size effect also effect the plastic behavior by creating geometrical constraints. So, those are obstruct dislocations to initiate and slide. So, we are not able to get the one particular dislocation dislocation means the defect, the through

which the material will be removed or it that particular cutting will initiate or the propagation will initiate, but that is difficult to find here. Because now we are looking at a individual grain and some of the grains are exactly reaching to the to the center of this particular line and that is difficult to cut through this material. And these are the very difficult to measure and find out the further possibility of cutting of this material.

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Now, coming to grain size to feature size now in conventional machining, we have seen that our tool is very, very large; that means, comparative through the size of the grains, and we can see this particular diagram; that this is our n mill cutter and this is the amount of material we are removing. So, we are cutting from this side. So, this is the vertical side, and this is the bottom side. And you can see the number of grains, which we are cutting from here these are very, very large in terms of numbers and in terms of layers also. But if you see the same thing at a micro scale, suppose we are considering the feature size around few of 100s of micron, then some times the grain size is also similar to that dimension.

So, what is problem in this particular case? Then when you are cutting a material because your cutting tool has also grain structure and when you are talking about the cutting tool diameter consider a 200 micron, then you have to use very, very fine particles of the tungsten carbide and cobalt so that you are end up with the very, very large amount of

grain so that you can get the required geometry to cut on to the cutting tool also. So now, here because of this what are the problems, let us see.

So, when the micro features and grain size are comparable is size. Now we want to cut the material. At a micro scale and which has a feature size of 100 micron or something. And we have a micro grain size also in terms of 100s of micron. So, grain size and the feature size are almost same. So, material behaviors is different in this case cutting mechanics changes due to the size effects. Now what happens in this case? Why material behavior changes? Because now if you see this particular thing and we are cutting this particular line we have already discuss, but let us go little bit more in there.

So, when you are cutting this material, 2 things happen. First thing is that your tool will be loaded severely in this particular case. Because now you getting an boundary of the grains or the getting a defect to initiate or slide the dislocation, it is very difficult in this case because 1 2 and 3 grains are only coming into it is picture when you are cutting the material. So, material behavior is a different everything depends on the size of the grain, size distribution orientation of the grains.

Now, size also matter that we are discussing here distribution; that means how they are distributed. Orientation also make different, because if they are uniformly oriented then there is a chance of that is something like this. This are very, very ideal structure and suppose your cutting tool locate is here then it can find a grain boundary very easily and that grain boundary is continuous in this case.

But now if you they are located something like this that is what this is the structure, then there is a problem that you may not encounter this particular boundary to initiate the slide cutting. And because of this different different phenomena what cutting mechanics changes due to size effects cutting mechanics; that means, now you have to look at to the individual orientation of the grain, earlier we were ignoring these thing when you are cutting at the micro micro scale or conventional machining, but we have to also see the micro structure of the material which we want to cut.

So, in this case you have to think very; very deplete to get into the machining zone. So, that you can get the more information about the characteristics of the grains of the material now ductile to brittle transition with depth of cut. Now till now we have seen

that, we have problem with the depth of cut depth of cut means uncut chip thickness, now what is going to happen if you increase the depth of cut of a some material.

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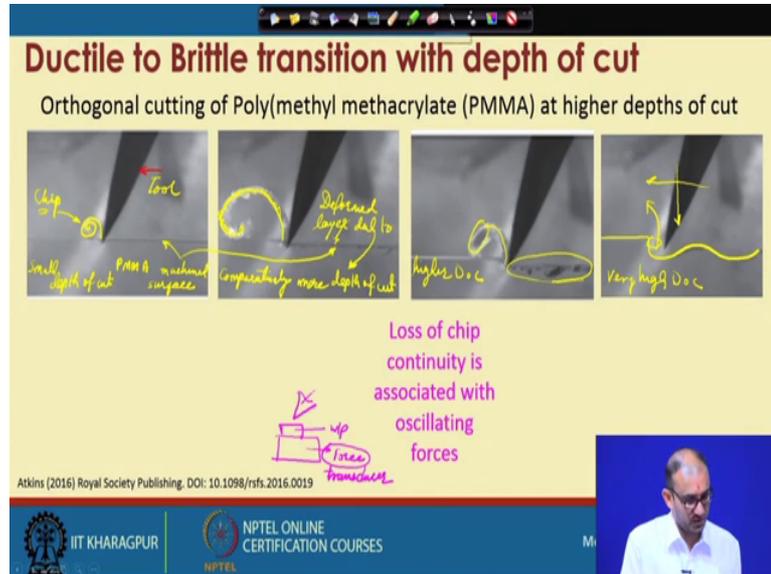


So, let us take one example of the PMMA. So, this is one of the polymer materials, and full form is the poly methyl methacrylate. And this material is well known use for the different type of micro fluids device, because it is very transparent also, and you can get a micro machine channels very easily. That we have seen in the example application section of the our course in the first or second lecture.

So now let us see. So, these are the high-speed image is of the cutting tool. So, this is the cutting tool. So, theses particular thing is the cutting tool, right? This is the PMMA material. And this is the chip. And here depth of cut is very small. Small depth of cut now you can see that old chip is coming out as a curly parts. So, it is a good sign of the cutting. So, we are getting a clear chip out of this is and this is consider as a shear mechanism or the shear mode of cutting.

Now we have increase this depth. So, let us see that now comparatively, comparatively more depth of cut. Now there are 2 ways to look into this thing, first thing is the chip. Now see chip is still curvature, but these are very, very segregated. If you see this particular thing these are very, very segregated.

And another thing is this machine surface. If you see this thing, machine surface, and see the same thing here. Now you can see here it is very, very clear surface; that means, there is no material is left. Uncut or no any fracture happens or no crakes nothing is here, but if you see these particular location you can find a very clear layer here which is deform. So, this is the deform layer, deform layer due to more depth of cut. So, let us continue further let us increase the depth of cut little bit more.

So, now we have further going down into the material. And now you can see the removal of the chip is little more difficult in first thick, and third one you can see that now material is not removed very, very efficiently chip is not in curvy nature, but some of the things is very, very bulky and some of the thing is very, very thin here in this case. Now if you see this particular thing is very, very bulky and here you can still get one curvature. But see the machine surface deformation it is very, very prominent here in this case. So, it is not the efficient cutting, let us further increase these thing. Now this is even more depth of cut. So, this is high higher depth of cut, and this is very, very high, very high depth of cut.

Now, in this case, now what is happening here in this case that now material is getting fractured severely? Now if you see this is the material now if you see the boundary. So, this is the boundary of the material. And now you can observe here the tool is not in contact with the workpiece at all, because when the depth of cut is very, very high what happen the fracture initiates instead of a plastic deformation, and many material ahead of the tool will come out as a discontinuous chip or a segregated material because of the high depth of cut the high velocity in this case. And that is why you will encounter some of the instances where your tool is not in contact with the workpiece surface. So, that is happening when you are machining some polymer-based material or some type of glass material, where the depth of cut is very important to in this type of material removal things.

Now, how to observe, or how to in get information out of this thing? Because if you consider, these thing is a happening at a micro scale even though we are telling there depth of cut is very, very high, but if you see a micro scale we can higher depth of cut we can considered as a 100 micron or 200 micron something. And this one is the lower case that is in terms of tens of micron. So, we need to get this information by some other mechanism so that we can understand that what is happening to the machining zone.

So, one of the ways of doing these thing is that we can find out what is the force is acting on to the materials. So, you put a dynamometer on to the workpiece right. So, what we are doing that let us put one dynamometer on the top of the workpiece we are putting the, and then we cutting with the cutting tool. So, this is the tool this is the workpiece, this is the dynamometer, force transducer, transducer. And then when it is cutting it will give one signal, and we have to observed this signal to get the information about the machining zone.

So, what is happening? The; so, let us draw one graph with respect to the travel of the tool on the x axis and y axis it is force, right? So, this is the diagram belongs to the first cut.

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Now if you see in this case. So, this is the tool travel. So, tool is moving in this direction, and we are measuring the forces. What is happening to the forces? So, initially when it is not in contact. So, you are; obviously, get a 0 force and when you are penetrating into the depth suppose these tool is gradually going into the material, then the forces will increase suddenly, and then when you are moving in this direction that is in feed direction your force will stabilize in a particular band or particular range.

So now if you see this variation this variation is very, very small in this case, right? So, this variation is because what depth of cut is very, very small amount of material which is removing out of this workpiece is also very, very small. So, your force signal is

somewhere here. So, let us consider this one is a reference signal, and it we consider this one as a small signal. But you are not getting any type of disengagement between the workpiece and the tool, because tool is in full contact with the workpiece throughout the cut.

So, this is what is getting the, whatever this variation is, there this variation is because of the many reasons that machine structure. Also play a important role here there are vibrations occurs stiffness of the machine tool is important, and the cutting mechanics the material which material you are cutting that also creates this signature. This will discuss in more detail in a sense apart, but let us right now consider this variation is unavoidable many times you get this things. Now let us move to this next figure. So, when you are getting a continuous chip your study cutting forces are occurs. So, this is consider the study cutting force.

Now, coming to the next part what is happening here in this case, that your chip is not similar to this chip now your depth of cut is increase little bit and if you see this particular diagram. So now, your variation in the cutting force is also little high. So now, it was oscillating a very, very small amplitude now this amplitude is increase. Because, now you are getting some fracture on to the machine surface. And your chip removal is also not very, very efficient compared to this first figure. So now, your oscillation is very, very high. But still it is in full contacts that full contact means you are not getting any type of cutting like this something like this.

So, there is no any type of open region between the in the signal. So, still it is in the full contact. But your amplitude it is increase; that means, you have a large variation in the forces. So, this variation also plays important role in the life of the cutting tool as well as the workpiece material quality. So, let us see the third graph. Now this one is the third one. Now in this particular case if you see this machine part there are large amount of deformer with the fractures. So, deformation or some type of unwanted things you are at the machine surface.

And chip is also different now it is coming in a very, very sediments you are not able to identify the, which particular shape of this chips are there. So now, in this continuous pressure, now your still it is in full contact now, but what is happening that force variation is very, very large in this case. Because sometimes it is able to remove material

very quickly and then suddenly it jumps to the downwards, because that material which is just ahead of the tool is already fractured; that means, their crack is already initiated before it is reaching to the surface. So, when tool is reaching to that location tool does not require so much amount of force.

So, it remove this much amount of material. So now, again the phase material is coming. So, again you need a very, very large amount of force, and that particular large amount of force is again coupled with the loose material, which is in this case. So, you are getting a very, very high fluctuation motion during this cutting at a high depth of cut. So now, let us move to the next slide, next toke this is the thing. So now, here we have seen that there are many different things compared to this. First 3 first thing is the, your tool is not in full contact. So, this is the surface of the workpiece which is machine. And chip is also not visible because, it is a pure fracture now.

It is not removing as a ducktail material. So, what is happening that, when your machining with a small depth of cut you can cut a brittle material also in ducktail one. So, that is what is happening. So, if you increase the depth of cut gradually what is happening here your pure nature over the actual nature of the brittle material comes into picture, and then it will do machining at a brittle fracture. What is the brittle fracture? That means, if you hammer a glass you will never get a chip, but glass will be scattered. So, same thing is happening in this particular case.

So, once the tool is in contact, initially it is touching the surface. Then let us this is the tool travel. So, it is traveling the tool in this direction continuous. So, initially this is the depth of cut depth of cut is very, very high. So, your force is increased and along with that it is moving in this direction. So, it is removing this much amount of material. So now, if this is the situation you are getting a off time; that means, you are not in contact with the surface tool is not in contact with the surface. So, this is the noncontact non contact region. So, your tool has removed this much amount of material it is coupe out this material. And then tool is coming into contact this. So, after off time again you will get the same peak and the same fashion of this particular first train and again you are getting this removal.

So now what is the important thing? That when you are cutting a brittle material your depth of cut is very small, then you are able to remove the material in the ducktail mode

and you can get easily chip. And if your depth of cut is very, very large there are 2 things happening one is the tool will get damage tool damage. And another thing is your workpiece is also degraded, quality of workpiece surface is down. So, this thing is more important in the precision machine, where we will covered the diamond turning operation, where our depth of cut is in a one micron or less than one micron and your cutting the silicon and some type of brittle material. So, here our object is that it is not always necessary to maintain or go with the higher depth of cut. Because we have seen in the earlier example, that your on cut chip thickness should be higher than the cutting edge radius.

So, here also it is the same thing, but here that ratio is very, very large in this case. Because you have penetrated your tool, such a large extent that your material property is playing important role, on the negative side because now your depth of cut is very, very large force fluctuation is very large, your stability of the tool is also questionable. So, this old thing will end up with the low quality of the surface as well as damage or the breakage of the tool.

So, let me finish this lecture here we will continue this topic in the next class.

Thank you very much.