Introduction to Mechanical Micro Machining
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Lecture - 15
Difference between macro and micro machining (Contd.)

Hello everyone and welcome to our course on Introduction to Micro Machining Processes.

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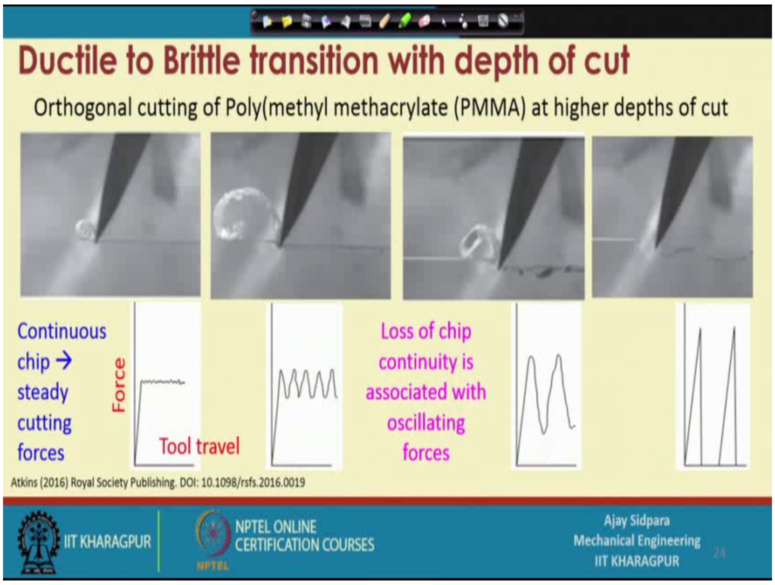

In the last class we have seen one example where depth of cut is playing important role in the cutting of a brittle material and we have seen that how this signature can be captured by means of measurement of forces. Because we are not able to get the visual information of this particular cutting operation throughout the machining. This is what we have seen here it is a high speed camera picture and that is many times difficult to incorporate in the actual machining or the production. This is for the research purpose we can get this information. But actual thing what we can get in practical situation is the force signal or some other signals by which you can man monitor the status of the cutting tool and the workpiece material.

So, this way we have understood that force data can be one of the important signatures of this machining operation where you can get some insight of the operation whether it is going perfectly right or there are some problems in this case. So, now, let us see what are the different mechanism by which the material is removed in a alloys.

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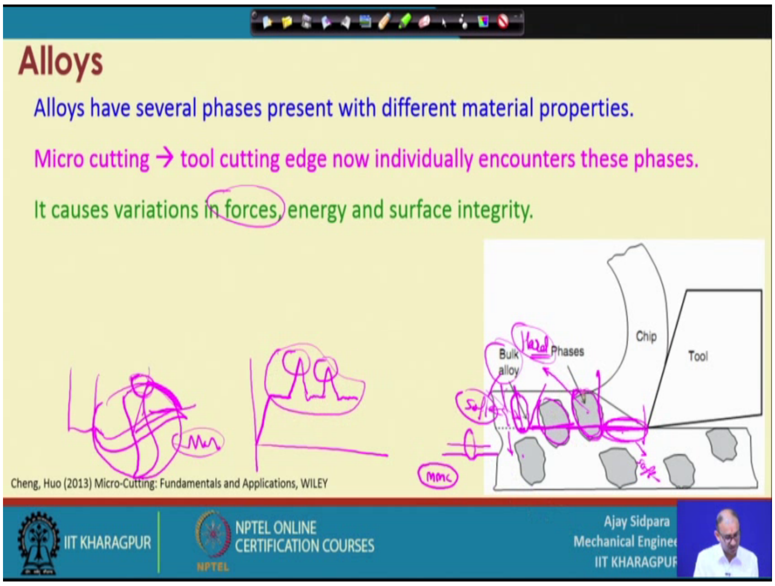

So, now if you see this is one of alloy yellow and there are two different phases available, this is the first phase and this is the bulk material. And now what happens that suppose this phase material is hard, hard and bulk material is little bit soft, now you are cutting a material this material. So, when your tool is moving in this direction, now this is the location of the soft material and then suddenly you encounter a phase of this particular alloy where the hard is the phase.

So, now when you are reaching this location at that time whatever the force signature you are getting here that will be suddenly shoot up because you are coming across this hard grain and you have to cut or you have pull out this grain. So, many times what happened that suppose the grain is located something like this that very very small amount of portion is located below this particular area and your tool is at this location.

So, at that time what time the whole grain will be pulled out because it has a high tendency to be a part of the chip compared to the part of the workpiece material. So, instead of a straight line what you will get the machine surface will be something like this and you can consider this one as a pullout. So, this will most many times happens in the metal matrix composite that is shortly called the MMC where your putting some type of metals in terms of some type of small grains or something like that this is also considered as a alloy.

So, now this is happening in this way here force variation is very very large because initially you are cutting a cutting in a soft zone suddenly hard material comes into way then again soft material then hard material and the location of this hard material also creates a different, different mechanism whether it is a what is the location how much percent is inside of this bulk material and how much is onto the chipset that is called uncut chip thickness part. So, those all things plays important role in cutting of this alloy material. So, let us go into more detail that alloys have several phases present with the different properties, different properties is mostly related to hardness and because we want to create some type of composite or some type of alloy so that we can get the different property onto the surface.

So, what happens because of that? The tool edge cutting edge now individually encounter these phases. So, this is what are these individual phases, even though it presence with the large scale what happens in the conventional machining it is very easy because many times this particular large phase will cut out through this particular boundary and that is the reason of, that is the reason that by which you can cut down this material efficiently in the conventional machining. But that is not happening in the micromachining because you even without the phase of this alloy you are end up with the machining at a different different phase because again this defect will play important role that we have discussed previously.

Now, what happens because of the it prior creates a problem with the forces now variation and will be very very high in the forces and again there is energy and the surface integrity is also a problem. So, forces we have seen that whenever it is encountering a soft material a force level will be very low. So, if you cut from here to here, what is happening in this particular case that your force signal will start from 0 then it will stabilize little bit because it is cutting this particular part. Then it will certainly rise it here because you are cutting this part again then again it will reach to this location because this particular thing will again at this location then again this part rise and something like this So, whenever you are getting this particular peaks you can understand that how many times you have your tool has passed through this grains of the different phases of the hard material.

So, this signatures are important to understand only thing that we should analyze this signal correctly because this is not the only signature by which you are getting this signal there may be something like that. Suppose you have end mill cutter and it has a 4 edge suppose consider right and after sometimes what happen there some one of the edges broken that you are not able to do any cutting. So, when it rotates at that time what will happen that it will create a one signal and when this particular edge will not give any signal because it is already broken, so you will not get the signal and then you are getting three peaks continuously because in this particular 360 you have one angle where the material is not present that mean these particular location or this particular angle will not remove any material because edge is not present there. So, in this case you also get the signal, but this is in terms of a single point cutting tool or we consider the only single edge is cutting the material. Then you can confidently tell that this is what is happening in this particular case.

Now coming to the energy because now energy also playing because when your cutting a material through the soft material you do not need a very very high power or the spindle or something, but suddenly it encount this grain then you have to supply more current to the spindle so that it can overcome the resistance of this what hard material and that is the reason your energy variation will be also large. Again soft material you do not need so much of energy again hard material.

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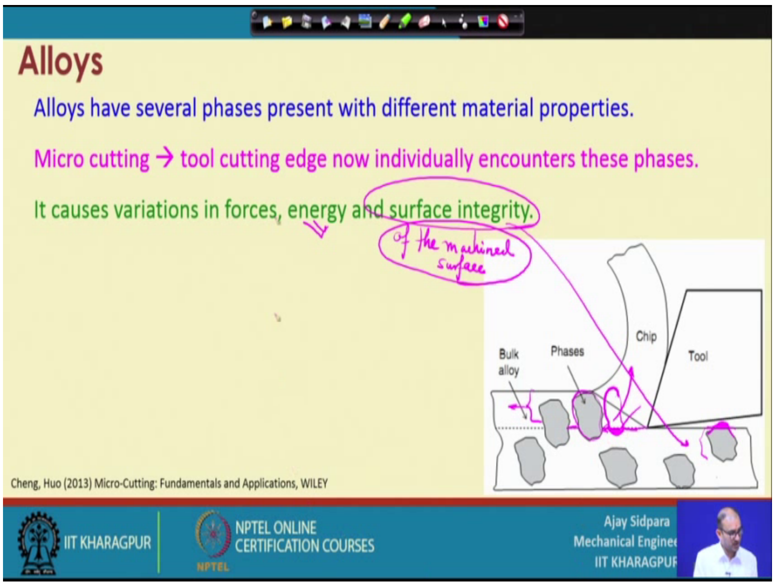

Surface integrated term is connected with the machine surface, integrity of the machined surface because what we are getting here that is important here. Sometime now you can see here that this particular grain is mostly located inside the grain. So, there is a high chance that this is particular thing is this much. So, this particular part is removed by the cutting tool.

Now consider this thing in particular now note this, but, let us consider this is the grain. Now, it is exactly opposite to this that only small portion is located inside the workpiece only inside the machining zone region, but most of the thing is within the uncut chip thickness. So, when these particular things will encounter then all this grain will go out. So, instead of flat surface you are end up with the scope or the cavity. So, this is what is happening in this case right.

Coming to anisotropic material.

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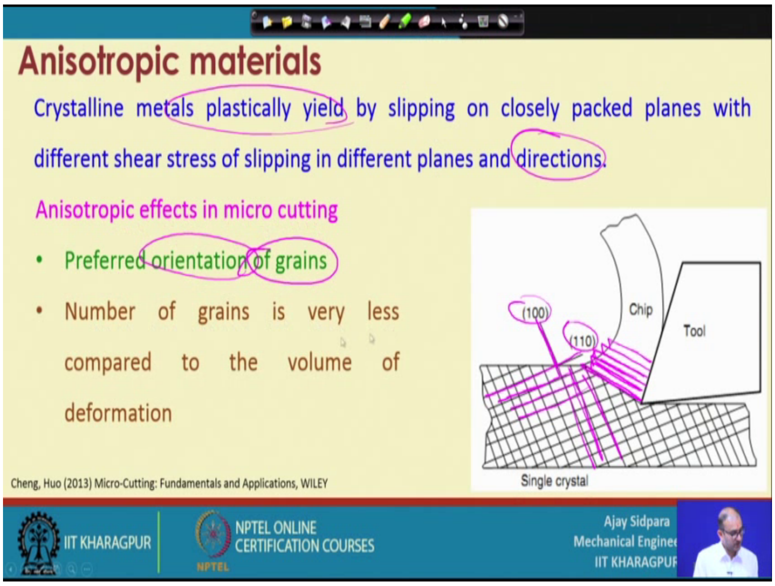

Now, anisotropic material means the properties are different in the different direction. So, if you have plane xyz plane your material will behave differently in different directs that mean hardness are different and some other properties are also different. So, let us consider this as single crystal. So, this is the 100 plane this is 110 plane and this is the tool and this is the cutting.

So, in crystalline material what happened the plastically yield by the slipping on closely packed plans with different shear stress on slipping on a different planes and directions. So, these are the, this is our shear plane angle and these are the different planes this is the plane and this is also a plane right. So, crystalline metals plastically yield by slipping on closely packed plane with shear stress of slipping in different plane and direction. So, we have different plane. So, these are the two different plan let us take these two different plane and different directions, because the different plants have different want this 100 plan has this direction and this 110 plan has this direction. So, when your tool is cutting this material now what will happen that we have seen that this, particular chips are something like this right. So, these are the step card of the uncut chip thickness and then it will remove as a chip.

So, wherever this is happening, these are the different different slipping plants. So, if it encounters this thing at that time you plastic if this whole material will yield plastically in this particular different direction and the different plane. So, anisotropic if I can micro cutting, now, this we consider is a macro machining conventional machining, but if you scale down the machining operation what is going to happen the preferred orientation of the grains.

Now, even if you cut the isotropic material now in isotropic material also we have seen that we are encountering individual grains. So, we have to also look into the what is the orientation of those grains. So, if you are cutting whether anisotropic material or isotropic material you have to understand that what is the orientation whether how much is projected about this line of the cut uncut chip thickness, how much it is penetrated inside that that will be decided by whether your too will cut the material or it will all the material will be scooped out along with the chip.

So, this is one of the material properties that preferred orientation of the grain is important to understand in the anisotropic effect of the cutting tool then the number of grain is very less compared to the volume of the deformation.

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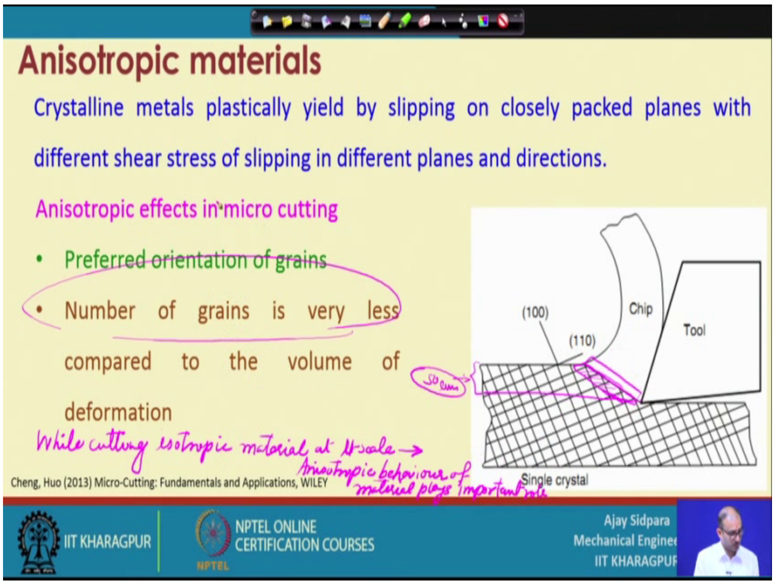

Now if you see this particular thing, this is the deformation zone and let us put this whole plan as a CR band and this particular def talker let us consider as a 50 micron right. So, when you are deforming something a very very small scale your end up with a very well less number of grains. So, that is what is number of grains are very very less compared to the volume of the deformation.

So, this is the volume of the deformation you can actually count also very how many number of grains are available. So, there creates a problem, even if you cut while cutting, while cutting isotropic material at micro scale anisotropic behavior of material plays important role right. So, this example we have taken for the conventional machining, but if you scale down the machining or the micro cutting in such a way that you are encountering individual grain. So, whether you cut isotropic material or the anisotropic material you have to consider these two things and when you are talking about these two things you are actually looking at to the anisotropic material. So, this is what happens when you cut a material at the micro scale.

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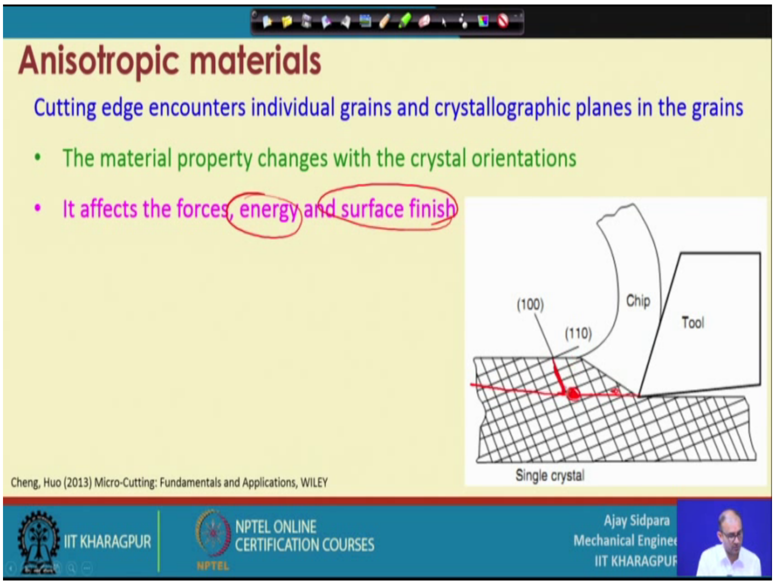

So, what happens in this case the cutting edge encounters individual grains and crystallographic plane in the direction. So, we know the individual grain we have seen in the last two slide and over crystallographic planes. So, these are the crystallographic planes. So, this is the one plane, this is the 100 plane and this is the 110 and 100 plane. So, individual grain and crystallographic orientation will encounter during the cutting operation. So, what happen that material property changes with the crystal orientation that we will see in the next slide that if we takes the one example of silicon what is going to happen with these. So, now each plain has different different properties. So, we have to find out which one is this particular phase is hard whether this is hard phase hard or soft or this is soft or hard, which one which phase is hard.

So, if you consider this is the cutting direction and suppose these phase is soft; that means, this is the soft material alright. So, this let us write this one is a soft and this one is a hard right. So, the material is weak in this direction correct and it is very very hard or it is very strong in this direction. So, when your tool is moving in this direction what is going to happen your chances are very very high that the material will be removed in this fashion.

So, this whole thing will come out as a chip, instead of coming out like in this direction because this plane is very very hard in this case. So, your material removal is a different in different different plane direction and that again affect the force is energy in the surface plane is because you are tool is at one particular depth the depth will not change with respect during machining operation. So, what is coming across it that plays important role, when it is coming like this in this direction now you can see that this grain has to be cut out this grain also here you are getting the point. So, it is very easy to cut it out in this direction, but many times it will not happen these thing. So, the you how to cut this grain again the orientation of this grain played important role that we have seen and then if you continue in this direction many times you can come across this grain boundary, but many times you may not come across this also.

So, energy also require high because every time you are encountering hard phase and the soft phase that is not because of the alloy, but because of the anisotropic nature of the material. And the surface finish is also different because when the hard phase is removed you may not get the exactly surface requirement as per your desired value, but you can get the something different than other than and the how to do some type of post polishing or post finishing operations. So, now, let us take one example of silicon that what happens in silicon.

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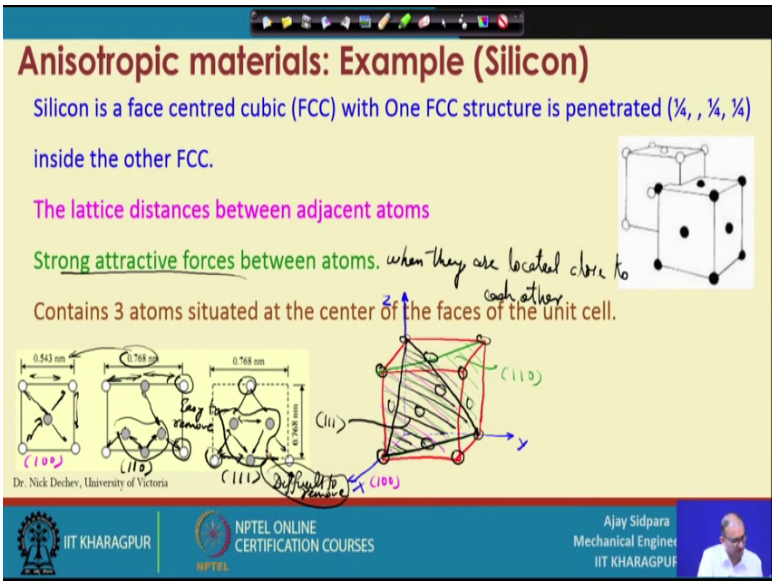

The silicon is a phase centered cubic with one FCC structure is permitted to the 25 percent in all 3 direction inside the other FCCs. So, these are the two FCC structure FCC means phase centered cubic where one atom is located at the centre of the each phase and other force are located at the corner.

So, this is the first FCC is second FCC it is penetrating with the one-fourth, one-fourth in all the three directions. So, basically we consider in ideal situation that it is a FCC structure of the silicon. So, what is happening in this case? Now let us do this whole thing here. So, this is let us consider as a block, this is considered as a X direction, this is Y direction and this is Z direction. Now, if you cut from this 11 plan. So, now, what happened the let us give the name of name also in the different different plane this is this thing.

So, now this one is called this one particular plane. So, this is the plane. So, this plane is in the X direction only. So, this plane is called 100 plan because this plane is not cutting X and Y or not contacting Z and Y and Z plan. So, this is called 100 plane. So, this is called 100 plan and we have seen here also that how many atoms are locate. So, atoms are locate at 1 2, one at the centre and other force at this location. So, these are the atoms this without any color in the circle this at the corner and whatever is the color at the centre grey color this is the at the centre part. So, this is 100 plane.

Now, coming to another one, a green color, if you consider this plan correct so this is cutting in both direction in X direction, one is in Y direction. So, this particular plan is called 110 plan, but it is not cutting the Y because it is parallel to the Y. So, this is 110 plan. So, when it is cutting this thing. So, we know that each and every phases 5 atoms. So, here also it is one it at the centre here also located one is at the centre here also at the centre here also at the centre and all the other phase also let us put one thing at the centre.

So, when you are cutting this particular plan. So, now, you can consider one two three and a 1 2 3 4, 4 are coming into from the corner part and 2 are from these parts, one is from the bottom and one is from the top and these are the two things which are inside because this is penetrated inside of this 25 percent from all the direction. So, it may cross this particular thing also. So, this is about the 110 plan and what is this 111 plan. So, 111 plan is this plan. So, now, let us consider your plan is cutting all these three. So, this is called this is called 111 plan.

So, now your plan is passing through all this three direction X Y and Z. Now let us see the how many things it has cut down. So, one two three are located at the corner it is coming in its way it is cutting from the bottom also, so it is coming from here that is coming from here and from the centre part it will come out with the two more from the central part, because of this penetration. So, now, this is the distance between the atoms in this direction. What is happening? Now, let me write this thing also first. So, this is 111 plane

So, now how to understand that how properties are different in different direction now that depends on how many atoms are located on a particular plane and what is the distance between those planes distance between those atoms. So, now, here let us distance between the edges and atom is important. So, this is the distance here in this case it is distance and; that means, how far this is from this distance and this is also what is the distance correct. So, that is the first thing strong attractive force between the atoms. So, if atoms are located very close to each other they are strong, strong attractive force is that means, when they are located close to each other that is that thing.

And then this is in this case. So, now, if you see this diagram the first one that is a 100 plane if you see this just a minute, the distance is very very large here, but if you see here this particular distance the distance between the two atoms is half of this part, so it is obviously, smaller than this part and then these atoms are also in its phase. So, distance are very very small again and this distance are; obviously, same in this case, but this distance are very very small.

Now, coming to the third one again the lengthwise it is same in this case, but now see this distance is very very large, but this distance are very very equal in all the cases. Apart from this thing what is another important thing here that it contains three atoms situated at the centre. So, now, if you see here, these are this 3 atoms which are located at the centre phase of the unit cell. So, what happened that if the atom is inside the material it is very difficult to break or difficult to disclose from that the side atoms are very easy to remove. So, whatever those things are located here these atoms, these are easy to remove and whatever this located this one and this one these are difficult to remove that is by itching or by sometimes a machining operation that is what is happening. So, here what is happening. So, this one is the weakest one. So, let me remove all this things.

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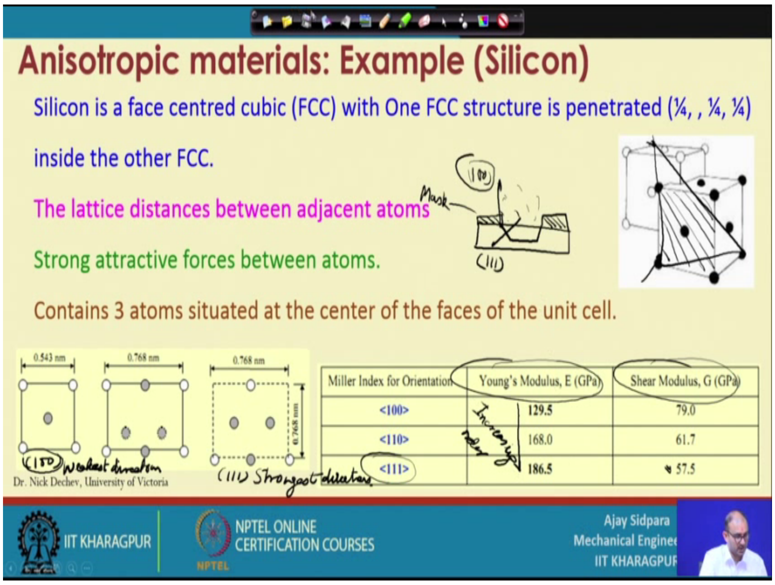

So, 100 is the weakest direction and this one is the strongest one strongest direction. That means it oppose or it will actually give the more resistance to the material removal mechanism by itching or by mechanical machining also.

So, how these things are different. So, let us see the properties. So, these are the properties. So, this is the miller indices. So, this is in miller indice is one of the ways of identifying that which what is this plan, but that we will not discussing here, but we consider 100 plant; that means, the phase along the X direction, but parallel to the X and Y it is not crossing X and Y. 100 that means, it is crossing X and Y, but parallel to the Z and one 0 111; that means, it is crossing all the three direction.

Now, if you see the Young's modulus it is one almost 130 E GPa in X direction, but if you see in this case it is very very high in this case increasing order and Shear modulus is also very very low in this case. So, Shear modulus; that means, your Young's modulus is very very high, but Shear modulus is low. So, in that case you are end up with more stronger location in the 111 plane.

So, what is happening in this 111 plane now you consider that your machining a silicon in this particular direction 100 plane because whole structure is coming on its way. So, if your phase is this one your tour will smoothly pass through this particular phase, but if you are oriented in such a way that you are end up with this particular location that is the 111 plane then removal is very very difficult in this case. But silicon is mostly micro electromechanical system related operation mostly it is processor or machine by itching process. So, you put the itching inside of that and put the silicon vapor in that and then you provided itching solution. So, it is something like that suppose this is the silicon and this is the mask because you do not want to cut the whole material.

So, this is called mask and then you provide a itch and on this surface. So, this each end will cut down this material this is the material and what is happening here that this is you consider 111 100 plane. So, it is cutting very easily, but whenever it is reaching this particular location then it is creating always some angle. So, this particular plan is the 111 plane. So, for machining and itching in this 100 plan is very easy, but cutting through this direction is very difficult in this case. So, this is one of the examples through which we can understand how many anisotropic material will behave in a different fashion compared to the isometric materials.

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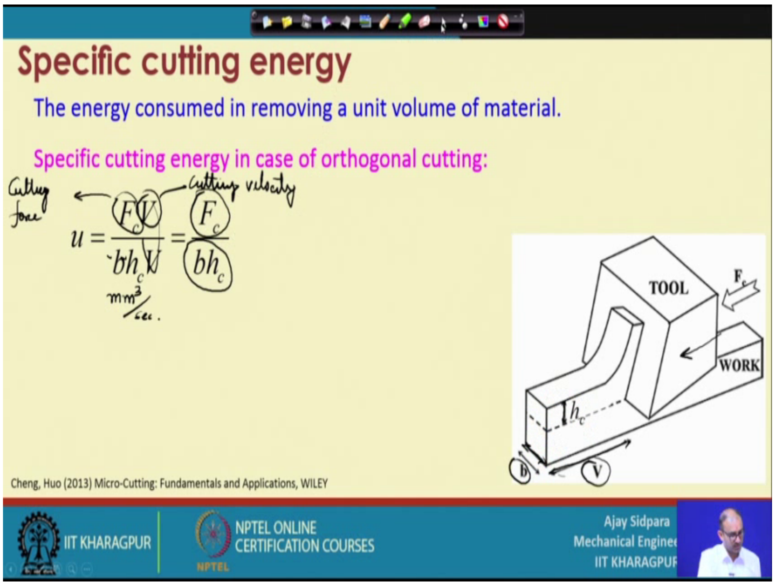

So, what is the specific cutting energy, that let us now see that how much energy we have to spend in cutting the material. So, this is defined as the energy consumed in removing a unit volume of the material. So, let us take this example of orthogonal cutting. So, your tool is moving in this direction, and let us consider the width of the tool is higher than the cut. So, your this V is the width of the cut h c is our uncut chip thickness and this is the V that is the total part of this part volume of this part. So, you are moving in this direction let us consider this is the V is the velocity. So, now, this is the part, so what is the equation for specific cutting energy in the orthogonal cutting this is what we are getting. So, that is the amount of power or amount of energy required to remove a unit material right.

So, this is the, F c is the cutting force this is the cutting velocity and this is the bh through this whole thing will come in terms of the millimeter q by second or minute with the right term let us put the second. So, this is in millimeter, this is millimeter, this is millimeter by second, millimeter per second any value. So, this is (Refer Time: 29:29), V V will get cancelled and then you are end up with the F c divided by b into h c. So, where it depends Z depends on what is the depth of cut, how much is the width, so obviously, it will cover the area of this part and then how much is the cutting force in this case.

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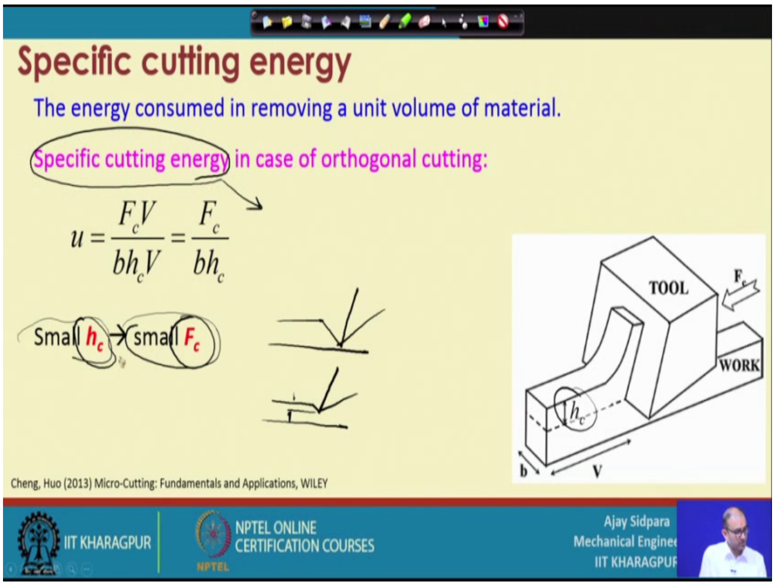

So, now, if you see this example very clearly what is happening that if you would reduce the uncut chip thickness; that means, if you reduce the cutting depth of cut then obviously, your force will be very very small correct. Because here we want to remove a small material suppose this is the depth of cut and now this is the depth of cut. So, in this case because of smaller you give depth of cut; obviously, your force is small. So, that is what is in normal machining operation. But in the actual work conventional machining process is we know that our h c is not very very small in this that is h c is very very small, but our force is a very very large because we have seen that specific cutting energy is very very high in grinding, but that is not the case in the machining part.

So, in the next class what we will see that how these things is happening that how the specific cutting energy is very very large when you cut a material at the microscale. So, let us finish this lecture here. We will continue this topic in the next class.

Thank you very much. Thank you.