Project of Materials (Nature and Properties of Materials: III)

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Lecture 22

Resolved Shear Stress

So, welcome again to the new lecture of the course, Properties of Materials. Let us briefly rewind what we did in the last class.

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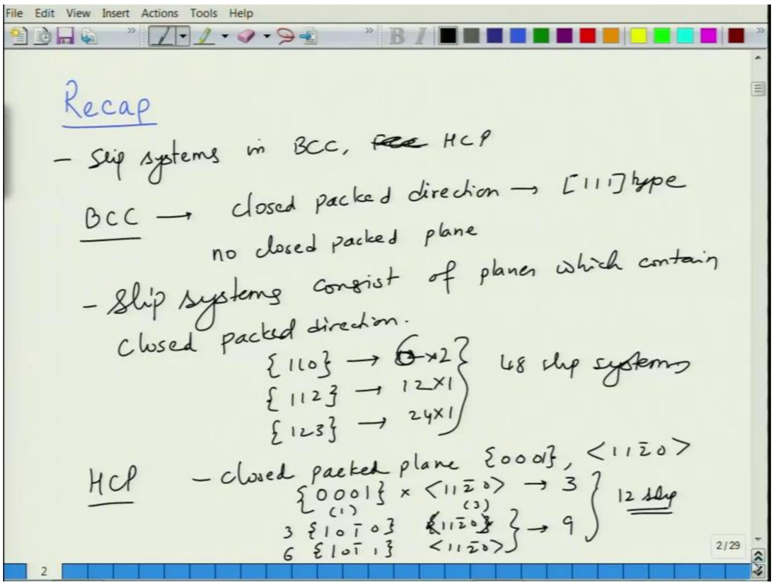

In the last lecture, we looked at, we worked out the slip systems in BCC, HCP materials. So, in BCC we saw, it has a closed packed directions of 1 1 1 type. But there is no closed packed plane. So, in this case, the slip systems which work are those slip systems. So, slip systems consists of planes which contain closed packed directions.

So, as a result, the slip systems are, so 1 1 1 direction is contained by 1 1 0 type of planes. So, 12 of them. Then we have 1 1 2 type of planes. Another 12 of them and then we have 1 2 3 type of planes which are 24 of them. So, 6 of these planes. So, 6 planes contain 2 of those directions. These contain 1, these contain 1. So, total of 48 slip systems as against 12 in FCC. Then we have HCP system. In this case, again the closed packed plane is 0 0 0 0 1, closed packed direction is 1 1 bar 2 0. So, different brackets.

So, first combination 0 0 0 1 into 1 1 bar 2 0. This gives you 3 slip systems. There is one plane, one of these planes and 3 of these directions. So, this give you 3. But the other planes also which can contain this directions. So, the planes which contain this direction could be, I am writing down brackets again and again. So, this is 1 0 bar 1 0 plane and then we can have 1 1 1 0, 1 0 bar 1 1 1 plane.

They again contain 1 1 bar 2 0 direction and then again these give, these give rise to what we call as. So, this will, there are 6 planes of these, there are 3 planes of these, each contain 1 direction each. So, they give you another of 9 slip systems. Total of 12 slip systems we have in HCP.

However, out of these three class of materials, the most, the easiest one is FCC because FCC contains a large number of closed packed planes. So, it has very large number of active slip systems. So, it is easier deform as compare to BCC and HCP. We come to that little later. Now, let us look at the phenomena of slip in terms of what is the required stress to carry out the slip.

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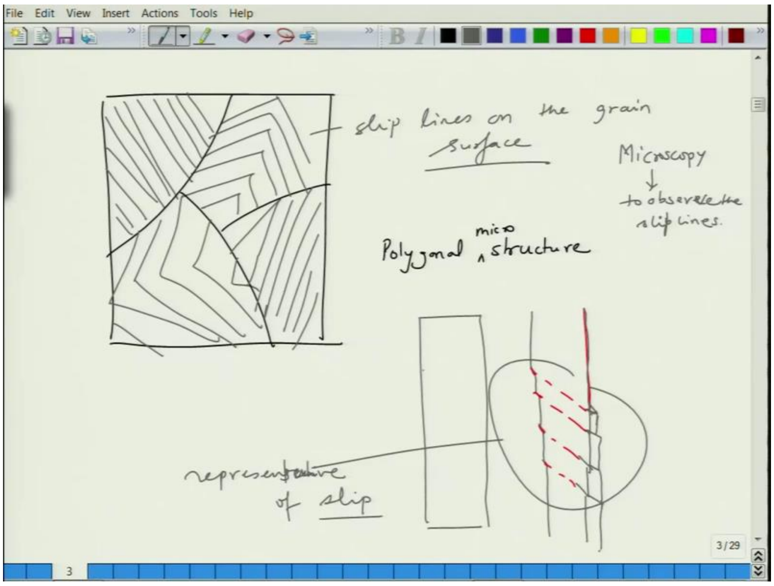

So, generally what you will see is that because of the slip system, so if you look at the polygonal structure. So, let us say, we have this polygonal structure of multiple grains. Polygonal you can say, micro structure. So, this is what you will see is that in the in these, because of the planes. So, grain has certain orientations. So, all of these grains will have certain orientation. So, you will see that slip, there will be slip lines on the surface of these crystals, which are, which appear as facets. So, they appear as sort of steps.

They can appear like this also and so on and so forth like this. So, you will appear this, you will see these slip lines on the grain surface. So, these slip lines actually are the ones which are representative of the fact that slip has happened on certain planes and those planes are of different orientation. They are oriented differently in different grains. So, since it is a polygonal structure, they also suggest that the planes are differently oriented.

They take in, they take place along different directions on different planes in different grains. So, now and if you just carry out the single crystal, the single crystal, let us say, if you take you a single crystal wire and if you look at it microscopically, microscopically speaking, the slip the surface looks like this.

So, you see these kind of terraces, the steps. So, this is, these are the steps. So, you have one slip plane, you have another slip plane, you have another slip plane, you have another slip plane and similarly, if you go to other side, you will see essentially this side will be more, something like that. So, we will see these steps on the surface. So, these steps basically are representative of the fact. So (())(6:26), so these steps from the surface, they are representative of, representative of slip.

So, basically and this can be examined microscopically, experimentally one can see the slip line from the surface using microscopy. So, how you can examine this is using microscopy to observe slip lines. So, these slip lines can be microscopically observed and now the question is if you have this kind of uniaxial deformation, can we calculate the stress that is required to take place the, to make the slip occur.

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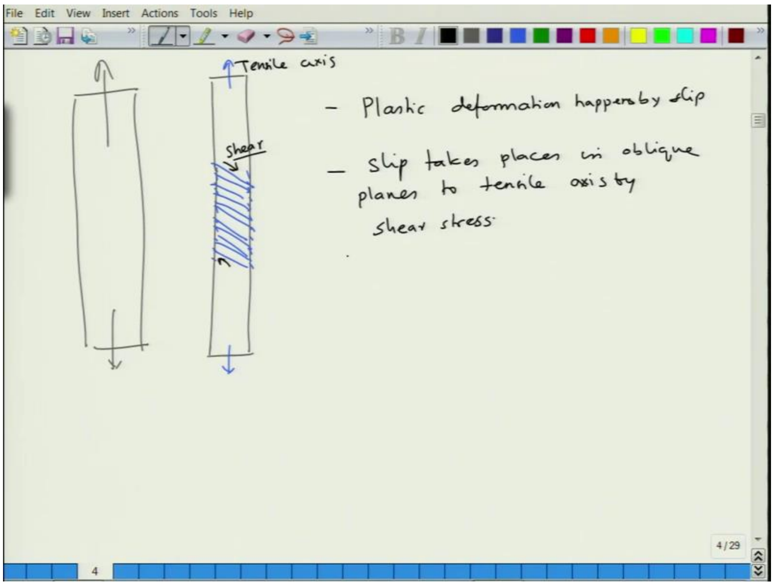

So, essentially you can see that you have a wire like this and as you start deforming, the wire surface will show these, it will get longer and it will show these kind of steps on the surface. So, all tough you are applying the stress along this axis, the movement of planes is happening in this direction. So, which means, there is a shear component that is acting. So, plastic deformation as we are saying happens by slip.

This slip requires stresses in these planes which are of shear in nature. So, this is your tensile axis. But for atoms to move in these planes, what you have is a shear component. So, essentially the slip takes place in oblique planes to tensile axis by shear, by shear stress. So, the question is, how does the deformation takes place in a tensile test?

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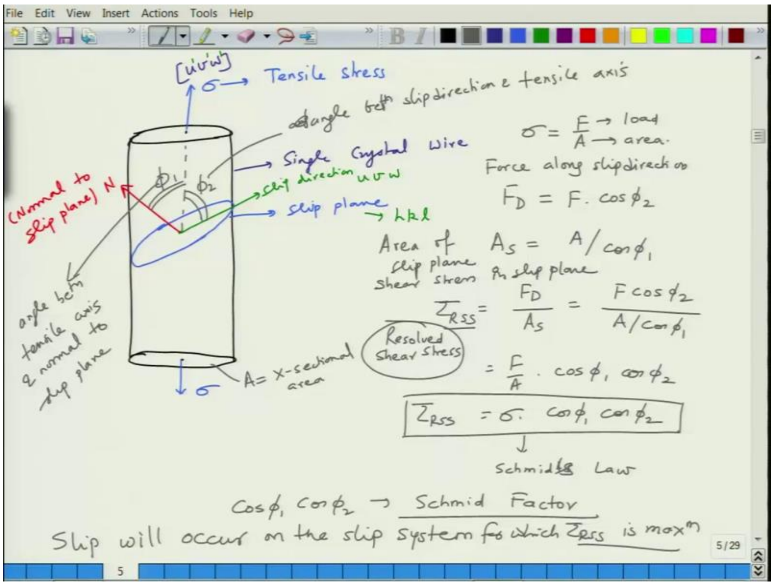

So, this is, this is what you have, you have a material whose schematic, let say a wire. A wire with across certain, certain cross section and this wire is subjected to a tensile stress. So, this is sigma, this is sigma. So, this is tensile stress that is applied to the wire. In this wire, it has certain orientation. Let say, u v w. Let us say this is a single crystal wire. So, this is single crystal wire, let say it has a slip plane which is oriented like this.

So, this is a slip plane that is there. This is the slip plane. In this slip plane, we have a slip direction. Let us say this is the slip direction which lies in this plane. So, I can say this is u prime v prime w prime. This is u v w and this is the slip plane h k l. So and this is the let say normal to slip plane. So, this is normal to slip plane. So, here we are interested in 2 angles.

The first angle is this phi 2 which is the angle between slip direction and tensile axis and then we have another angle phi 1 which is the angle between tensile axis and normal to slip plane. Now, phi 1 plus phi 2 can under special circumstances can be 90 degree but they do not necessarily have to be 90 degree. They can be different than 90 degrees. So, the question is when you apply this tensile stress we want to work out what is the shear stress on the slip plane, the slip direction due to this applied stress.

So sigma, let us say the cross section area is A. So, sigma is equal to load divided by area. So, this is load, this is area. So, now force along the direction of slip direction can be calculated as, so this is the angle, along the slip direction. So, force along slip direction, just do the force balance. It is FD and FD can be given as F into cos of phi 2 and if I look at the area of slip plane by geometry. So, area of slip plane and area of slip plane by geometry will be A divided by cos of phi 1.

So, if that is a case then, the shear that is resolved stress, the resolved shear stress will be equal to force along the slip direction. So, this is the shear stress within the plane. So, shear stress in slip plane, this is equal to force along the direction of slip divided by area of the slip plane and this is F of cos phi 2 divided by A divided by cos phi 1. So, this will be F divided by A into cos phi 1 into cos phi 2 or it will be sigma into cos phi 1 cos phi 2.

This is the resolve shear stress that is in a slip plane when a tensile stress, is applied to the wire. So, this is called as Schmidt law, Schmidt's law and cos phi 1, cos phi 2 is called as Schmidt factor and the shear and so basically you can see that whenever, whenever your cos phi 1 cos phi 2 is highest, for a, for a given slip for. So, you may have multiple slip systems. The slip will start on that slip system on which the resolved stress magnitude will be highest.

So, slip will occur on the slip system for which tau RSS is maximum. So, this RSS is basically resolved shear stress and different slip systems will have different orientations. So, you will have to calculate phi 1 and phi 2.

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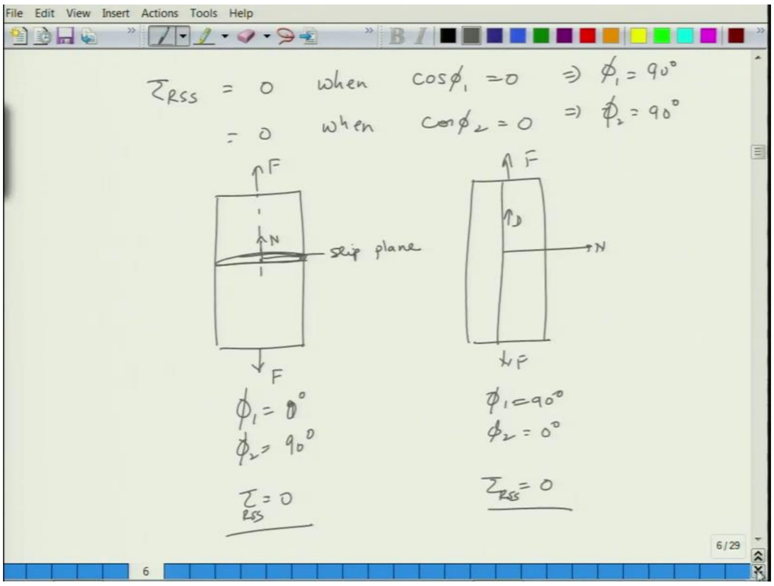

So, one thing you can see very clearly, the tau RSS of course will be 0 when cos phi 1 is equal to 0. It is also 0 when cos phi 2 is equal to 0, which means phi 1 is equal to 90 degree or phi 2 is equal to 90 degree. So, basically when you apply a load, if you have a parallel slip plane if you have a perpendicular slip plane which means, so this is slip plane.

This is the normal, this is the F for force. So, the angle between force and the normal which was angle phi 1, which means phi 1 is equal to 90, 0 degree and phi 2 is the slip direction is 90 degree. So, this will lead to tau being 90. So, if your plane is perpendicular, there is no slip. Another thing that you can see is that, if your plane is parallel, if your plane is like this, then of course you can see this is normal, this is D.

So, in this case, phi 1 is 90 degree, but phi 2 is 0 degree, so again the tau RSS is equal to 0. So, these are the two configurations when slip will not occur because there is no resolved stress on these, any of these 2 planes. But you can do calculations otherwise.

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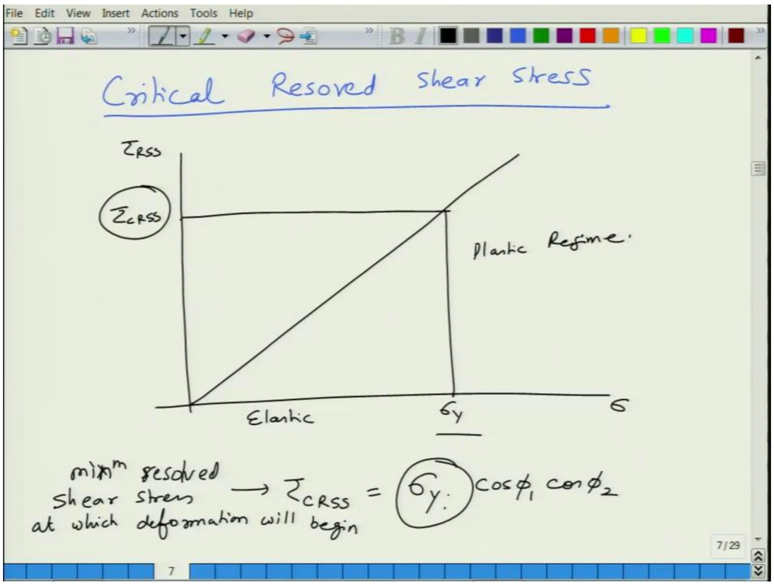

And what you can see is that, this resolved shear stress gives rise to a concept of what we called as Critical Resolved Shear Stress and basically what it means is that, if you plot tau RSS as a function of sigma and sigma keeps increasing.

So, deformation will occur only when the resolved shear stress reaches to a stress which is corresponding to the yield stress. So, this is tau CRSS. So, this is, so when the when the resolved shear stress is such that your, the value of resolved shear stress is lower than the corresponding yield stress then, you are in elastic regime and after that you are in plastic regime.

So, the moment your resolved shear stress increases sigma y, you start deforming. So, basically your resolve shear stress has to exceed this value, corresponding to sigma y which is called as critical resolved shear stress, CRSS. So, RSS has to exceed CRSS for plastic deforming to occur and this RSS will be different on different planes. On certain planes it may be lower than CRSS, on certain other planes, it will be higher than CRSS.

So, basically you can say tau CRSS is given as, so the sigma become sigma y into cos phi 1 cos phi 2. So, this is the yield stress which you have to insert there. So, minimum, so essentially critical resolved shear stress is the minimum value of resolved shear stress.

So, we can say minimum resolved shear stress at which deformation will begin. If CRSS is, if the resolved shear stress is less than tau CRSS corresponding to yield stress, you will be in elastic region. You will not have any defamation what so ever.

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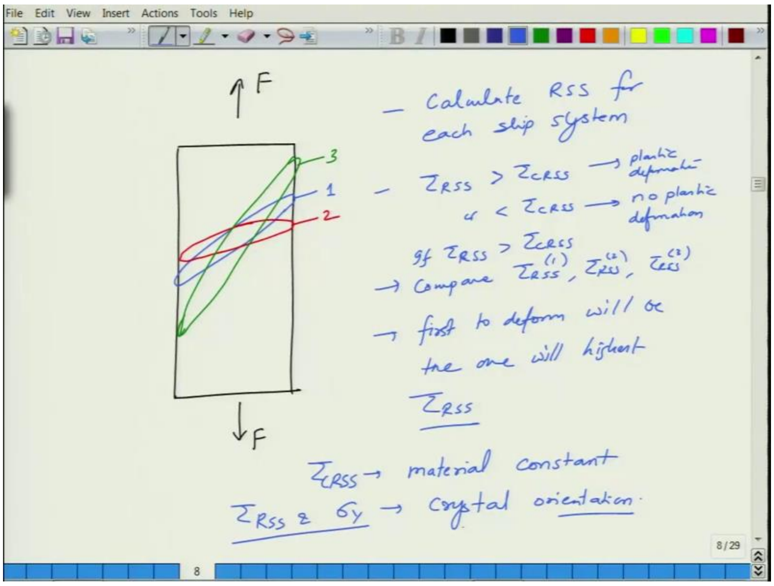

So, if we, you can see that now if you have a configuration like this, then, you have a force in this direction like this. So, you may have one slip system which is oriented in this fashion, you may have another slip system which is oriented in another slip this fashion, you may have this slip system which is oriented in this fashion, so, these are different slip systems.

So, this is 3. This is 2. This is 1. So, what you got to do is that, you need to calculate the resolved shear stress for each of them. So, calculate resolved shear stress for each slip system. Then see whether tau RSS is higher than, is higher than tau CRSS or lower than tau CRSS for each of them.

So, obviously if it is lower than tau CRSS, then no plastic deformation at all. If it is higher than plastic deformation then, tau CRSS, then plastic deformation will be possible. Then you compare if tau RSS is bigger than tau CRSS then compare tau RSS for one plane, tau RSS for second plane and tau RSS for third plane.

First to deform will be, the one will highest tau RSS. So, basically you can say in this context tau CRSS is a materials constant, provided phi 1 and phi 2 value are constant. However, tau RSS and tau RSS and sigma y will depend upon crystal orientation. So, for a given value of sigma y, you can achieve tau CRSS if you change hi 1 and phi 2. So, or if you change phi 1 and phi 2 then, sigma y will have to change to give you tau CRSS. So, tau CRSS is a material constant. Tau RSS and sigma y will depend upon the crystal orientation.

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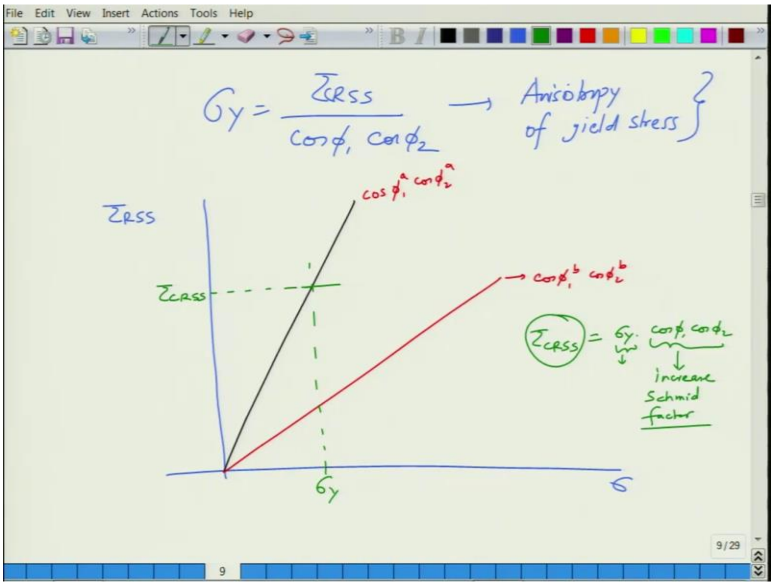

So, this basically gives you what we call as so, sigma y is equal to tau RSS divided by CRSS divided by cos phi 1 cos phi 2. So, this gives you basically anisotropy of yield stress and we know since stress is a, stress (())(22:32) deform is a, is a tensor. So, different grains will have different stress values. So, yield stress of a single crystal will depend upon the direction of the applied load or the orientation of crystal with respect to the load applied. So, let us say, you have a situation like this in which you make a plot of tau RSS as a function of stress and we see that we have two possible situations.

One is this, we use a different colour. One is this. Second is that. So, this is for cos phi 1 a cos phi 2 a. This is for cos phi 1 b cos phi 2 b. So, here we can see that, this is we can see if you compare the compare the two, then if this is the sigma y. Then, this is tau CRSS, so you can see that slip system with highest resolved shear stress is the, is the active slip system and this is because of Schmidt factor being the highest.

So, Schmidt factor orientation of the crystal plays a dominant role in, at what value or when the plastic deformation will so start. So, if you have a slip system, it may start deformation at lower yield stress if it is oriented appropriately. So, you have tau CRSS which is a combination of sigma y cos phi 1 into cos phi 2.

So, you want to achieve this value of tau CRSS. So, you can, you can keep this fixed and then increase this, so that you can achieve increase Schmidt factor. So, for a given material with similar yields stress, if your orientation of the crystal is such that, cos phi 1 cos phi 2 is maximized, you can start deforming that orientation far quickly as compared to other orientations. So, this now you can do some more exercises on this.

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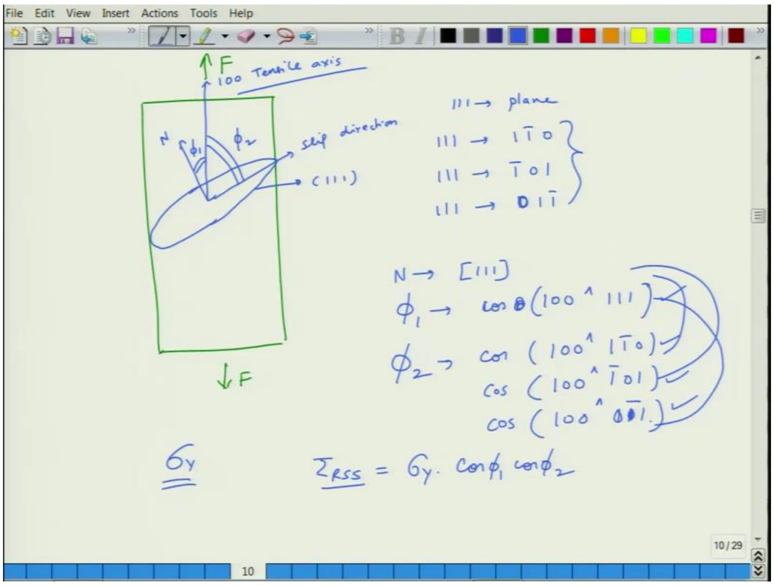

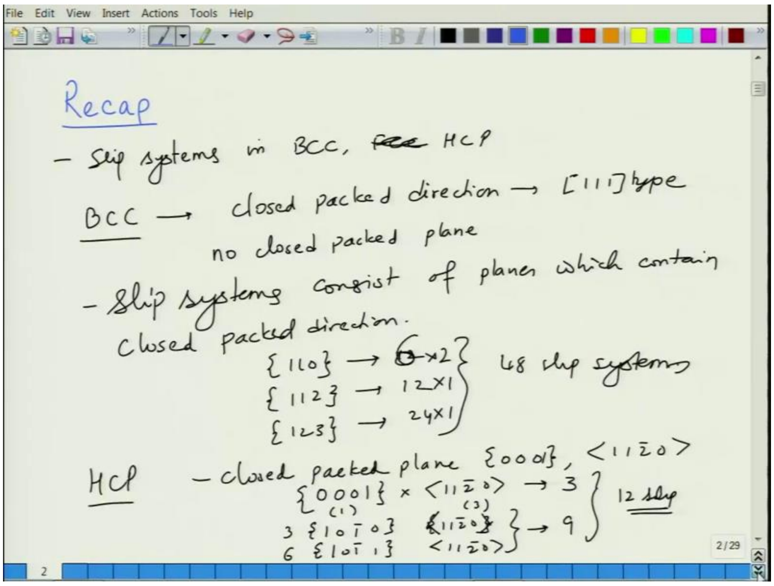

So, one can do, one can do a simple exercise. Let us say, you take this kind of orientation, F. Let us say, I take a, I take a plane which is let us say, 1 1 1 plane. In 1 1 1 plane, I have this as slip direction and let us say I have tensile axis as 1 0 0 is the tensile axis. This is slip direction and this is the normal to plane.

So, this is your phi 1 and this is your phi 2. So, 1 1 1 plane has 3 directions. So, 1 1 1 plane can have 1 direction as 1 bar 1 0. It can have another direction as bar 1 0 1 and it can have another direction as 1 0 1 bar 1. So, I will have to calculate the 3, so I have 3 directions which means I will have 3 phi 2s.

So, for each of these the slip, so the normal is along 1 1 1 direction. So, my phi 1 is fixed. Phi 1 is, phi 1 is the angle between cos of angle between 1 0 0 and 1 1 1. But phi 2 can be angle between 1 0 0 and 1 bar 1 0. It could be cos of angle between 1 0 0 and bar 1 0 1 and it could be angle between 1 0 0 and 1 0 0 1 bar 1. So, I need to find out this and I need to find out this, this and that and then I see what is tau RSS. So, if let us say, the sum sigma y for a given material or for a given orientation then sigma y into cos phi 1 into cos phi 2.

So, I can see one combination is this, second combination is this and the third combination is that and out of these 3 values, then I will make a comparison which one will start deforming first. So, we will, we will do one calculation of this in the next lecture. What we have done in this lecture is, we have just looked at the concept of resolved shear stress and see.

So, basically what we see that you have slip lines on these crystals and these slip lines are the certain angle to the tensile axis and this can be easily seen in the microscope. So, basically what we have saying is that, when you apply tensile stress, since the, since the slip direction and the slip plane is in different axis as compared to tensile axis inclined, which means there is a shear component acting.

So, what we did was, we took a model of single crystal system with a slip plane in it with respect to tensile axis and we worked out what is the resolved shear stress along that, around the slip, to along the slip direction. So, the material will deform when the resolved shear stress on a particular orientation is highest provided it is above the yield, the critical value of stress that is required deform the material. So, we will do a simple calculation in the next class. Go through this and if you have any question, you can post them on the online portal. Thank you.