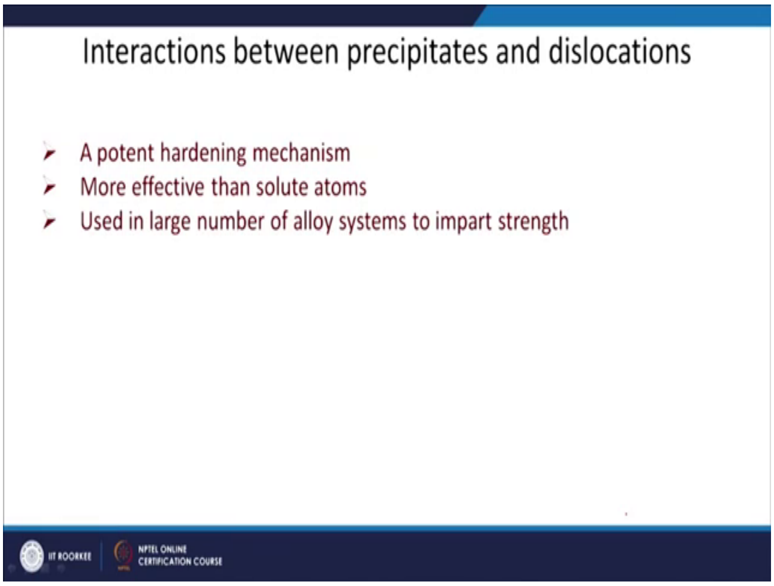
Materials Science and Engineering
Dr. Vivek Pancholi
Department of Metallurgical & Materials Engineering
Indian Institute of Technology, Roorkee

Lecture – 31
Strengthening mechanism III

Hello friends today we will start with the next strengthening mechanism ok, and that strengthening mechanism means particle or precipitation hardening. So, basically we have already seen that we, we can have a small precipitates within the grain and these precipitates can act as a barrier to the dislocation movement and that is how you can give strengthening to the material ok.

So, one of the very important mechanism for giving strength to aluminum alloys ok, and some of the super alloys which are used in high temperature applications for example, turbine blades and so on. These precipitates are very important to give strength to the material ok.

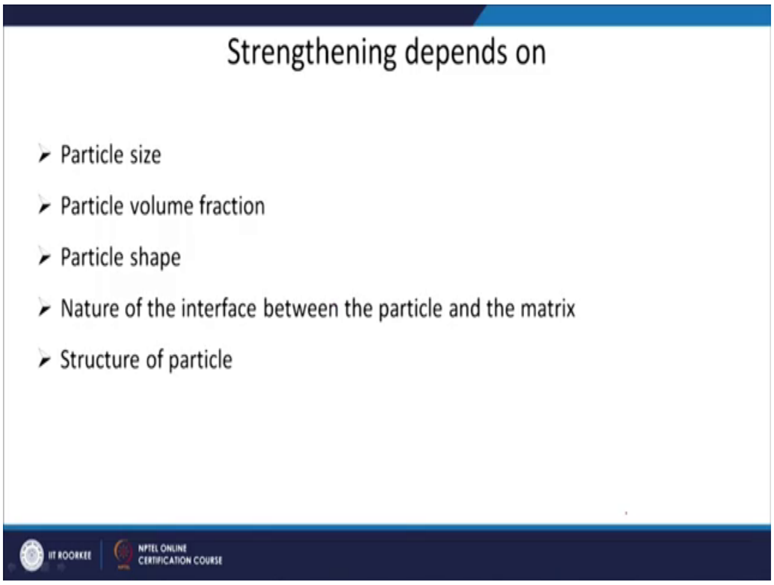
(Refer Slide Time: 01:10)



So, if we want to see the interaction between precipitates and dislocation ok, it is a very important hardening mechanism, more effective than solute atoms we have already I have already told you that a solute solution hardening or hardening because of the solute atoms is not a very strong obstacle, it is a weak obstacle because there is a very small strain field associated with solute atoms that interact with the strain field of dislocations and that is how you get the hardening ok.

So, it is not a very effective one, but if you can get precipitate in the material from the same solute atoms ok, if you can precipitate then the precipitates are very important hardening mechanism, and it is used in large number of alloy systems to impart strength as I just told you ok. So, the strengthening if you see strengthening depends on particle size, particle volume fraction particle shape ok.

(Refer Slide Time: 02:11)

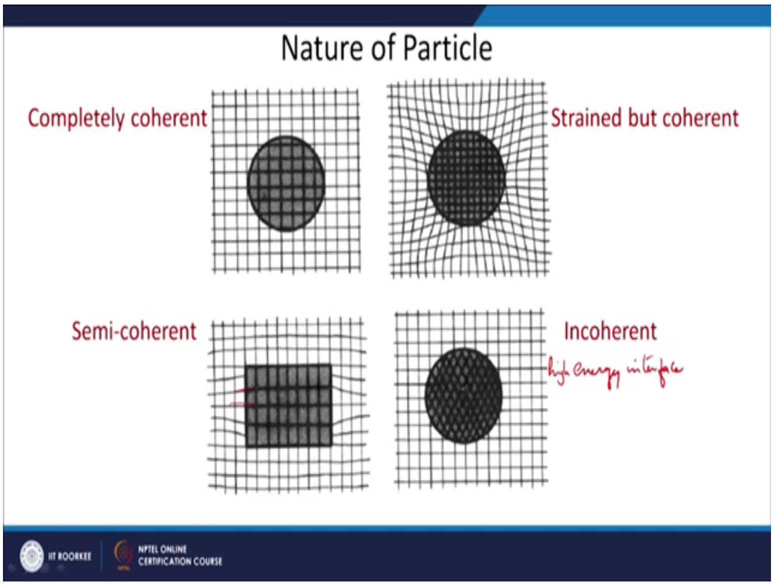


So, size of course, if it is small or big and so on, particle volume fraction means how much, how many or what is the total fraction of those precipitates with respect to the friction of the parent phase ok. So, what is the fraction of that, so more the fraction it is better particle shape if it is spherical if it is a kind of a plate kind of shape and so on.

This is one of the most important, nature of the interface between the particle and the matrix that what kind of interface is there ok. I have touched upon this particular aspect earlier also that the interface can be coherent in that case you will see that the atomic arrangement is continuous throughout from precipitate to the matrix the arrangement of atom is continuous.

And you would not see any change in the arrangement, if it is incoherent then it will be totally different the crystal structure the atomic arrangement will be totally different between the two, and what is the structure of particle crystal structure. So, if we want to see the nature of the particle as I just discussed there can be different ways in which particle can be can have interface with the matrix ok.

(Refer Slide Time: 03:36)



So for, for example, the first one the completely coherent precipitate you see this, the dark phase here is shown as a particle. So, it may be of some other solute atoms are there may be some different crystal structure is there ok.

But the important thing here is that if you see consider this the grid as the arrangement of atoms. So, this can be considered as crystallographic planes also ok. So, if you see the plane which is going in the matrix like this it is continuous in the precipitate also ok. So, that there is no break in the arrangement and it look like a continuous arrangement, only difference will be that there is a difference in the chemistry within the precipitate.

So, you may have more solute atom here less solute atom in the matrix ok. So, only difference will be the that it has different chemistry otherwise the lattice parameter and the structure is more or less same, I can have coherency, but there may be slight difference between the way the atoms are arranged in the precipitate and the matrix, though the arrangement of the atoms in the precipitate and the matrix is same, but the lattice parameter is different ok, so arrangement is same they are arranged.

Let us say if it is f c c the, so both in both it is f c c, but the lattice parameter can be slightly different. So, my precipitate can still maintain the coherency across the interface ok, but with some kind of strain ok. So, you can see that there is a strain in the matrix around the precipitate.

So, you can see in the precipitate we have made the grid finer the grid in the matrix is little bit coarse. So, lattice parameter of matrix is more lattice parameter of precipitate is less. So, you still can maintain the coherency, but you have to have some kind of strain I have to stretch the bonds and so on ok, to maintain the coherency. So, depending upon whether the precipitate is soft or the matrix is soft the strain will be accommodated in that particular phase. So, in this case we are assuming that the matrix is soft in comparison to the precipitate.

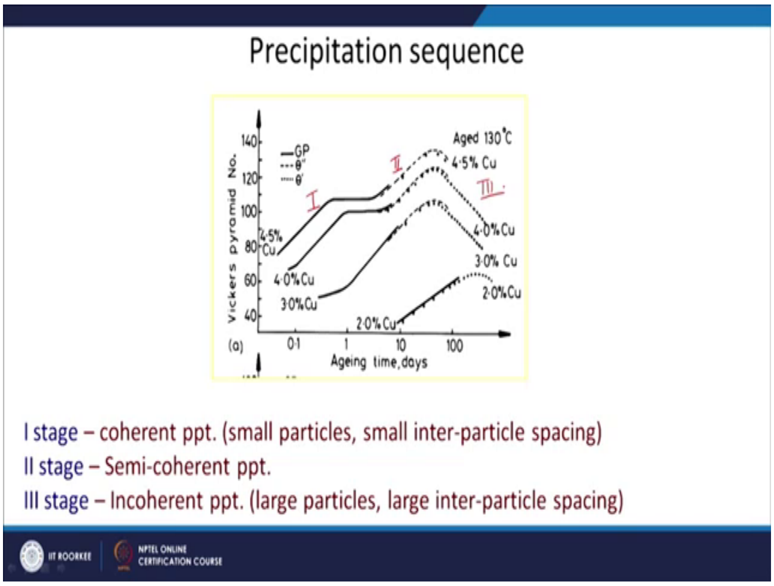
So, you can see the hole strain is accommodated by the matrix now sometime it may happen that my this material is highly strained, so it does not want to be in that strain condition. So, we can convert this kind of, situation into a semi coherent interface, where now you have a dislocation which is accommodating the strain. So, if you have too much strain what you can do you can insert an extra half plane ok, and thereby you can relieve the strain in the other atomic planes.

For example you can see here that in this there is a continuous arrangement here you have continuous arrangement here ok, but this atomic plane is not having any corresponding plane in the matrix. So, this is kind of a dislocation in the matrix which is now able to accommodate all the strain in the you can say y direction for example, if you take this as x direction. So, in y direction the arrangement is coherent ok.

But in this interface it is in semi current ok, some dislocations are there, and in case of in coherent you can see that the grids are totally different what we have the grid in the precipitate is totally different than the matrix and again you can see that it, it is trying to have a spherical shape. So, we started with the spherical shape and in coherent phase also we are trying to have a spherical shape the reason for that is that I want to reduce the interfacial area ok, or I want to minimize the total interfacial area and for the given volume we know that it is very is fair as the minimum surface.

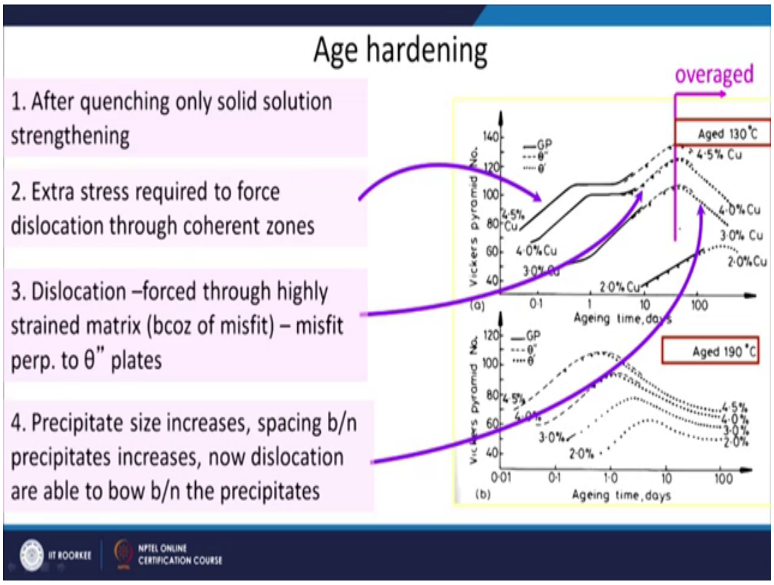
So, because in coherent when you have in coherent interfaces the energy of the interface will be very high it will be high energy interface. So, to minimize the interfacial area my precipitate would like to have a spherical shape, this is already we have seen that you can have different stages of precipitation and depending upon that you will have different hardness ok. So, coherent precipitate small particle, a small inter particle spacing ok.

(Refer Slide Time: 08:33)



So, you have numerous small g p zone and the distance between those g p zone is also very small then you can have semi coherent precipitate in the stage second ok. So, this is my stage one this is my stage second and third is in coherent precipitate large particle, large inter particle spacing. So, in this when it started coming down that is my stage three ok. So, you can have this type of stages already we have discussed about this when we were discussing about precipitation.

(Refer Slide Time: 09:08)



So, now we will also discuss in terms of that how dislocations are going to interact with the these precipitates at that time we did not talk about this ok. How now the strengthening will come in this type of precipitation ok. So, you first step is after quenching when you are doing a quenching only you have solid solution hardening; that means, all the solute is in supersaturated condition of course.

It does not want to remain in the matrix, but because we have quenched it is in that condition ok. So, in the stage one after just after quenching whatever strength you will get is only through solid solution is strengthening because all the solute is in the solution then comes the next part that you now require if extra stress required to force dislocation through a coherent zone. So, you have those g p zone which has coherent interfaces.

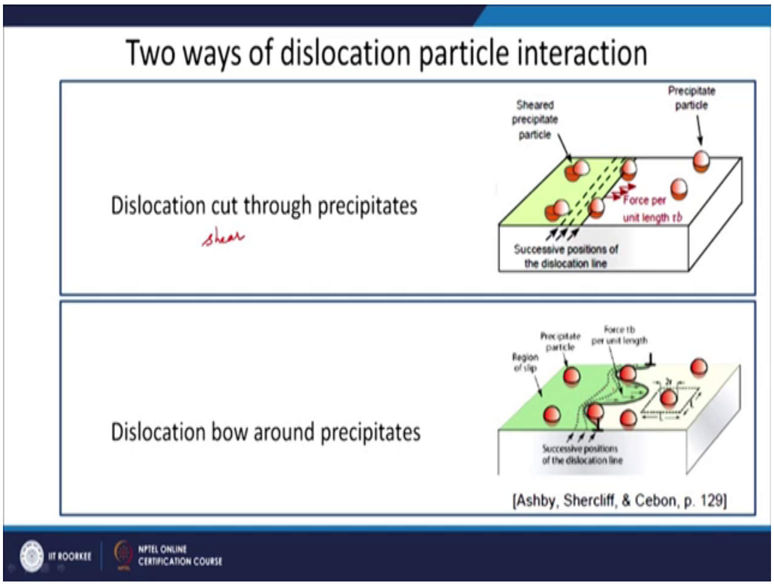
Now, my dislocation has to go suppose you are talking about aluminum and you are talking about this copper g p zones ok. So, when my dislocation is moving ok, so it has aluminum atoms. So, aluminum have its own bond energy, so when dislocation is moving it is breaking bonds and forming new bonds the in the copper where the copper reach g p zones are there the bond energy will be different. So, when it is going through this,

because of this different atmosphere it will you will need require an extra stress to move the dislocation ok, and that will be seen in the initial part of the hardening in and during aging process ok. The second third stage is when dislocation is forced through highly strained matrix because of misfit ok. So, misfit perpendicular to theta double prime plates ok. So, that is there are different type of precipitates as I told you which form during the precipitation sequence ok, so these have a semi coherent interfaces ok.

So, my dislocation has to move through this kind of a interfaces ok, so you need now extra stress to move the dislocation and that is what you can see in the hardening of this particular ageing precipitation sequence, then the precipitate size increases spacing between precipitate increases and now dislocation are able, able to bow between the precipitate ok. So, that is the stage when it started coming down, my size has increased and my inter particle distance has also increased. And so now dislocation can move by bowing between the precipitate we will see all this mechanism in the later slides.

So, these are the different interactions between the dislocation and the precipitate during the aging process ok. So, now, there are two ways in which dislocation and particle can interact.

(Refer Slide Time: 12:19)



One is dislocation cut through precipitates ok, so this is how the shearing process is there. So, cut through or you can say shear through ok, so either it can be shearing of the precipitate or you can say it is cutting through the precipitate ok.

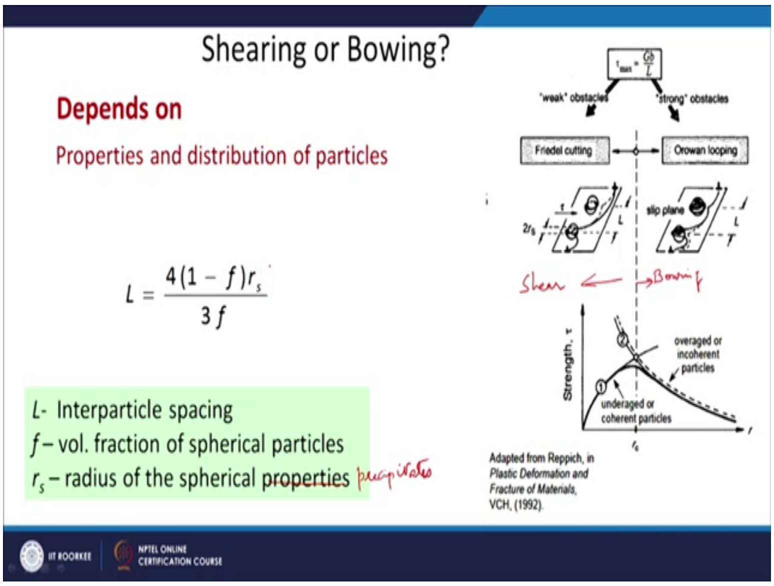
So, you can see that dislocations are precipitates are shown here its spherical precipitate. So, they have shown a cut section and that dislocation is moving ok. So, they are showing successive position of the dislocation line ok, and force is applied perpendicular to the dislocation line and it is a spherical shape.

So, when the dislocation is moving through the matrix and through this precipitate a spherical precipitate then it is cutting it and when it as we know that when the dislocation move my plane slide by one atomic distance. So, equal to one burgers vector, so similarly the precipitate will also displace by that amount of distance ok.

So, that is what you can see here that my precipitate is displace now ok, by some amount equal to the burgers vector ok. So, this is one mechanism with cutting through the precipitate. So, it is like a knife cutting through something or it can bow around the precipitate ok. So, another mechanism is that this is a dislocation ok. So, it is bowing around the dislocation ok, so it is like a again kind of a arrow and bow kind of thing that you are stretching the bow ok. So, it is like that is why it is called bowing around the precipitate ok.

So, these are the two ways which will, will be applicable in which condition that we will see now. So, shearing or bowing depends on the properties and distribution of particles ok.

(Refer Slide Time: 14:22)

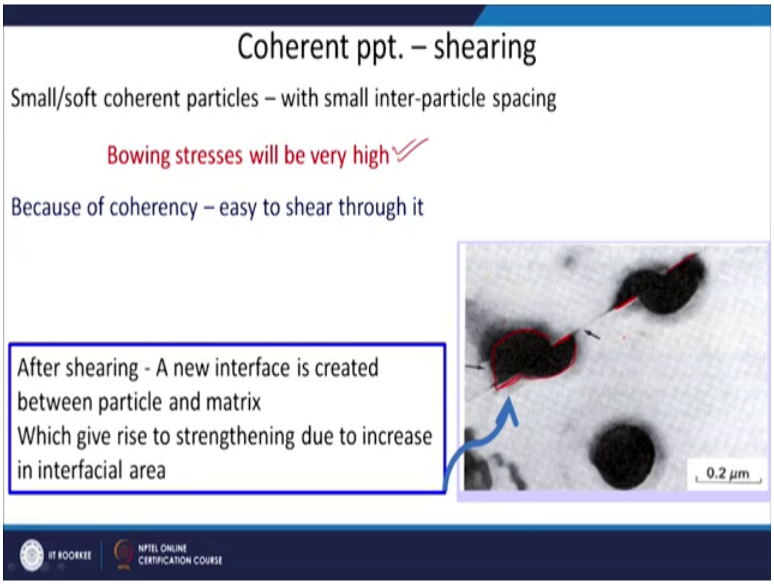


So, for example, you can see here that the under edged or the coherent particles you have shearing type of processes. So, particle gets sheared because it is already coherent. So, dislocation can move in the same atomic plane without any problem. So, when it is a coherent precipitate you have shearing ok, so this is cutting or shearing in this it is shear and for in coherent over edged particles you have looping or bowing in this direction ok.

So, bowing in this direction and cutting in this direction. So, weak obstacles are dislocation is able to cut strong obstacle it likes to bow around it ok. So, if it is weak I can easily cut through it, if it is strong or if it is hard, then I the dislocation like to bow around it. So, this is these are the two ways and I can also give you a inter particle spacing of any precipitates ok. If I know the volume fraction of the precipitates and what is the radius if it is a spherical precipitate ok. So, this is not properties radius of the spherical precipitates and this fraction.

So, if I know fraction and the radius I can give you that what will be the inter particle spacing between the two ok. So, as shown here as l the particle spacing between the two precipitates, I will keep on using some time particle precipitates these are two same things ok, so you should not get confused in this.

(Refer Slide Time: 16:09)



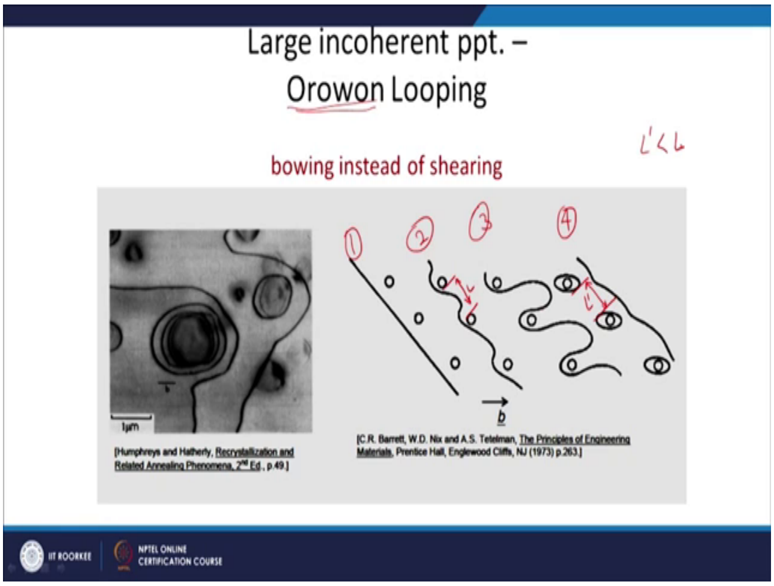
So, coherent precipitate, so as I told you that there is can be shearing or can be bowing shearing usually takes place when your precipitate is weak ok. So, coherent precipitate the because there is a coherency the interface is very low energy ok.

So, the dislocation precipitates shears through the precipitate. So, a small soft coherent particle with a small inters particle spacing, in this case the bowing stresses will be very high ok. So, because of coherency it is easy to share through it. So, as you can see these there is one nice micrograph is shown here, so the dislocation is moved through the particle.

So, it has now sheared by one burgers vector, so after the shearing a new interface is created between particle and matrix which give rise to its strengthening due to increase in interfacial area. So, it is like they say one dislocation moves it is easy for first dislocation to move ok, but what will happen because it has created this new two new interfaces. So, earlier only the interface was due to the spherical nature of the particle, but because of the cutting now the total interfacial area is like this and there is creation of two new interfaces here.

So, now when the next dislocation comes for that it will be difficult for the next dislocation to move through the same plane ok, from which has moved ok. So, now the strengthening is there because of increase in the interfacial area for large in coherent precipitate. So, the earlier one was for small coherent precipitate.

(Refer Slide Time: 17:55)



For large in coherent precipitate Orowon looping will be there ok, it was proposed by the scientist and on his name it is called Orowon bowing or Orowon looping ok, so it is bowing instead of shearing now ok.

So, basically this is again a micrograph showing the bowing process ok. So, you can see a dislocation is bowing between these two particles here ok. So, the total mechanism if you see this is my dislocation line these are the precipitates ok. So, when in the next stage, so this is my first stage next stage and they are bowing between the precipitate ok, if I keep on applying the shear stress what will happen it will bow more ok. So, you, you can see it is how it is bowing and what will happen these two will have two different burger vectors just opposite burgers vectors or later on it will anneal it each other.

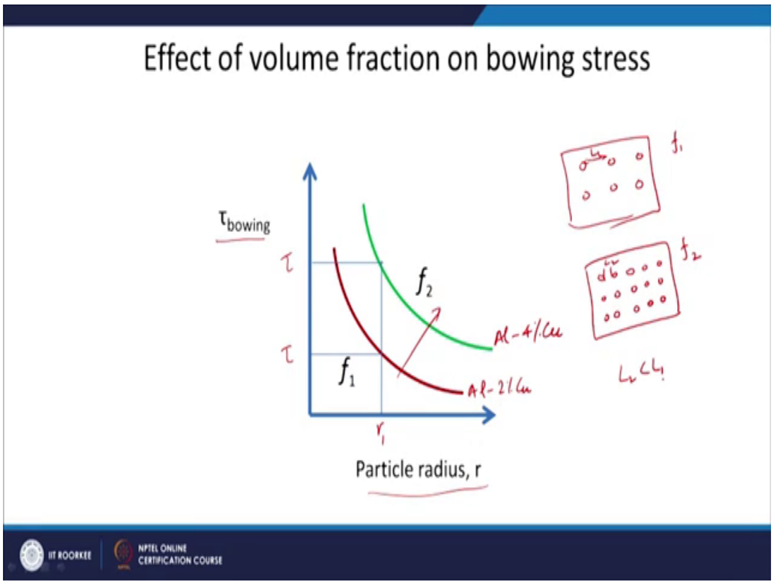
So, what will happen you will leave a loop around the precipitate and the dislocation will go through ok. So, these are the four stages in which the dislocation interacts with the precipitate. So, these are large precipitate with more spacing and these are these are the four steps of how the bowing takes place between the precipitates very similar to frank reed source if you remember ok.

So, there we said that you have now one additional dislocation loop in each, with each precipitate ok, now the how the strengthening comes through this process. So, when the one dislocation moves it has left these loop around the precipitate ok. So, now, the earlier the inter particle spacing if you, so this is the distance between the precipitate. So, now, when the loop is left behind ok, so now, the effective distance between the particle has become l prime and l prime is less than l.

So, when once one dislocation goes through this and leaves a loop now my distance has my distance between the particles has decreased. So, for the next loop when it when the next dislocation when it comes it sees and a smaller inter particle distance ok. So, it will become difficult for it to loop through you can see that if I bring the, the anchor point very close it I will I have to apply more stress to for the bow ok.

So, if I have a longer string I can easily stretch a string if I bring anchor point very close it will be very difficult for me for the same string very difficult for me to displace it by the same amount ok. So, that is what you get the strengthening as the dislocations are moving through the precipitates. Now, what is the effect of volume fraction on bowing stress ok, so these, these are the two curves.

(Refer Slide Time: 21:18)



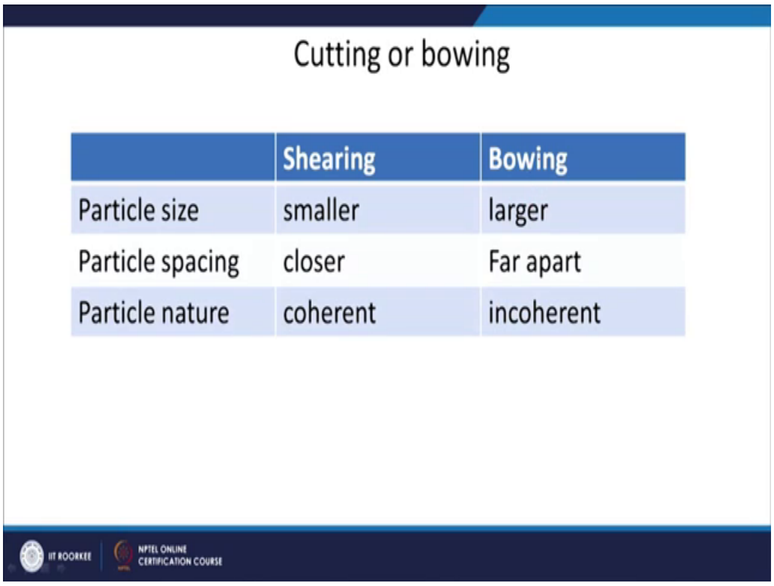
So, this is my stress required for bowing and this is my particle radius r ok. So, there are two different volume fractions of precipitates how I can change the volume fraction by taking an alloy of higher solute content. So, if I want to have more volume fraction, I will increase the solute content in the, my alloy. So, for example, this is for a let us say just for arguments sake it is for 2 percent copper this should be for aluminum 4 percent copper.

So, I have more coppers, so more precipitates will form. So, I will increase the fraction of the precipitate ok. So, this is how the precipitate will fraction will increase and if I have increased friction for the same radius for example, if I want to compare between the two fractions ok. So, for this radius r 1 here this will be the stress required for bowing for the same radius if with higher action this is will be the stress required for bowing ok.

What will happen with this when the radius is same and the friction is increasing suppose I take a volume of material like this as radius is same, but friction is f 1 for example, in first case? So, let us say these are the precipitate arrangement, so my this is my distance between the particle ok, so for the same volume if I take for f 2 now radius is same, but fraction is more. So, I have to have precipitate very close to each other ok.

And now the inter particle is distances has, come down let us say call it as L 2 ok. So, L 2 is less than L 1, so my bowing stress will be more ok. So, and that is why you we will require a higher shear stress for bowing now just a comparison between cutting or bowing and that the particle size for small particle size shearing will be the dominant mechanism for larger particles.

(Refer Slide Time: 23:34)



Bowing will be the dominant mechanism you can understand that a small particle I can easily shear if it is a large particle shearing will be difficult.

So, instead my dislocation would like to bow around it, particle spacing if particles are closer close to each other inter particle distance is less, then shearing will be the dominant one and if the particle are far apart or inter particle distance is more than the bowing will be the preferred mechanism, particle nature for coherent particles shearing will takes place for incoherent particles bowing will be the preferred mechanism of the of deformation ok.

So, with this I would like to thank you these, these are very important one of the important strengthening mechanism through precipitates and, depending upon what type of precipitates are there you can have different mechanism ok and you can also understand that as the dislocations are moving through the precipitates slowly the material will start getting strengthened ok. So, after movement of one dislocation the when the next dislocation comes it will be even difficult for the next dislocation to move through the same number of precipitates so.

Thank you very much.