Materials Science and Engineering
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Lecture – 28
Plastic deformation II

Hello friends. We were discussing Plastic Deformation in the previous lecture ok. So, let us go forward and discuss plastic deformation and little more. So, this one more lecture is devoted to plastic deformation and in this we will look at that how the stress strain curve are you are going to get for single crystal for example, and then we will look at the another type of deformation mechanism that is called twinning so if you look at a tensile curve of a single crystal ok.

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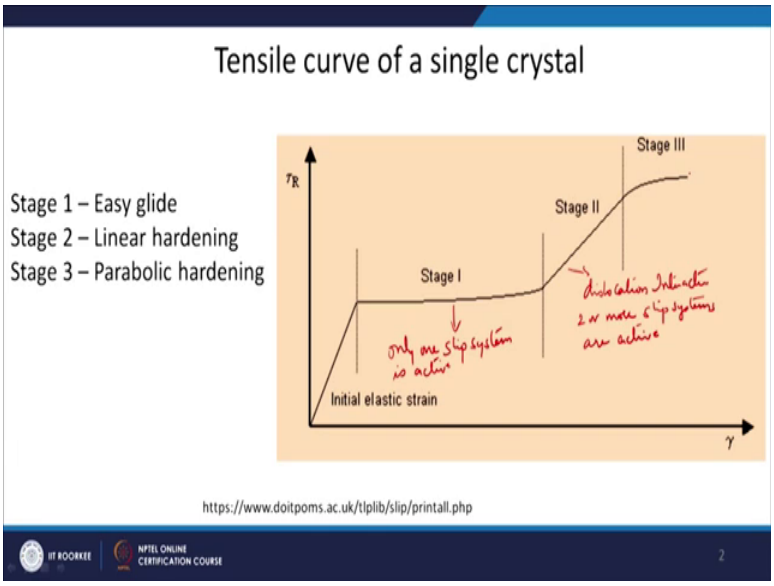

So, initial studies when people were trying to understand this deformation, people did on the crystal to at least understand that; what is the role of cystography or cryptographic planes direction in this whole for deformation process.

So, the Schmidt factor which we discussed that is also for a single crystal ok, that is why you are able to tell that what is the angle between the tensile axis and the cryptographic plane or what is the angle between cryptographic direction and tensile excess in a poly crystal because every grain will have a different orientation you cannot say for the whole single sample.

So, those work or those analysis are only for a single crystal. So, right now we want to understand that if you take a single crystal what will be your tensile curve already we have seen tensile curves ok, but those are for all polycrystalline material. So, let us see what happens if you take a single crystal ok.

So, if you take a single crystal ok, again we will start with the elastic part of course, and then you have what we call as a stage one deformation then there is a stage two deformation and stage three deformation. What do we mean by this stages stage one is easy glide means whichever plane has satisfy the maximum Schmidt factor ok, that will of course, take part in the deformation ok.

So, all the deformation is right now taking place on the those planes where the Schmidt factor is satisfied or where you have found the higher one and the shear stress on those planes in that particular direction has reached the critical resolved shear stress. So, then the deformation will takes place.

So, this is easy glides all the plane of that particular orientation are taking part in the slip process. And then you have a linear hardening we are we have not discussed too much detail about this single crystal deformation, because the course is a in this particular course we cannot go into that kind of details, but actually when the deformation takes place there is a rotation in the crystal and later on we will find that some other planes are also satisfying the condition of maximum Schmidt factor, and there is a another planes and direction where the deformation is taking place ok.

So, when this dislocation on two different slip plane start interacting ok, you have this stage two hardening ok; that means, this is actually related to dislocation interaction when two or more slip system are active whereas, in this case on the one slip system is active ok.

And of course, later on when a you have kind of a saturation that how much strain a material can take ok, you will start seeing that there is a decrease in the rate of the hardening and it is almost becoming a non-linear parabolic kind of curve ok. So, that is my stage three hardening in a single crystal.

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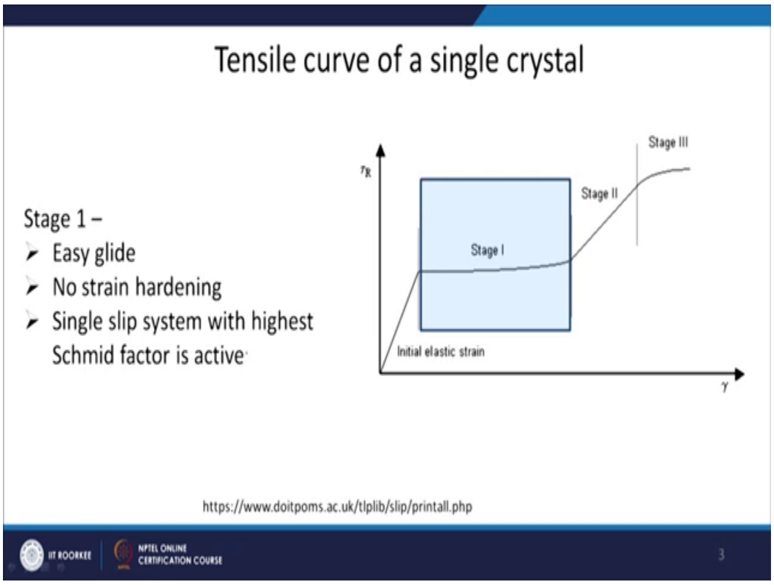

So, if we want to look little bit in detail, so in stage one you have easy glide, and of course, there is no strain hardening you can see that as the function of strain my stress is a constant here ok. So, there is no strain hardening single stress system with highest Schmidt factor is active as I told you just now ok. So, in this stage one only one slip system is active then comes the stage second now you see actually the strain hardening part.

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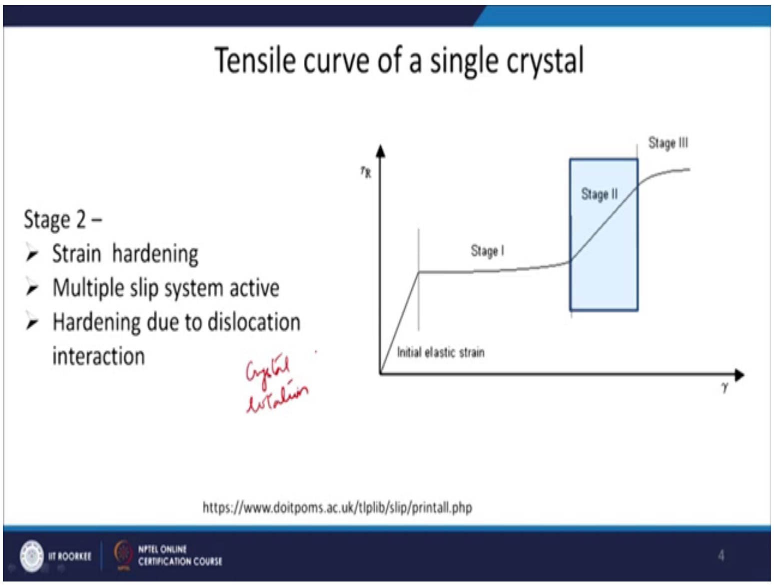

This we will again come back when we will discuss the strengthening mechanism, that what do we mean by this strain hardening, why I you get a strain hardening because now multiple system slip systems are active.

So, now dislocation are now interacting with each other and now it is becoming difficult for a material to deform ok. So, it is giving a response in form of higher stress required for deformation, hardening due to dislocation interaction as I told you that multiple slip system become active after a certain point and that is actually because the of I will just tell you that what do we mean by this actually, why are this multiple slip system become active that is because of crystal rotation.

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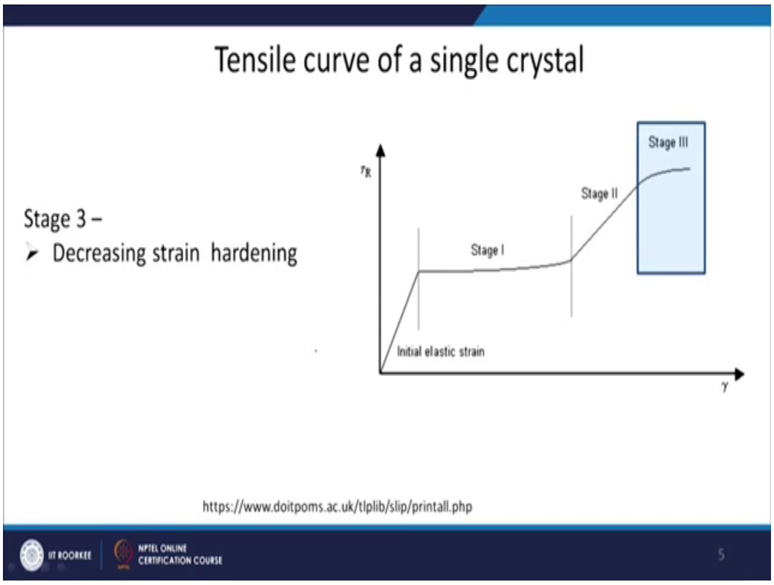

Then we come to the stage third where you have decreasing strain hardening as I told you ok. So, these are the three stages of deformation you will see in a single crystal. Now, how it will different from a poly crystalline material.

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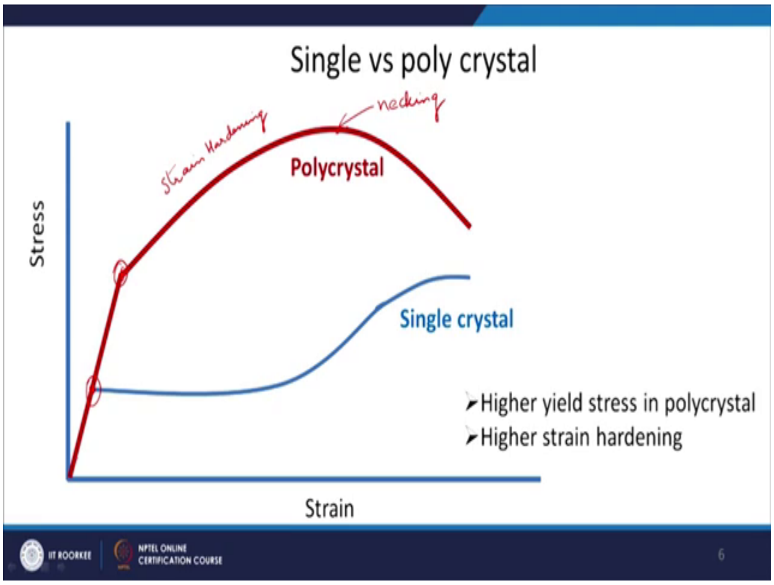

So, already we have seen that in a polycrystalline material you again have a elastic part and then the strain hardening part. So, is this strain hardening part in poly crystal, where you have uniform elongation and then half this is the point where somewhere this the necking will start and then you have a non-uniform deformation whereas, in single crystal you have a kind of you know strain hardening region then the linear strain hardening region and then a non-linear strain hardening region.

So, if you compare these two you have higher in this yield stress in poly crystal and higher strain hardening ok. Just compare to a single crystal you get more strain hardening in poly crystal, and at the same time the yield point ok.

The yield stress is also higher in case of polycrystalline material the reason is that because of grains there are there is lot of when you take a single crystal the there is no constraint on the crystal from surrounding it is, it is just a there is only one constraint on the single crystal the way you are deforming. So, you have to hold the samples only those ends are under constraint, but on the sides there is no constraint.

So, now if you understand that I start putting the constraint from the sides then now it becomes even more difficult for material to deform. So, both the yield stress will increase and the strain hardening capability of the material will increase in poly crystalline material as opposed to a single crystal. So, if we want to understand this strain hardening part.

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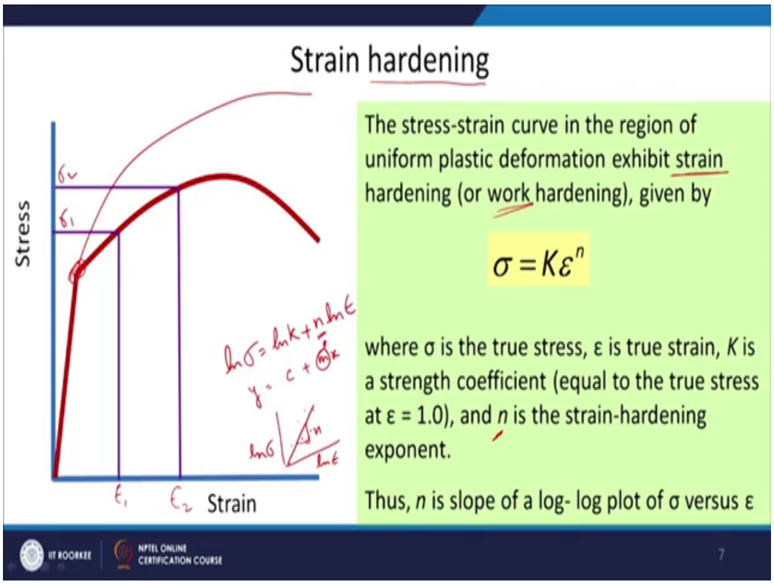

So what happens you have elastic part this is your yield point and then you have plastic deformation uniform plastic deformation ok.

So, I am giving a strain to the material as you can see here ok. So, this is a let us say I can call it as epsilon 1 this is I can call it as epsilon 2 ok, and corresponding stresses are there sigma 1 and sigma 2 ok. So, as a function of strain if I am keep on putting the strain in the material my response of the material is becoming higher and higher; that means, the resistance to deformation is becoming higher and higher ok.

So, the response of the material is measured in terms of stress. So, as I am putting strain in the material the stress the response of the material is also increasing so; that means, by imposing a strain in the material I am able to harden the material, I am able to increase the strength of the material, and that is why we call this as strain hardening we are a material is becoming harder to deform.

So, the stress strain curve in the region of uniform plastic deformation exhibit strain hardening or work hardening. So, either you can call it as strain hardening or you can call it as work hardening. Why we all it as work hardening because people used to saw that there material is getting hardened if you are working on it.

If you suppose do any work on the material suppose your are just hammering one. If you take aluminum for example, bar and you start hammering that you will see that after sometime it is becoming difficult to deform or to give the same amount of strain as you work able to do when you just started working on it ok.

So, that means the material gets work hardened you are working on it and it is getting hardened ok. In more technical term actually what you are doing is you are putting strain in the material and the, material is getting hardened because of this strain in the material. So, you can either call it as strain hardening or work hardening both the terms means same thing.

And if I want to express this non-linear behavior I can express the stress in as a function of strain with a with a power over it because it is some kind of a exponential behavior my stress is dependent on strain and with an exponent end and k is your some material cost end.

So, your sigma is true stress of course, you will do all the analysis using true stress analysis right now what we have drawn is actually India engineering stress strain, but we will all the analysis using the true stress curves. So, it will be like this something like this. So, we will do all the analysis using true stress and true strain. So, the sigma is true stress epsilon is true strain k is a strength coefficient equal to true stress at epsilon 1.

So, where ever you get hundred percent strain whatever is the true stress value will be there that is my strength coefficient your n is the strain hardening exponent and how I can get that if it if this particular equation is exponential. So, basically if I take logarithm on both side this equation will become something like this.

So, your exponent will come here when we take log like this. So, it will it is a now equation of a straight line with the slope n ok. So, it is y is equal to m x plus c kind of equation. So, where m is your slope and that is equal to n. So, if I plot this particular equation on log with sigma versus epsilon lon of sigma versus epsilon then n will give you the slope ok.

So, if you see it will be simple curve like this lon epsilon lon sigma and it will be some straight line like this, you will get some points for which you will have a best fit line here and the slope will give you the this strain hardening exponent this is how you get the strain hardening exponent from the experimental data.

Now, coming to another type of deformation mechanism as I told you that one of the deformation mechanism is what we have already discussed is the slip process ok.

So, basically two atomic planes slip over one another ok. In fact, a the closest analogy you can take for this kind of slipping process is if you take a deck of card playing cards, you put the deck like this and you just apply a shear stress on the deck what will happen is you will start getting a shear deformation. And main microscopically if you see let me just we are discussing this.

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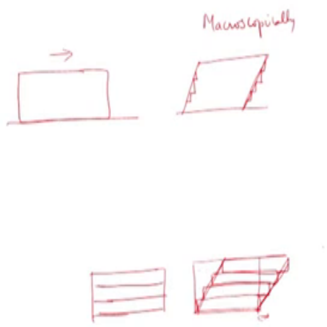

So, suppose initially, and this is how your deck of card will be and now you are applying a shear stress here this is this end is at the lower palm proper palm is applying the shear stress ok. What will happen this deck of card will slip, and you will see that it is becoming something like this isn't it.

If microscopically I see microscopically a relative term of course, microscopically if I want to see for each card what I will see I will see that each card has displaced by some amounts. So, actually at the level of card you will see that each card is displaced by some amount and so on.

So, each card has displaced by a some amount and that is what is creating this total shear. So, you can consider each card as plane over which you are applying the shear stress and the planes are getting deformed. So, you have cryptographic planes like this and they are getting slipped ok.

So, after sometime this one will slip and. So, this is the first plane then the next plane is slipped by one atomic distance for example, another next one is a slipped over this one then third one is slipped over this one.

So, though is at atomic distance in terms of crystal planes and now if you see microscopically if I do not go into the up to the atomic scale, I what I will see I will just see one plane like this that initially it was like this and now it has deformed by an amount like this.

So, this is what the slip process for deformation is ok. So, for plastic deformation now it will not come back once it is slided it has slided. So, I cannot bring it back to the original position. So, this is my slip process for plastic deformation, now coming back to twinning. So, twinning already we have discussed that a the crystal across the twin has the mirror image.

So, basically if your atomic arrangement across the twin is something like this then across the twin.

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You will have mirror image of this atoms placed at the just what you will get a mirror image if I just put a mirror here ok. So, that is what you have deformation by twinning is mirrored over this one just to make it more clear with a nice image. So, this is how the twinning is going to be.

So, deformation twinning it is also known as mechanical twinning, because twinning can be by two reasons one is through deformation process.

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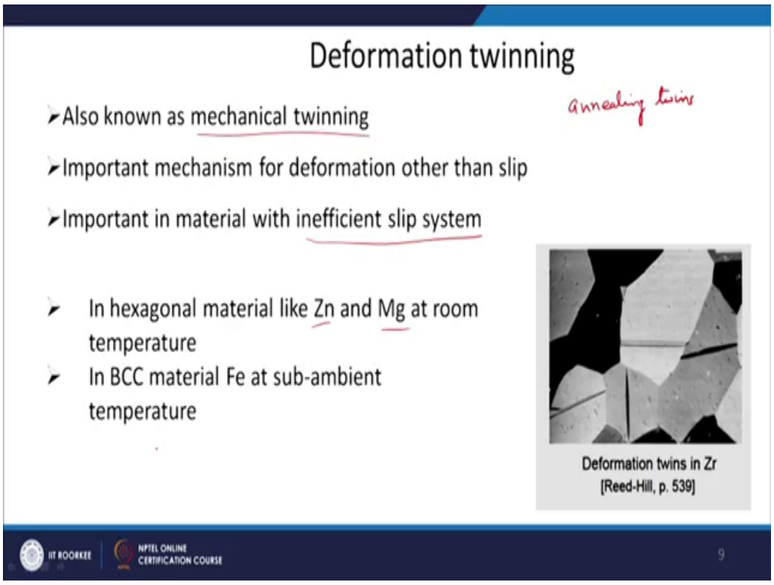

The for, that we will call it as mechanical twinning sometime twin forms during the annealing process also. So, those annealing those twins are called annealing twins during the transformation and so on ok.

So, those are annealing twins and these are because of a some mechanical deformation. So, that is why these are called mechanical twins or you can call this in deformation twinning very important during mechanism for deformation other than slip. So, one process is already we have discussed which is called slip this is another deformation mechanism were you can have a deformation in some material actually these materials are those which have inefficient slip system.

So, if you remember when we were discussing slip system we said FCC is a very efficient system for slipping it has twelve close peg planes and close peg direction combination of twelve slip system. And all the twelve have a close peg planes and close peg direction which is what we want in case of bcc actually you do not have any planes plane which is a close peg planes.

So, only some planes which are very near to that definition ok, but again those are not very efficient. So, number of slip systems are very high, but none of them actually satisfy the close peg condition.

So, actually you do not get very high ductility in bcc as compared to an FCC crystal HCP again you have some planes which are close peg planes and close peg direction, but the number is very small only you have three slip systems like that and the basal plane 0 1 plane ok. So, this is a very important process the twinning process is very important process in this kind of system where they do not have efficient slip system.

So, for example, in hexagonal material like zinc magnesium at room temperature if you do any deformation you will always going to get some twinning in bcc the material also for example, steel at sub ambient temperature it will deform by slipping process at little bit high temperature the deformation by slip process becomes easier because at high temperature it becomes easier for you to slide the atom over one another.

So, there you would not see the deformation through twinning, but if you go to higher lower temperature then you will start seeing that the deformation is through twinning process. Now why I actually this twinning takes place ok, just a comparison in this case we are deforming a single crystal.

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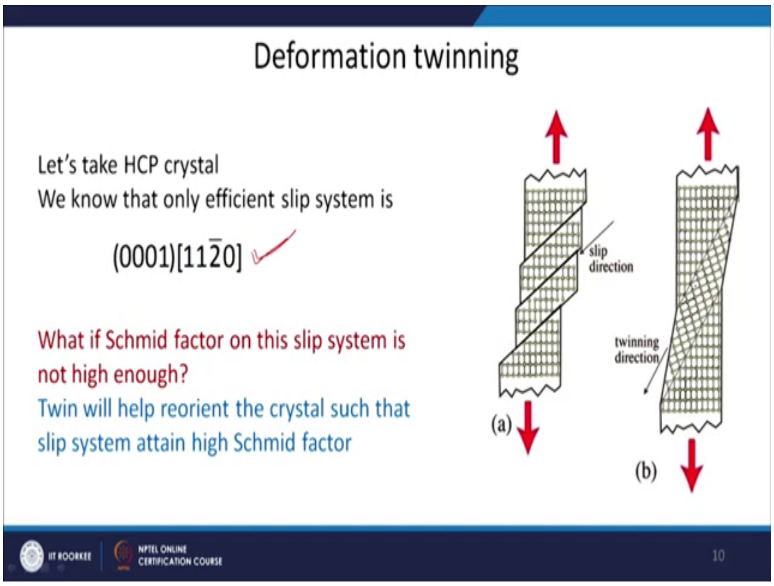

And you can see that the slip is taking place on some cryptographic planes where you have satisfy the maximum Schmidt factor condition ok. So, the crystals are sliding over one another.

Now, the problem is let us take an example of HCP crystal we know that the efficient slip system or the close peg condition which we have is satisfied by this slip system, what if this particular slip system is not oriented such that it is going to give you the maximum Schmidt factor ok, you are applying the stress you are deforming the single crystal ok.

And now my stress is continuously increasing in the system ok, but if my thisbasal plane is not oriented, such that your able to reach the maximum Schmidt factor or maximum resolved stress resolved shear stress then how it is going to deform you can keep on putting the stress in the system.

So, what material will try to do is it will try to reorient the crystal and we already know that twinning actually reorients the crystal you get a mirror image. So, reorientation takes place, so I can reorient the crystal. So, for the initial arrangement is not able to give me the maximum resolved shear stress for slipping process.

So, what my material is trying to do is now it is re it has reoriented the crystal here ok, you can see now the orientation or the arrangement has changed and by doing that the material is trying to align now these planes such that they will be able to deform plastically ok, deform by a slip process ok.

So, this is the whole idea of bringing twin into the system that to reorient the crystals such that you are able to satisfy the condition for deformation in some slip planes where you have a close peg arrangement.

So, this is about the deformation twinning and with that our deformation kind of how the plastic deformation mechanism is there ok. So, one is slip another is twinning will be completed ok. And now we will use this idea as about deformation to dislocation and all these things to understand that can I do something to my material so that the strength of the material can be enhanced.

So, that is what now is our concern that if I can do something to the material and that is why, where the whole engineering comes the whole desire the material design comes that how I can change the microstructure or I can change the or Taylor the micro structure to get the properties which I desire. So, can I manipulate this to get strengthening in the material because the strength is one of the important parameter to understand, and to get in the material? So, that is what we will start within the next lecture.

Thank you.