Thermo-Mechanical and Thermo-Chemical Processes
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Lecture-07
Dynamic Recovery

Hello friends, so, I in this microstructure evolution the first topic which we want to take is dynamic recovery. So, we want to see that how the dynamic recovery brings the microstructural changes in the material. what is the basis of this dynamic recovery. So, this we will discuss in this particular lecture. So, if you kind of define where the dynamic recovery will be an important process.

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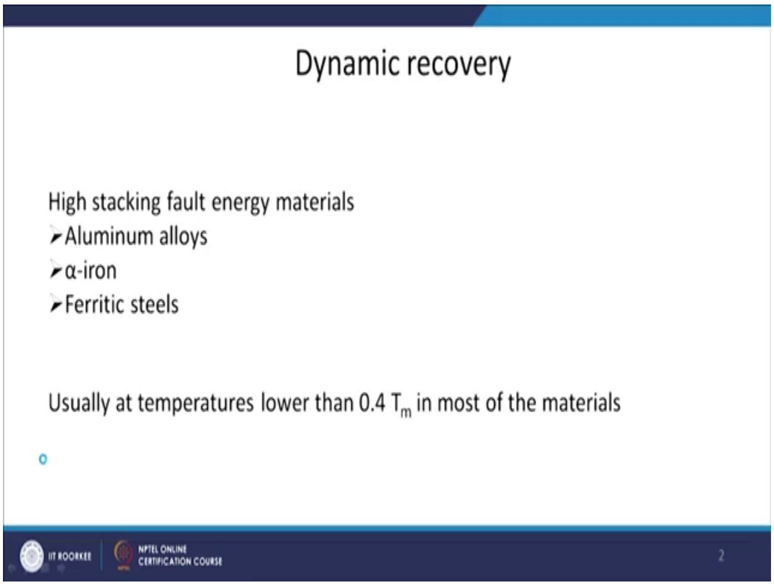

So, in terms of materials for high stacking fault energy materials that means, the stacking fault energy of the material which has high stacking fault energy these kinds of materials show predominantly dynamic recovery, instead of dynamic recrystallization they show dynamic recovery ok. So, these dislocation like to recover rather than want to remain inside the grain.

So, in this (refer to above slide) aluminium alloy is one of the very important alloy system, your alpha iron and ferritic steels all these are come under high stacking for energy materials and they show predominantly dynamic recovery. And usually if you do deformation at lower temperatures then you will mostly see dynamic recovery in most of the material. So, at lower temperatures and in the material, which has high stacking fault energy you will see dynamic recovery as the predominant process through which the restoration of the material property takes place Excuse me.

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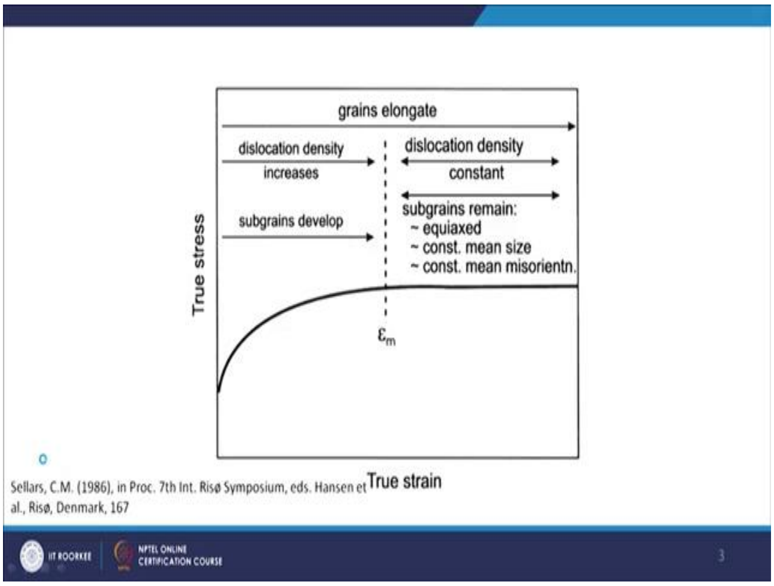

So, if you want to see that how we have already seen (above slide) I think in stress strain curve for dynamic recovery that how the stress strain curve will look like. So, usually we say that after the initial part where the strain hardening is taking place, this strain hardening is when your dislocation density is increasing dislocation multiplication is taking place. That is the part when you will have a strain hardening and as we have just seen in micro structural evolution that this is the phase where the sub grain will develop.

So, dislocation will multiply, they will interact and at the same time all these dislocation rearrangement will takes place and form this small sub grains with the low angle grain boundary around them and these are the initial part of the strain hardening part in the hot deformation process and after a certain strain you will see that now stress is independent of a strain that means, you have reached kind of a steady state process and with strain there is no change in the stress.

So, now in this particular segment your dislocation density is constant. So, dislocation density can be constant when you don't have any generation. But in this case what happens is that the generation and the taking out of this dislocation or any annihilation of dislocation these two processes kind of become equal the rate of these two processes become equal. So, the dislocation multiplication and dislocation removal from the grain is equal the rate is equal so, that you do not see any change in the flow stress.

So, dislocation density is constant means the generation as well as the annihilation is constant whereas, in the initial process it was predominantly generation and annihilation rate was lower. So, that is why you see the strain hardening and usually the sub grains also remain equiaxed more or less with constant means size and constant minimum mean misorientation. So, there is not much change in the microstructure also.

So, it has reached a steady state condition. So, when you have this kind of condition then we say that the material is deforming through dynamic recovery process that the dynamic recovery process is the prominent process in this particular segment. Just as a word of caution don’t think that if a flow curve is continuous showing a strain hardening there is no recovery there.

If you are doing a high temperature deformation or any deformation more than 0.3 Tm or 0.4 Tm and so on, the recovery will always be there. The dislocation recovery will keep taking place. Only thing is which process is dominating. So, if you are seeing a strain hardening continuously for example, that’s a stress strain curve and but it shows a continuous strain hardening that means the generation is more dislocation multiplication is more and dislocation recovery is less, recovery will take place.

Similarly, when the softening is taking place there may be additional process of let’s say recrystallization also, but maybe recovery will be there in that condition also and in the steady state condition of course, these two matches very nicely and we say that it is predominantly controlled by dynamic recovery. Now, if you see hot deformation, you can divide the hot information this term into two terms deformation of course.

So, whenever you have deformation, there are only two ways with which you can do plastic deformation through dislocation activity or through twining. So, twining we are not considering here that much. So, mainly it is through dislocation movement. So, when you impose strain in the material to carry that strain, you need that many dislocations. So, dislocation density will increase with the strain and that is why you see the strain hardening.

So, any deformation process you will have associated dislocation generation and then dislocation moment. But at high temperature another thing which happens what we call as equilibrium vacancy concentration. So, at any temperature about zero Kelvin, you will have some vacancies in the material and vacancy is a thermodynamic defect, so, it will always be there and the change of equilibrium vacancy concentration as a function of temperature is exponential (refer below slide).

So, as you keep increasing the temperature it will increase exponentially. Now, what these vacancies do is that they actually help in the recovery of the dislocation.

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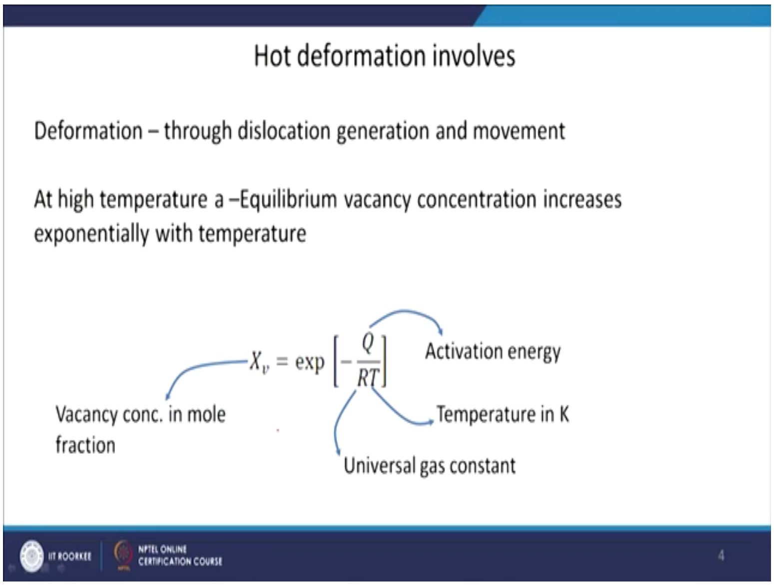

So, if you want to just see a relationship vacancy concentration in mole friction is related with activation energy and the temperature. The temperature is a very important factor here activation energy will be constant for formation of vacancy. So, as you increase the temperature there will be exponential increase in the vacancy concentration ok. So, now, how these vacancies help in the recovery process?

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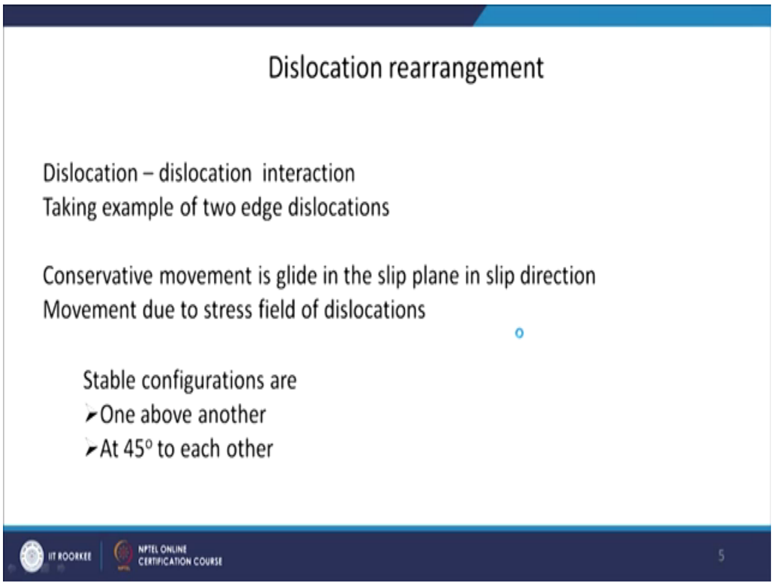

So, when you have deformation first so, dislocation will increase, dislocation interaction takes place. Now when dislocations are involved in absence of let's say temperature also there will always be some interaction between the dislocation. So, if you want to see any two dislocation for example, I take two edge dislocation of same sign. Now, they will also have some stress field associated with them (refer to above slide).

So, you will have a compressive stress field here and tensile here similarly, compressive here and tensile here. And if they are close to each other, their stress field will interact and these two dislocations would like to come one over another. If the dislocations are not of opposite sign again taking the edge dislocation that these two dislocations would like to arrange in a way that they are at 45-degree angle to each other.

So, this is the usual interaction in absence of temperature also this kind of gliding, so, dislocation will move only in its particular slip plane and the slip direction. And if they are close enough where their stress field can interact with each other they would like to arrange in a particular fashion and this is how they will try to arrange if of the same sign, one over another and if opposite then at 45-degree angle. So, this is this is a usual conservative motion of dislocations.

Now, when you are at high temperature there is an additional moment which you are allowing a dislocation to have and which is what we call it as dislocation climb, which is a non conservative movement, glide is we consider as conservative movement and the climb as non-conservative movement.

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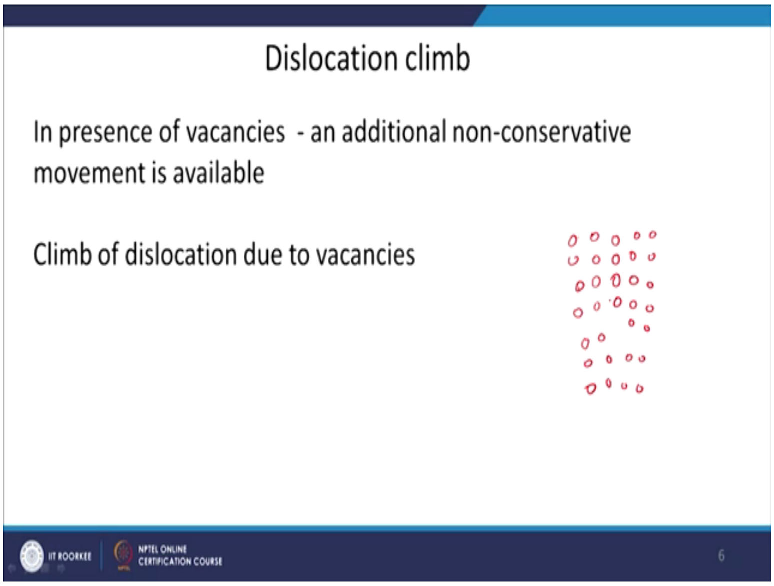

So, just to make you understand this climb process, suppose again taking the edge dislocation (refer to above slide). I'm just drawing hope I am drawing it correctly here, this will come here and so on and then there will be next layer, and so, you have edge dislocation, which is ending somewhere here. So, now, let's say there is a vacancy as you increase the temperature there will be more vacancies. One vacancy is jumping and suppose it has first come here, there is a vacancy here now.

Now this atom sees these vacancies. Then let's say this atom jumps here is now coming here. So, vacancy has moved from this place to this place. Now, this the additional plane which is therefore the edge dislocation, this particular atom at the end of the dislocation also sees this particular vacancy and it jumps here. So, let erase this one now from here and create this particular one, here. So, what you can see here is that the dislocation has climbed by one atomic distance now.

So, what you can see here is that dislocation has climbed by one atomic distance ok. So, the vacancies how they are helping is that this dislocation now climb. And that is how a dislocation can recover or dislocation can be removed from the grain by this climbing process. So, this dislocation climb can happen only when you are at sufficiently high temperature where the equilibrium vacancy concentration is of certain amount.

Then only it will be effective process for dislocation climb and also you can say that because diffusion is a temperature dependent process. So, for diffusion of vacancies also you need a high temperature. So, for creation of vacancies as well as our diffusion of vacancies for both you need high temperature then only you will have this kind of climbing process and this type of climbing can keep happening as more and more vacancies are there.

So, you have dislocation generation due to deformation and you have dislocation recovery through this kind of climbing process, dislocation climb and also this climbing process then helps in kind of rearrangement of dislocation. And as I told you that this rearrangement you can develop a small or low angle boundary.

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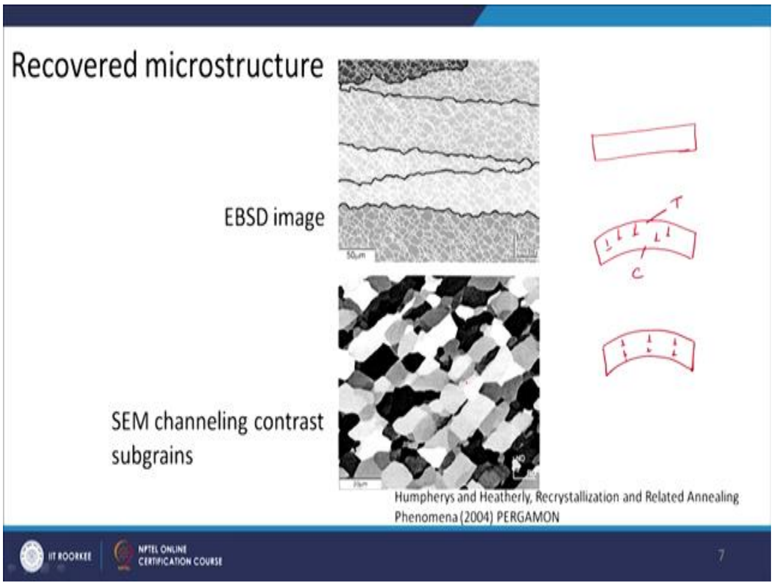

For example, let us say I have a crystal like this and I am now deforming it (refer to above slide). So, let us say I have deformed it like this. So, now, you can see that there is a tensile strain here and compressive strain here. The length is shorter in the bottom and then it is more towards the top. So, to have this kind of straining, definitely I will have to introduce dislocations here. So, initially these dislocations are all randomly arranged.

But suppose if I also do it at sufficiently high temperature then what will happen that this dislocation will like to rearrange and then this particular crystal again the same strain is there, but now let us say the dislocations are arranged in a particular fashion. So, suppose you have started with a single crystal, now, you can see that this single crystal is divided into small sub grains and this dislocation arrangement can create a low angle grain boundary.

As you must be knowing model of grain boundaries through arrangement of this dislocation like this one over another. So, individual grains sub grains are there which is surrounded by this low angle grain boundary. That is what you can again see I have taken the same micrograph here that these are your high angle grain boundary and bigger grain is divided into smaller sub grain which is surrounded by this low angle sub grain boundaries.

Now, another way to look at these kind of sub grains as I told you in optical microscopy you would not be able to see, another way to look at it is called a SEM channeling contrast. So, using scanning electron microscope and in that there is a technique called channeling contrast, channeling contrast actually use the orientation information of the grain to give a grayscale image here (refer to above slide).

So, this small sub grains which you can see here also I think if you see the scale it might match 50 micron is here and there are let’s say 5 or 6 grains here so around 10 micron and here it is 20 micron again 10 micron So, these sub grains are right now in this particular microstructure is around 10 micron. So, you can see this small sub grains within the grain using this particular technique. So, you can use different techniques to view different microstructural features.

So, a typical recovered microstructure will look something like this with high angle grain boundaries and the grain is subdivided into sub grains you and this subgrains will be surrounded by low angle or sub grain boundaries.

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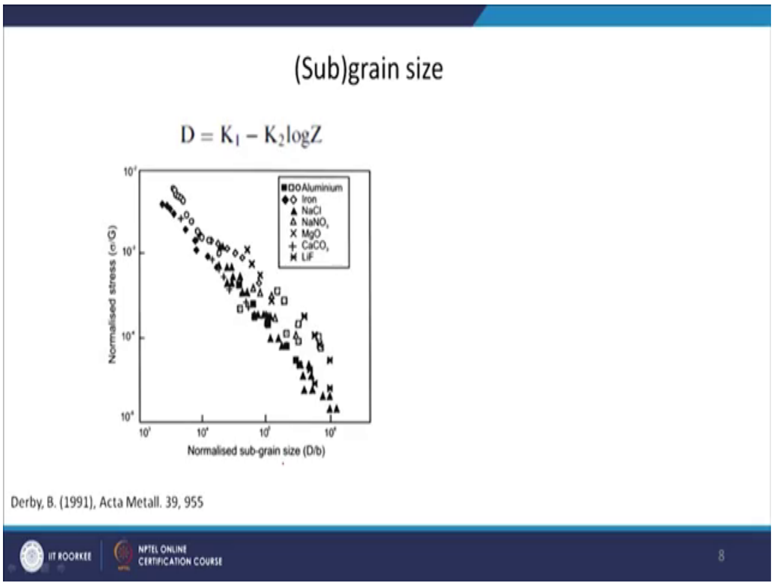

Now sub grain size also I can kind of quantify as you can see that I, if I know the sub grain size, I can plot a relationship between the sub grain size and the normalized stress for example in this particular graph, what you can see is a normalized sub grain size and this is a normalized stress and this you can actually relate with a relationship like this. So D is your sub grain size and Z is your Zener Hollomon parameter if you remember I think we have discussed it earlier also this Z is actually something like this (refer to above slide).

Actually, it takes into account both the strain rate and temperature in their single parameter. So, actually the effect of strain rate is that if you increase the strain rate then the flow stress will increase, because you will have more dislocation and then they will interact and so on the rate of generation of dislocation will be high as you increase the strain rate, if you decrease the temperature, again the effect on the stress is that it will be higher the flow stress will be higher as the temperature is lower.

So, if I want to show stress will be higher when you have higher strain rate and lower temperature. So, these two effects is combined in this Zener Hollomon parameter as I told you earlier also. So, when the strain rate is high temperature is low means Z will be high. So, you can see now that there is a relationship between I can kind of have the flow stress as function of some function of Z, that as Z increases my stress increases.

So, you can see that when normalized is increasing here that means the Z must be increasing here and what is the effect of that on the grain size as the stress is increasing means I can say that my Z increasing in this direction or I can say my strain rate is increasing in this direction and temperature is reducing in this direction. So, as my Z is increasing or normalized stress is increasing my grain size is refining.

So, now you can see that I can now control the microstructure if I want a finer sub grain size I have to deform the material at higher strain rate and lower temperature. Now, what is the drawback of that for a practicing engineer for example, if I increase the strain rate and do deformation ay lower temperature my flow stress will be higher. And when the flow stress will be higher that will have impact on all my machinery which I am using.

For example, if I am using rolling or extrusion ok. So, my roll mill has to be designed for that kind of flow stressed, I will require higher energy for deformation because flow stress is higher. So, what microstructure I need for a certain property and how I am going to get it this is all interconnected. So, when you have normal more normalized stress means you will have finer grain size or finer sub grain size.

So, these are some important relationships in the dynamic recovery process that how the micro structure will be changing. So, you can see that a big grain which is surrounded by high angle grain boundary then kind of get subdivided into sub grains, something like this. So, these are all low angle grain boundaries and this size is again controlled by the deformation parameters, which is our strain rate and temperature.

So, these all are controlled together to give you a certain microstructure. In recovery mostly, we will say that if you see optical microscope, you would not be able to see any big change in the micro structure of course, the grains will be elongated because of the deformation process. But with different strains, you would not be able to see only it will get elongated, more. But other than that, you would not be able to see much change.

The texture also would remain more or less similar and there would not be much change in the texture of the material. But internally there is a refinement through sub grain formation and the change in the sub grain size. So, thank you with this our dynamic recovery part is over. Now we will discuss dynamically recrystallization.

Keywords- Dynamic recovery, edge dislocation, vacancy.