Introduction to Materials Science and Engineering
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Lecture - 133
Creep mechanisms

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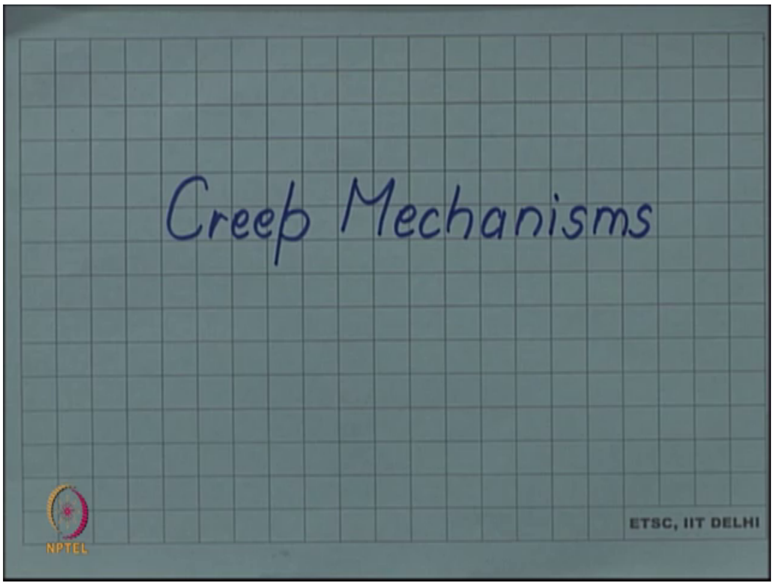

Let us discuss Creep mechanism. Creep as we have seen is plastic deformation and we saw that plastic deformation happens due to the motion of dislocations, but creep in the dislocation mechanism, we also saw the phenomenon called strain hardening that is beyond a certain point the material hardens such that the deformation stops. So, at a given stress the deformation plastic deformation is finite.

If you want a further plastic deformation a stress has to in stress has to be increased. So, but in creep, we are seeing that at constant stress itself we are getting continued plastic deformation. So, there may be mechanisms in creep which are different from normal plastic deformation.

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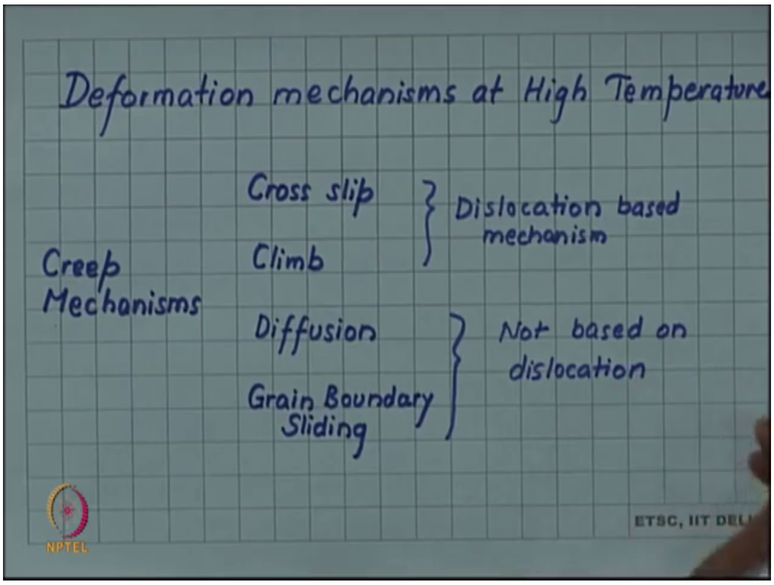

So, let us look at what are those mechanisms. Four important mechanisms have been identified; cross slip, climb, diffusion and grain boundary sliding. Cross slip as you know is of a screw dislocation and climb of edge dislocation.

So, both involve dislocation. So, they are still dislocation based. So, just like at low temperature, dislocations play an important role, at high temperature also, they still play a role in creep. So, this is a dislocation based, but diffusion and grain boundary sliding, these are two mechanism of plastic deformation which are not dislocation based; independent of dislocation and they occur only at high temperature and do not happen at low temperature. So, they are particularly effective in creep.

So, these are not based on dislocations. So, high temperature deformation need not necessarily be a dislocation based deformation.

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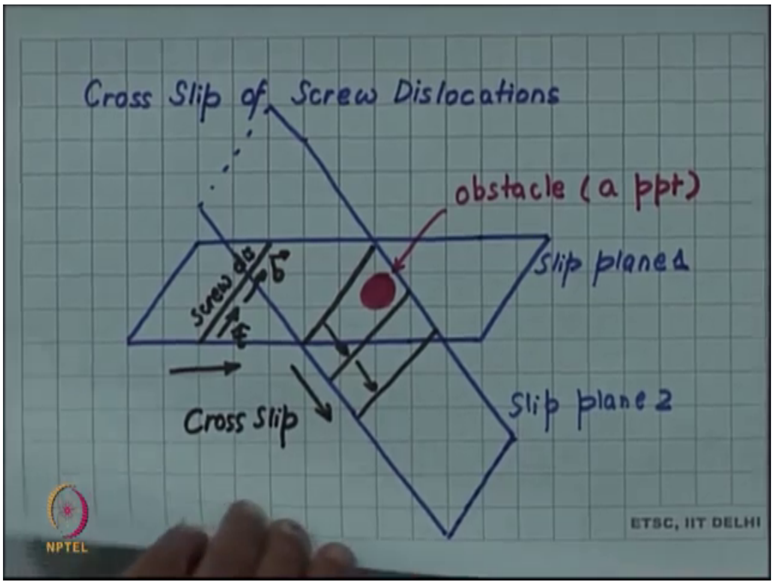

We have already seen cross slip of screw dislocations; when we were discussing, the dislocation display the topic of defects and dislocation. So, let us say that this is a screw dislocation which was moving for. So, if it is a screw dislocation the t and b will be either parallel or anti-parallel; let me make parallel in this case.

So, if this dislocation was moving under the stress in this direction and suppose that the crystal contains some hard particles reinforcements or precipitate we have talked about precipitation hardening. Suppose, there is a precipitate sitting there and the dislocation cannot cut through the precipitate can. So, it acts as an obstacle. So, this is in obstacle to dislocation motion, let us say a precipitate.

So, this dislocation will be obstructed when it comes let us say here, but if other plane is available for sliding the dislocation can avoid this obstacle by if it is a screw dislocation. So, then this other plane is also a slip plane. So, if this is a slip plane 1 and this is slip plane 2, so the dislocation can avoid the precipitate particle by starting to glide in this direction. So, this motion of this change of the slip plane is what we call cross slip. So, if cross slip was not happening the plastic deformation will stop at this point, but if cross slip is possible then since dislocation continues to move on a different plane the plastic deformation will continue. Another mechanism is climb of an edge dislocation.

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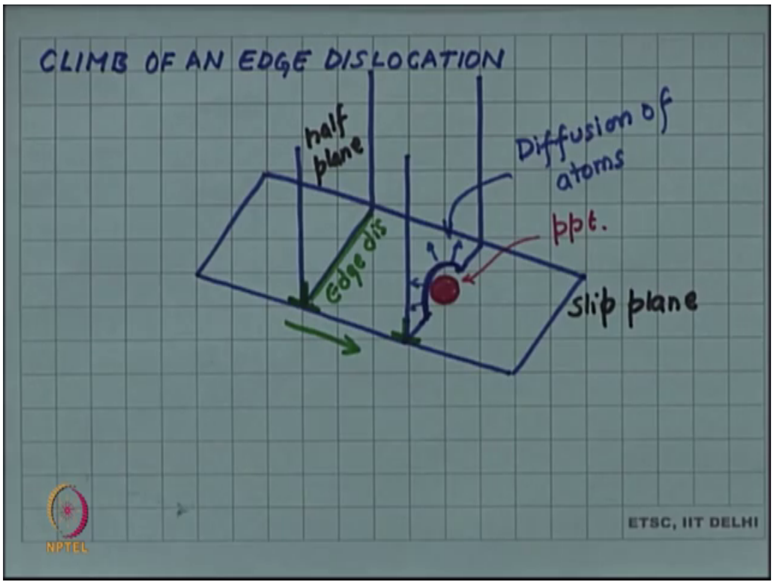

So, we have seen shown a slip plane here. So, let us call this the slip plane. So, this horizontal plane here shown is a slip plane, the vertical planes which I have drawn here is the half plane of an edge dislocation. So, this line; this line will be the edge dislocation line and schematically you know we can represent it by an upside down T.

So, that is an edge dislocation, this is in edge dislocation and that edge dislocation let us say is moving in this direction and again there is a precipitate particle sitting on the slip plane, this is a precipitate particle which is sitting on the slip plane. Then in the normal situation the dislocation will be stuck by this precipitate particle and can move only at a continue to move only at a higher stress, we had considered that in precipitation hardening; either the dislocation will have to cut through the precipitate which also requires higher stress or it can form a loop around the precipitate which again needs higher stress.

But if the temperature is high like in case of creep deformation; then what can happen is that atoms at the bottom edge of the dislocation line can diffuse out which is what we call climb up. So, this segment of the dislocation line this segment of the dislocation line has climbed up and thus is able to avoid the precipitate and the dislocation line can continue to move. This does not require any higher stress only requires a higher temperature for these diffusion to happen. So, diffusion of atoms are involved in the climb of edge dislocation.

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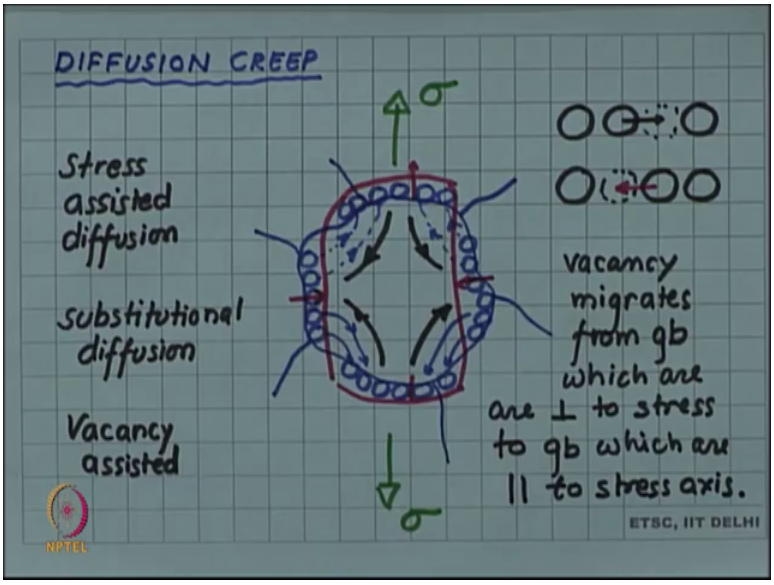

Now, a dislocation free mechanism is so called diffusion sometimes called Diffusion Creep or diffusion flow. So, suppose this is showing this is an schematic of a grain and these are all a grain boundaries and if this grain is subjected to a stress, if this grain is subjected to a uniaxial tensile stress, then you know that the grain will try to elongate in the direction of the stress, whereas, we will try to compress in the direction perpendicular to the stress. This elongation and compression, of course, can be obtained by dislocation motion as it happens in low temperature, but at higher temperature since diffusivities are higher an atomic jumps are easier.

One mechanism which is possible that atoms which are on grain boundaries perpendicular to the a stress axis sorry, the grain boundaries parallel to the stress axis, they can moves to grain boundaries perpendicular to the stress axis. So, if this atom moves from here and let us say joins here, this atom moves and joins here, similarly this atom moves and join here. So, let us say atoms migrate this way. So, if these atoms migrate and join, then you can see and similarly on this boundary we can have atoms which have migrated from this side.

So, if this happens then you can see that the size of the grain is increasing along these boundaries, but it is decreasing on this side after the diffusional migration the grain shape will be something like this; which is exactly what this stress is trying to do is to increase the length in this direction and contract the dimension in this direction. So, you can see that this in incrementing length as well as transverse contraction can simply be achieved, if the atoms migrate in this way. Such migration is not possible at low temperature, but at higher temperature due to higher atomic mobility and higher diffusion rate such migrations are possible. This is and this is a diffusion which is not governed by Fick's Law in the simpler form which we had talked about that is diffusion due to concentration gradient because there is no concentration gradient here, only stress is applied.

So, this is a special kind of diffusion which we have not talked about earlier, but and we are not going to discuss it in any detail here also, but we will simply note that this is a special diffusion mechanism which is a stress assisted diffusion; these diffusion paths which I am showing is happening because the stress is trying to increase the grain size this way and decrease the grain size in this direction. So, the atoms have a driving force for this kind of motion; obviously, this is not these atoms are atoms which make up the crystal, they are not interstitial atoms.

So, these atoms can diffuse only by substitutional diffusion mechanism. So, diffusion is a still substitutional and for substitutional diffusion, you need vacancy this is vacancy assisted and again you know that vacancies are more available at higher temperature and vacancy concentrations are higher at higher temperature. So, this kind of diffusion is more possible because of higher temperature which is available during creep. So, if we try to put the path of vacancy, if we do not look at the atoms, but look at how the vacancy are migrating.

So, you can see that vacancy will migrate just the opposite way. This is a as you know that if you have if you have a vacancy and an atom jump atom jumps into a vacant site. So, if I if I draw it like this. So, this atom jumped into this vacant site. So, which means the vacancy which was there jumped in the opposite direction. So, atomic migration direction and the vacancy directions are different and this is stress assisted diffusion leads to vacancy migrating from grades from grain boundaries which are you can see the grain boundary which are perpendicular to stress to grain boundary which are parallel to stress axis.

So, this is a stress assisted diffusion of vacancy which leads to diffusion creep. There is no dislocation required, but if vacancies move this way the atoms move the opposite way and the deformation will happen.

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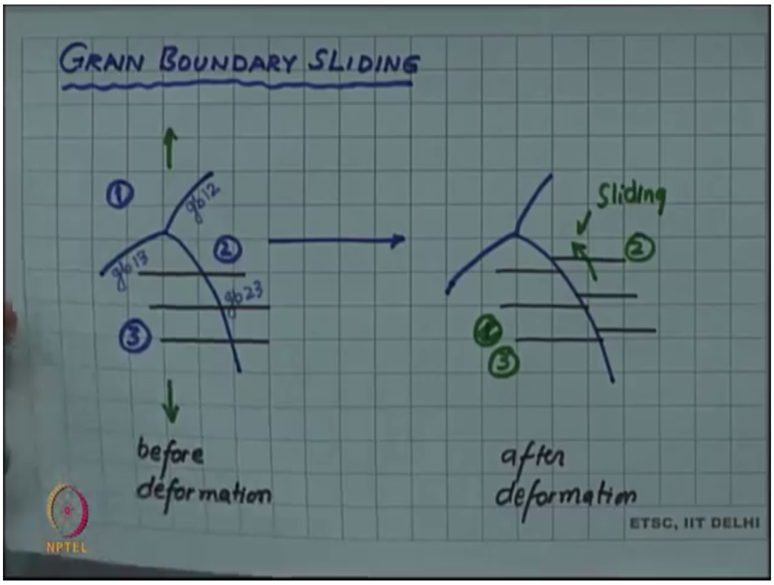

Yet another a diffusion mechanism; yet another is a deformation mechanism which does not involve dislocations is the grain boundary sliding. This again happens at higher temperature, here I am showing you a schematic of let us say three grains; this grain 1, grain 2 and grain 3 and these are the grain boundaries. So, this is grain boundary 1 2, grain boundary 1 3, grain boundary 2 3, and now if this system is again subjected to stress, then at higher temperature grain boundaries become weaker than the grains. So, they act like somewhat a viscous liquid along the grain boundary, liquid is a little stronger term, but they it is easier for the grain to slide on these grain boundaries at higher temperature under the influence of a stress. So, if shear stress is there on these boundaries the grains can slide. This has been actually observed in experiments by drawing some test lines across the boundary.

So, suppose if I draw test line across this boundary before deformation which are continuous across the grain, then after deformation then after deformation one finds that these lines have become discontinuous. The continuity across the boundary is lost and you find something like this. So, which means this grain, grain 2 had slid upwards with respect to grain 1 across the grain boundary. So, grain 2 and grain 3 are sliding on the grain boundary 2 3. So, this is yet another mechanism which is possible and this is again possible at high temperature. Because at high temperature only the grains become weaker, the grain boundaries become weaker and allow for this kind of sliding.

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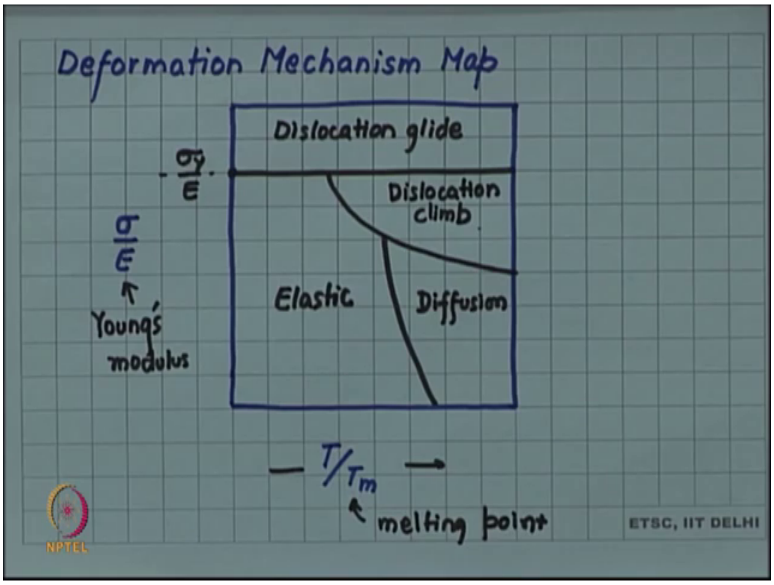

Finally, I am interesting way to present the deformation as a function of stress and temperature is what is called the deformation mechanism map and a simpler form of this map is what we will draw now. So, we have something called yield stress. So, the y axis is stress versus the modulus Young's modulus.

So, y stress is the y axis is stress but it is normalized with respect to Young's modulus and x axis is temperature but it is normalized with respect to the melting point. Then at a value corresponding to yield stress. So, this will be sigma y by E. So, the yield stress will be reached at that yield stress, you will have a plastic deformation. So, this will be due to dislocation glide. Then you have at lower temperature, you have different regimes, the dislocation climb or dislocation based creep which we talked about is here; whereas, a diffusion based creep which we talked about is here and in this regime at low on the lower stress side and sorry the lower stress side and the lower temperature side the deformation is still elastic.

So, this is an elastic regime. So, as you increase the temperature at a constant stress you will go from elastic to plastic deformation at some higher temperature because diffusion based mechanism will start to take place. If the stress is high then you can go into the dislocation climb mode also. So, this regime the dislocation climb and diffusion regime is that creep regime and the glide regime is the normal plastic deformation and the rest is elastic deformation. So, this kind of deformation mechanism map can help in understanding the various mechanism of plastic deformation as a function of a stress and temperature.