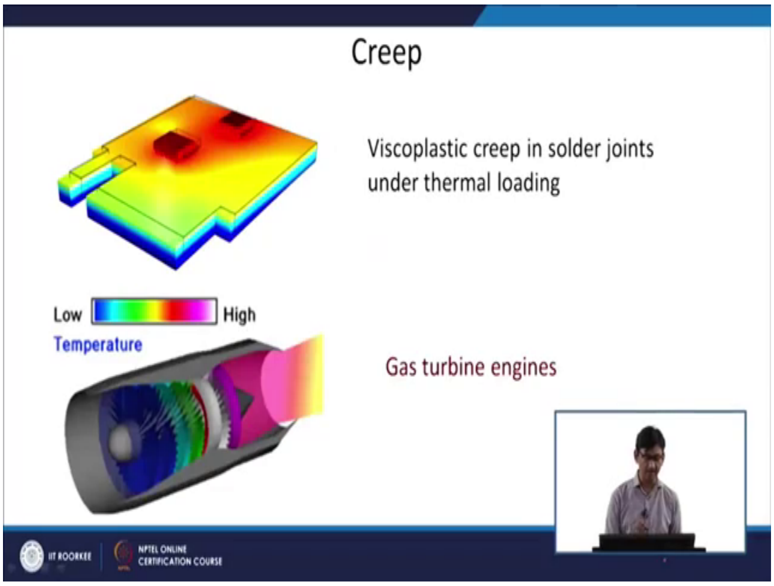
Materials Science and Engineering
Dr. Vivek Pancholi
Department of Metallurgical & Materials Engineering
Indian Institute of Technology, Roorkee

Lecture-36
Creep

So, Hello friends; Today's lecture will be on High temperature deformation and that is called in a word Creep Behaviour and this type of deformation takes place for any material which is exposed to very high temperature and under certain load conditions. Then it will keep on deforming as a function of time.

So, if you see the Creep application that the understanding of Creep is required. So, it can cover a very large size scale.

(Refer Slide Time: 00:58)



Creep

Viscoplastic creep in solder joints under thermal loading

Gas turbine engines

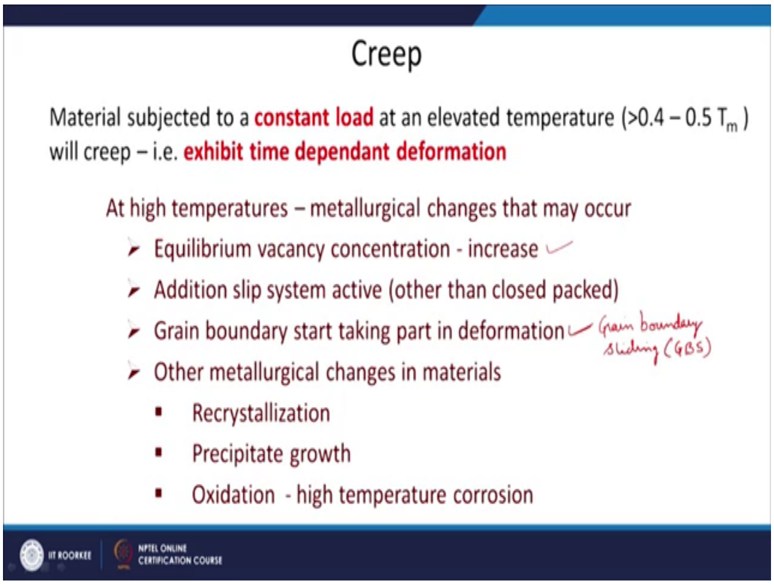
For example, it can be important for a electronic circuit where because of the flow of the current all the components are exposed get slowly heated up and with the time ok, all these older joints and the wherever there is a connection between the circuit and some component; these are exposed to high temperature.

So, it will keep on experiencing some strain as a function of time and slowly at some point of time, it will fracture and your component will fail. So, it is important in a electronic circuit. Similarly, it is important in for example, a gas turbine engine or steam turbine which is used for power and power plants or gas turbine which is used in forever in an in an aeroplane and these material, as a you can understand you are exposed to high temperature ok.

Now, we are all thinking about having a ultra supercritical power plants. So, the temperatures are going to be very close to 650 degree Celsius or 700 degree Celsius. So, these material are exposed to very high temperature and as you can understand the turbines rotate at very high rpm and so, there will be large centrifugal force acting on the rotating part.

So, under high temperature, under this loading condition the materials deform. So, it is a very important area of material science to understand that how the Creep takes place and how you can design the material to reduce this deformation at high temperature. So, Creep, if you want to define it is a material subjected to a constant load at an elevated temperature. So, elevated temperature also has to have a definition that what do we mean by elevated temperature.

(Refer Slide Time: 03:08)



Creep

Material subjected to a **constant load** at an elevated temperature (>0.4 – 0.5 T_m) will creep – i.e. **exhibit time dependant deformation**

At high temperatures – metallurgical changes that may occur

- Equilibrium vacancy concentration - increase ✓
- Addition slip system active (other than closed packed)
- Grain boundary start taking part in deformation ✓ Grain boundary sliding (GBS)
- Other metallurgical changes in materials
  - Recrystallization
  - Precipitate growth
  - Oxidation - high temperature corrosion

So, elevated temperature is around any temperature above 0.4 or 0.5 of the melting point of that material ok.

So, under a constant load at this temperature some materials usually show deformation ok. So, it shows a time dependent deformation ok. So, as a function of time the material will deform. So, at high temperature, other material metallurgical changes which usually occur; we already know that equilibrium basic vacancy con concentration will increase as a function of temperature. Some additional slip system become active ok.

This we have not discussed, but usually we say that the close packed planes and close packed directions are the preferred slip system for deformation. But at high temperature additional slip system can be active. For example, in FCP case, other than basal plane which is the close packed plane and the direction in the basal plane; you will also have slip process in the prismatic or pyramidal plane ok. Depending upon their c by a ratio of that particular material; And then, grain boundary start taking part in deformation ok.

This is a very important deformation mechanise which starts operating at high temperature. So, at high temperature it is not necessarily that you will have only deformation through dislocation movement through the grain, but the deformation can be through grain boundaries lighting which is what we called as that grain boundary start taking part in deformation and the process is called Grain boundary sliding ok. In short, we also says GBS.

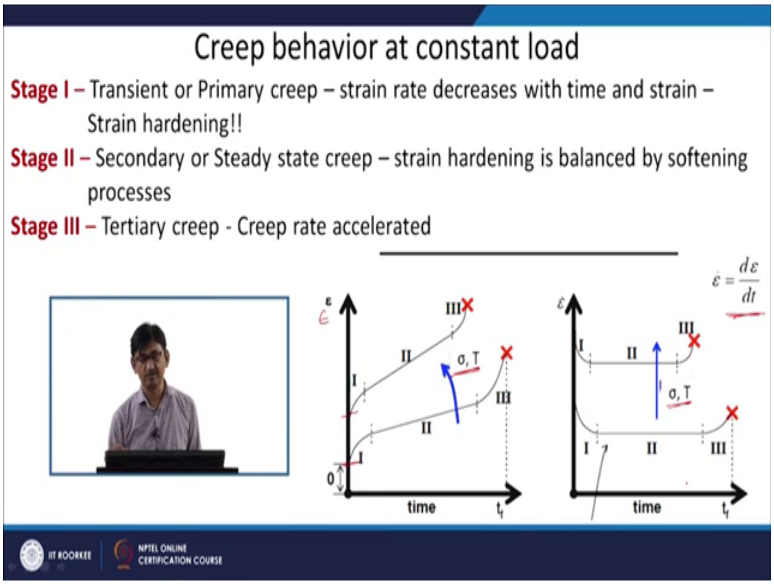
So, instead of deformation through that this location within the grain, the grain boundary itself restart deforming and kind of slide one grain slide with respect to the another one.

Other metallurgical changes we will take place can may occur that you will have re-crystallisation process at high temperature ok. Precipitate growth will always take place at high temperature. You will have more diffusion of atoms, solute atoms of precipitate growth takes place. So, whatever you have planned that these are you should be the size of the phrase precipitate. This should be the inter particle spacing ok, but at high temperature it will try to have small larger particle with smaller surface area ok.

So, at high temperature because diffusion is easy; So, a small particle will shrink and the big particle will grow and slowly you will have precipitate growth or it can have oxidation problem. So, at high temperature, most of the material are susceptible to get oxidized ok; because you always have a oxygen environment around it; So, at high temperature material start getting oxidized ok. So, oxidation is one of the big problem corrosion problem for high temperature materials.

Now, Creep can be divided into 3 stages ok. So, if you see strain here.

(Refer Slide Time: 06:31)



Creep behavior at constant load

Stage I – Transient or Primary creep – strain rate decreases with time and strain – Strain hardening!!

Stage II – Secondary or Steady state creep – strain hardening is balanced by softening processes

Stage III – Tertiary creep - Creep rate accelerated

This strain is shown on y axis timing time in shown on x axis ok. So, as soon as some load is applied, you will have some deformation in the material ok. At 0 time and then, you will see that the strain is or what you can say here the slope between strain and time is coming down as a function of time. Then, it has it is showing what we call is Steady state behaviour that is the second stage. So, the strain vary as a function of time in a linear manner and then you have the transient condition.

Again, another transient condition that is called the Tertiary stage; the third stage ok and in this case, the strain varies as the function of times the strain accelerates as a function of time. So, if you take see the slope here the slope is continuously increasing and then, you will have fracture. If I increase the stress or temperature in both the cases the whole of this deformation mechanism will shift to higher strain; So, if I think in increases the stress on the system or increase the temperature of the system.

Now, you will have more strain at 0 time and then, you can see that the slope of this linear curve is also more than the previous one. So, steady state Creep will also be higher and the material will fracture at much lower and time duration at shorter duration, it will fail ok. So, if material is exposed to high temperature or it is under higher load, the material will fraction at the lower time ok. So, this 3 stages are given here. First is Transient or Primary Creep is strain rate decreases with time and strain ok.

So, strain rate is decreasing here, you can see the slope is decreasing as a function of time; Second stage, a Secondary or Steady state Creep ok. This is one which actually you try to understand in more detail. Strain hardening is balanced by softening processes. So, here both the hardening and softening processes are balanced. So, hardening process is this location generation and they interact with each other. So, that is called Strain hardening. Softening processes are for example, dislocation get recovered. So, you again reduce the dislocation density and material become soft.

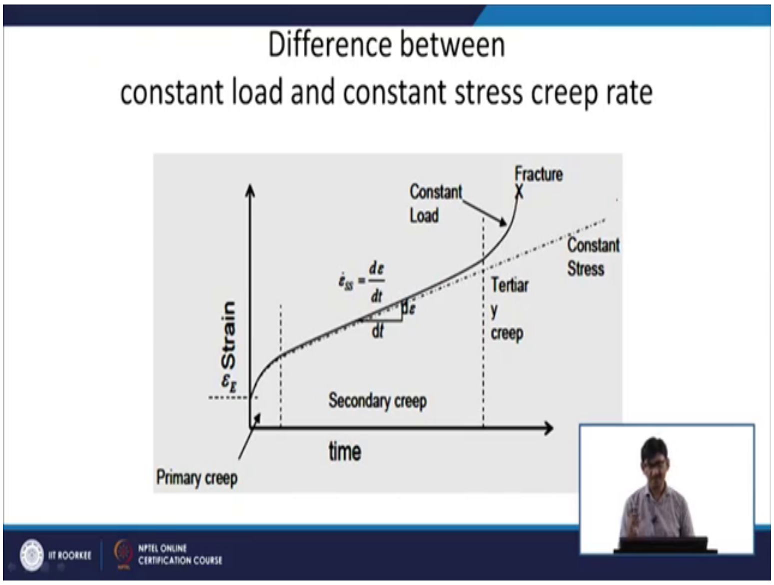
So, the generation of this location and recovery of this location both are kind of balanced in this particular region and that is why you get this linear behaviour. In tertiary Creep the Creep rate again accelerated at the last stage ok. This is due to because of the deformation the whatever part is there the cross sectional area is continuously reducing.

So, it will reach a stage where, now it cannot be able to take that load anymore ok. So, then there will be a very fast reduction in the area as a function of time sense stability will be there and you your Creep rate will increase ok. So, the strain time curve can also be shown as the strain rate time curve ok.

So, strain rate is nothing but the change in this strain as a function of time d epsilon by d t. So, if that also we can plot. So, you can say that in the first stage, the strain rate is decreasing because here the slope was decreasing and in the second case, the slope was constant, strain rate is constant in the second stage and the third stage, the strain rate is increasing ok. Again, you can see the effect of stress and temperature. So, at lower stress and temperature the strain rates will be lower. At high stress and temperature the strain rate will be higher and the time to rupture will also be smaller.

Now, what is the difference between a constant load and constant stress creep data? Ok. In Creep, actually we have a constant load. So, you can understand that the stress is continuously increasing on the on the material because the cross sectional area is continuously reducing. As the length increases of the sample ok, the cross sectional area will reduce. So, continuously for a constant load the stress on the system is continuously increasing. So, you can do test in two ways either you do it is a constant load.

(Refer Slide Time: 11:16)



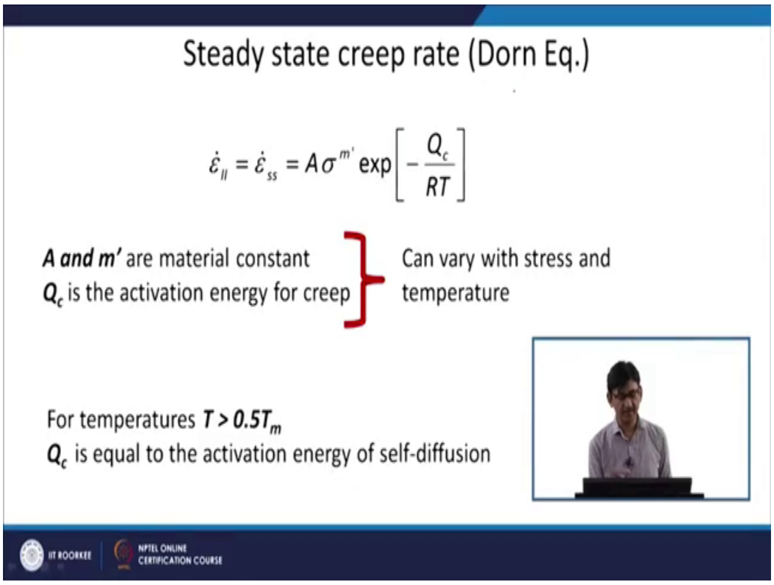
Difference between constant load and constant stress creep rate

Then, you get this typical curve S shape curve ok; which we have just discussing the previous slide. If you do it on a constant stress; then, you do not get the this tertiary stage because this tertiary stress is due to the reason of reduction in cross sectional area. So, for a constant load the stress on the system will increase, but if you are maintaining the constant stress condition; that means, you are taking care of the reduction in the area ok. So, you are reducing the load also on the system as your cross sectional area is becoming a smaller and smaller.

So, that is why for a constant stress, you will not get this tertiary stress stage. The second stage will keep continuing because I will keep reducing the load to maintain the constant stress on the system. In the stage, second these 2 where more or less will be equal only when the tertiary stage starts, when the cross sectional area is very small which will not be able to take that constant load and suddenly, you will see the rise in the stress and rise in the strain rate basically. So, for a constant stress, it will be same linear curve will be extending without any tertiary stage and ultimately it will fracture.

So, that is as I told you this stage second is of importance to us because that is the stage which is which covers the longest time in the Creep in the Creep curve and the material will undergoes this second stage for the longest time ok. So, we want to understand and we want to kind of characterize or quantify that particular stage to unders the understand the Creep phenomena.

(Refer Slide Time: 13:11)



Steady state creep rate (Dorn Eq.)

$$\dot{\varepsilon}_{II} = \dot{\varepsilon}_{ss} = A\sigma^{m'} \exp\left[-\frac{Q_c}{RT}\right]$$

A and m' are material constant

Q_c is the activation energy for creep

Can vary with stress and temperature

For temperatures $T > 0.5T_m$

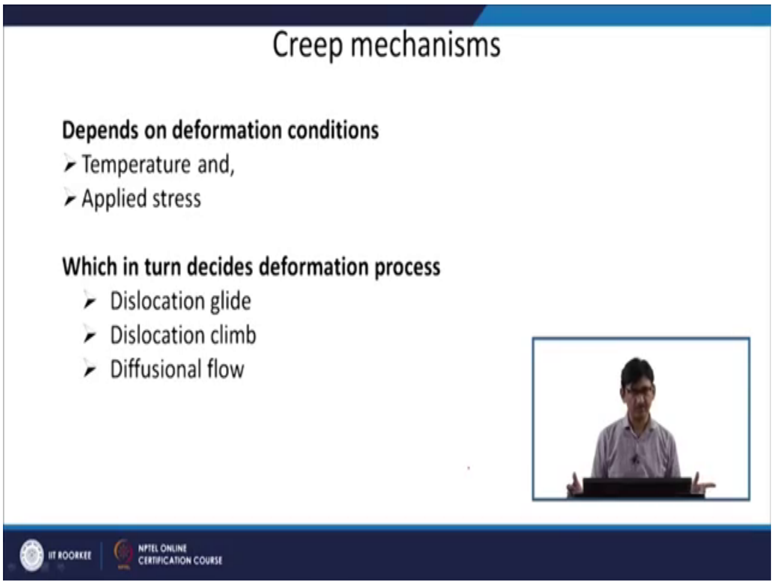
Q_c is equal to the activation energy of self-diffusion

So, the steady state Creep rate can be given by an equation like this ok. Epsilon dot second or epsilon dot s s that is steady state here A sigma to the power m prime exponential minus Q c by RT. So, m is your exponent here; because these are as a function of stress this strain rate we will change and it follows some kind of exponential behaviour.

So, A and m prime are the material constant here ok. So, I will see constants Q c is the activation energy for Creep and both this can vary with stress and temperature. For temperatures more than 0.5 of melting point that is where we do the Creep kind of test. Q c is equal to the activation energy of self diffusion ok. So, the activation energy of Creep is related with the self diffusion of atoms ok. So, please recall what we discussed during diffusion. So, Creep is intimately related with the self diffusion of atoms ok.

Now, the Creep mechanise depend on deformation conditions. So, temperature and applied stress.

(Refer Slide Time: 14:30)



Creep mechanisms

Depends on deformation conditions

- Temperature and,
- Applied stress

Which in turn decides deformation process

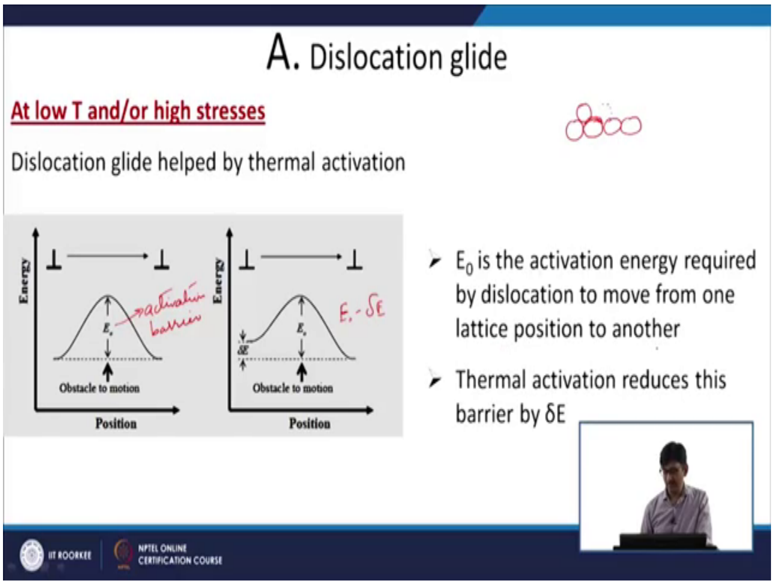
- Dislocation glide
- Dislocation climb
- Diffusional flow

For example these two already we have seen that how they increase the Creep rate and they also in turn decide what will be the deformation process. So, depending upon temperature and applied stress, we will see that there are different deformation mechanise which are operating ok.

So, whether the Creep is dominated by Dislocation glide or it is dominated by Dislocation climb process or it is dominated by Diffusional flow; that is decided by that what is your deformation conditions ok.

So, that if you look at the Dislocation glide process ok.

(Refer Slide Time: 15:14)



A. Dislocation glide

At low T and/or high stresses

Dislocation glide helped by thermal activation

- E_0 is the activation energy required by dislocation to move from one lattice position to another
- Thermal activation reduces this barrier by δE

So, this is acting at low temperatures and high stresses ok. So, low temperature high stress, it is like our normal deformation processes; where, we have already seen that the deformation or the slip process takes place by movement of the dislocation; so Dislocation glide.

So, here only the temperature is how it is helping that the Dislocation glide is helped by the thermal activation. So, we want to see that how when the dislocation moves, how the potential energy changes during the movement from one a atomic side to the next atomic side. If you see that the if this location is here, it is in a in a low energy configuration ok. Then the dislocation is moving to the next position, it has to climb over the atom which is in the bottom of this atomic plane ok.

So, where the your half plane is ending, there will be one atom here ok. So, if I I can show you. So, suppose this is the position of atom and when it is moving, it has to move from here to this next position. So, this next position is like this.

So, basically it has to kind of a climb over this bottom atom and go to the next position ok. So, this climbing of the atom is called is can be shown as a change in the potential energy. Do not confuse it with the dislocation climb. It is just you during the glide process, it has to go over the bottom atom kind that is the kind of scenario is there ok.

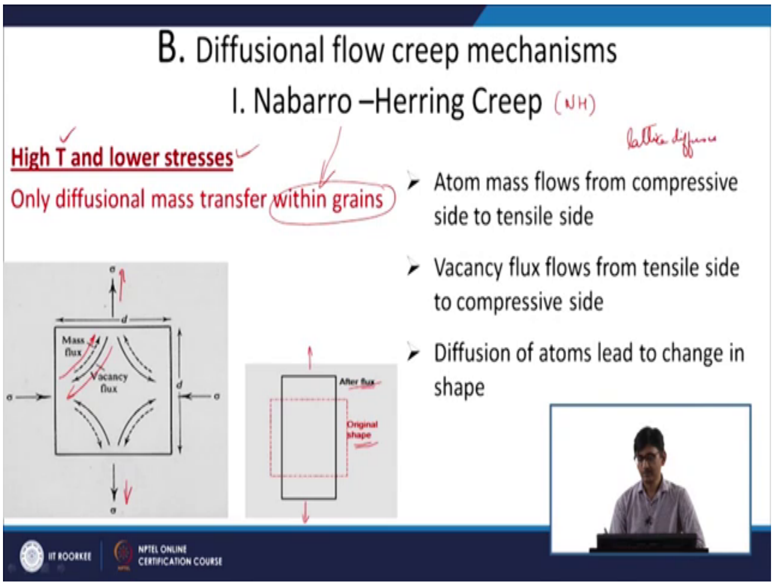
So, during this process the potential energy changes like this; it is minimum here. Then, it goes to the maximum and then, again when you go to the next atomic side, it goes to the minimum potential energy configuration and this is my obstacle to the dislocation movement. So, E naught is basically you can call it as activation barrier. So, this much activation energy is required to move a dislocation from one position to the next one.

Now, what thermal or temperature does here ok; it reduces the because of the thermal vibration, the atoms vibrate on their mean position ok. It kind of gives you additional platform for the atom to go from one position to the next one. So, that extra energy which is given by the temperature is called delta E here. So, you can see my dislocation is already at higher potential energy and then, at the next position.

So, now, it has to climb only barrier which is E naught minus delta e ok. So, this is what is helping here for dislocation to move. So, E naught is the activation energy required by dislocation to move from one position to the another and thermal activation reduces this barrier by delta E. So, if you keep on increasing the temperature, this delta E will keep on increasing and it will become easier for dislocation to move ok. So, that was the that is already, we know that dislocation movement, dislocation movement gives you deformation.

Now, the second one is that Creep through diffusional mechanise ok.

(Refer Slide Time: 18:57)



B. Diffusional flow creep mechanisms

I. Nabarro –Herring Creep (NH)

High T and lower stresses

Only diffusional mass transfer within grains

lattice diffusion

- Atom mass flows from compressive side to tensile side
- Vacancy flux flows from tensile side to compressive side
- Diffusion of atoms lead to change in shape

So, Diffusional flow creep mechanise. In this there are couple of mechanisms are there. So, first is Nabarro-Herring Creep or we also called it is called it has NH and this is applicable at high temperature and lower stresses ok.

So, how high temperature is helping here? We already know at higher temperature, you will have more equilibrium vacancy concentration and because this is a diffusional flow; that means, you will need vacancies for diffusion of atoms. So, this is this is going to be applicable at higher temperature and lower stress. So, lower stress means I have not applying enough stress for dislocation to move ok. So, for movement of dislocation, I need certain stresses, shear stresses. So, if I am keeping the stresses low, I am not initiating the dislocation movement and I will be relying more on diffusion processes.

So, in Nabarro-Herring Creep, the diffusion is only through within the grains. So, it is only going to be lattice diffusion. So, the mechanism like mechanism is like this suppose, you consider this as a one grain kind of a cube here on the one side is shown here and the stress is applied in this direction tensile stress. So, what will happen if I am applying a tensile stress in this direction? I am kind of creating more space for atom by applying a tensile stress ok.

So, what will happen? The atom still I would like to go into the side where the tensile stresses are there and these are the induced compressive stresses because of the tensile stresses. So, I am trying to compress something ok. So, atoms are getting compressed in this direction and I am applying a tensile stress in this directions. I am opening spaces here; kind of I am a stressing the bonds here. So, what will happen? The atoms will have natural tendency to move from compressive side to the tensile side ok. They will get more space therefore, to accommodate atoms and vacancies will move in opposite direction to this mass flow.

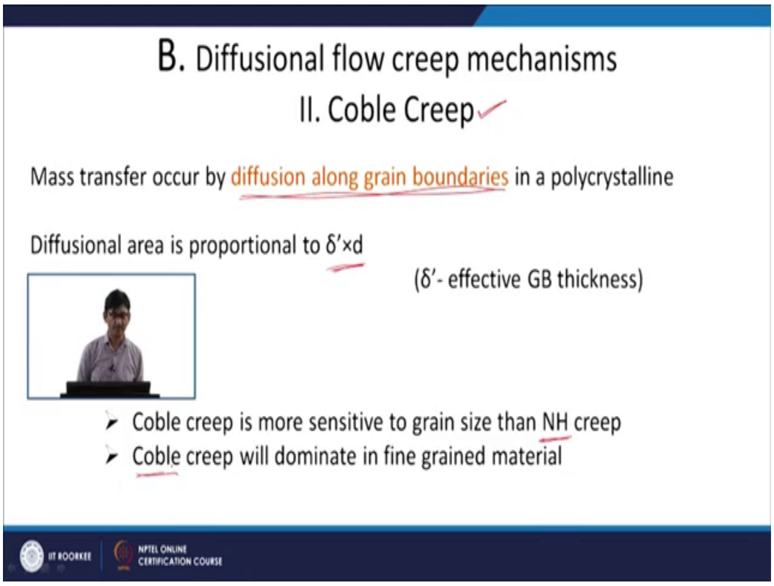
So, basically because vacancies are moving like these, atoms are going to move like that and how vacancies are there? Because, we are doing this particular deformation at very high temperature; So, high vacancy concentration will be there ok. So, mass flow will takes place from compressive side to tensile side and the vacancy flux will be moving from tensile side to compressive side ok.

So, overall you will see that the my material is getting stress in the tensile direction because atoms are coming from compressive side and getting deposited kind of in the tensile side.

So, your elongation is there. So, the original shape is shown here in the red colour and after deformation, it will be elongated in the tensile direction and getting the or cross sectional area is reducing in the compressive side ok. So, that is what is written here Atom mass flow from compressive side to tensile side; Vacancy flux flow from tensile side to compressive side ok.

And Diffusion of atom lead to change in the shape. So, that is why this is NH Creep which depends on the diffusion through the grains. So, it is dominated by lattice diffusion. So, it is obvious that if you kind of want to find out the activation energy for this diffusion, it will be equal to the self diffusion of atom ok.

(Refer Slide Time: 22:58)



B. Diffusional flow creep mechanisms

II. Coble Creep

Mass transfer occur by diffusion along grain boundaries in a polycrystalline

Diffusional area is proportional to $\delta' \times d$

(δ'- effective GB thickness)

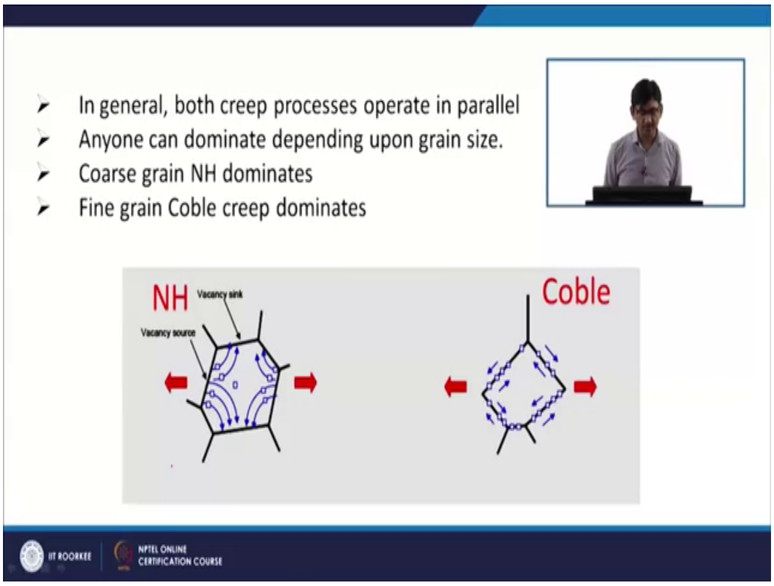
- Coble creep is more sensitive to grain size than NH creep
- Coble creep will dominate in fine grained material

Now, Diffusional flow creep mechanisms another Creep mechanisms called Coble Creep ok. And in this case, the diffusion along grain boundaries is important. So, diffusion is not through within the grain, but the diffusion is taking place from the grain boundary in a polycrystalline material..

Diffusional area will be equal to the width of the grain boundary and what is the size of the grain ok. So, Coble Creep is more sensitive to grain size then NH Creep. So, you can understand that because the mass flow is through grain boundary. So, if I keep on reducing the grain size, I will have more grain boundary area. So, the Coble Creep will start dominating it for finer grained materials ok.

So, Coble Creep will dominate in fine grained material because you will have more grain boundary area as compare to Coarse grain material. So, in Coarse grain material, you will have NH Creep and Fine grain material, you will have Coble Creep ok. In general both the Creep processes operate in parallel ok. So, anyone can dominate depending upon the grain size ok.

(Refer Slide Time: 24:16)



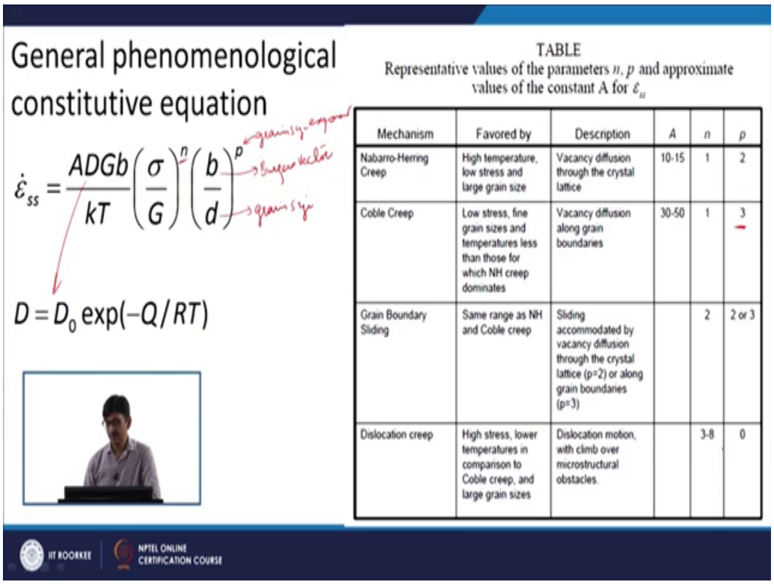
- In general, both creep processes operate in parallel
- Anyone can dominate depending upon grain size.
- Coarse grain NH dominates
- Fine grain Coble creep dominates

So, Coarse grain material NH NH Creep dominates. In Fine grain material, the Coble Creep dominates and that is how the deformation process is there. So, in this direction you are having the tensile stresses ok. So, the vacancies are flowing towards the compressive side and the atoms will flow in the tensile side.

In case of Coble Creep ok, the diffusion of atom is taking place through the grain boundary ok. So, the atoms are moving through the grain boundary towards is tensile side and that is how the deformation is taking place.

So, we can express all the Creep kin kind of phenomena through a phenomenological constitutive equation ok.

(Refer Slide Time: 25:10)



General phenomenological constitutive equation

$$\dot{\varepsilon}_{ss} = \frac{ADGb}{kT}\left(\frac{\sigma}{G}\right)^{n}\left(\frac{b}{d}\right)^{p}$$

$$D = D_0 \exp(-Q/RT)$$

TABLE
Representative values of the parameters n, p and approximate values of the constant A for $\dot{\varepsilon}_{ss}$

Mechanism	Favored by	Description	A	n	p
Nabarro-Herring Creep	High temperature, low stress and large grain size	Vacancy diffusion through the crystal lattice	10-15	1	2
Coble Creep	Low stress, fine grain sizes and temperatures less than those for which NH creep dominates	Vacancy diffusion along grain boundaries	30-50	1	3
Grain Boundary Sliding	Same range as NH and Coble creep	Sliding accommodated by vacancy diffusion through the crystal lattice (p=2) or along grain boundaries (p=3)		2	2 or 3
Dislocation creep	High stress, lower temperatures in comparison to Coble creep, and large grain sizes	Dislocation motion, with climb over microstructural obstacles.		3-8	0

Which gives an equation like this; So, epsilon dot s s is equal to there are lot of parameters are here, but you do not get scared by this equation. These are not very difficult equation to understand ok. As we just discuss that my Creep phenomena depends on the grain size.

So, at Coarse grain you will have NH Creep; for Fine grain, you will have Coble Creep ok. So, there is a grain bond grain size dependent parameter is here ok. So, d is your grain size and b is your surface vector. So, it is all this values are kind of normalise with some constant and you have an exponent here. So, this is a grain size exponent.

Now, here is your somewhere stress sigma which is acting on the system that is normalised by the shear modulus G and again there is a constant for that which will be called as stress exponent. Then, here A is a constant depending upon the material and deformation condition. D is your diffusion coefficient which is given by an question like this; already we have seen this. G I just told you shear modulus shear modulus of rigidity; b is surface vector; k is Boltzmann constant and T is the temperature of the deformation ok.

So, this is these are all the parameters here and depending upon the deformation mechanism, the values of these parameters are given here ok. For NH Creep, it is favourite high temperature low stress and larger grain size description, it is vacancy diffusion through crystal lattice ok. A will be in this range, n is equal to one and p that is the grain exponent is equal to 2.

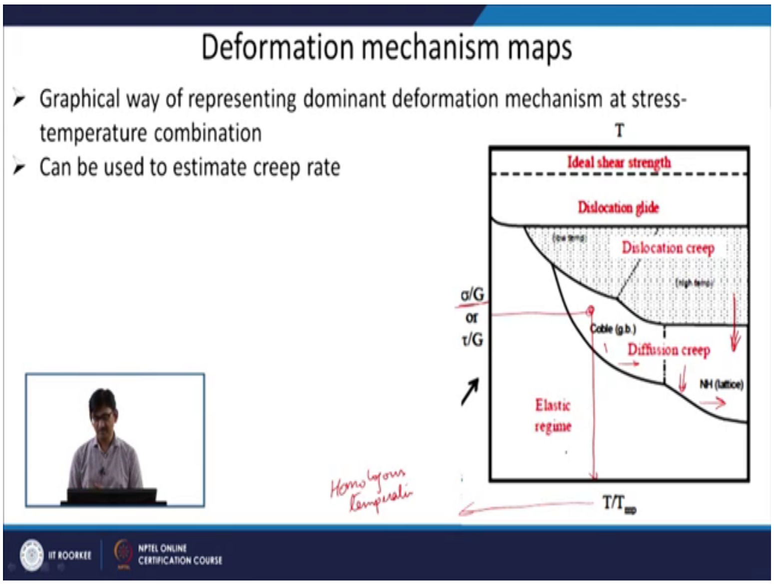
For Coble Creep, it is favoured at low stress fine grain size and temperature less than those for which NH Creep dominates. So, this is at a lower temperature ok; where, the diffusion through grain boundary will be dominating ok. Vacancy diffusion along grain boundaries, A will be in this range n is again 1 here and p is 3.

So, you can see that in Coble Creep the grain size is the dominant and that is why you have a higher value of exponent here. Grain boundary sliding favour same ranges NH and Coble Creep sliding accommodated by Vacancy diffusion through the crystal lattice and in this case the n is equal to 2 and p is 2 or 3 ok.

So, 2 at Coarse grain material, 2 for Coarse grain material; 3 for Fine grain material. Dislocation Creep is applicable at high stress lower temperature in comparison to Coble Creep and NH Creep, dislocation motion with climb over micro structural obstacles ok. n is around 3 to 8 and p is 0. So, there is no grain size dependency in case of dislocation creep ok; whereas, there is a high stress dependence on the in case of dislocation Creep.

Where as in case of diffusional creep, there is a stress dependence is very small ok. So, stress is not a very important parameter; where is in dislocation creep, there is a large stress dependence ok. We can actually divide all these different mechanism a deformation mechanise apps; also very convenient way to see that in which zone which kind of deformation mechanise or Creep mechanism we are going to dominate.

(Refer Slide Time: 29:21)



Deformation mechanism maps

- Graphical way of representing dominant deformation mechanism at stress-temperature combination
- Can be used to estimate creep rate

So, this is a graphical way of representing dominant deformation mechanise at a particular stress temperature combination can be used to estimate Creep rate ok.

So, you can see on the x axis, we have plotted t upon G melting point. So, this is a melting point of that material and when you express something like this is called Homologous temperature; get any temperature divided by the melting point of that temperature.

On the x axis, you have a stress which is normalised by the modulus of rigidity or in case shear stress also you can expressed in terms of shear stress ok. So, this is your ideal shear strength of the material which we have calculated theoretical shear strength; below that you will have a dislocation glide mechanise.

Now, we can start saying that had high temperature, we just said that NH Creep will be dominating. So, it is diffusion through lattice, NH Creep will dominate at higher temperature lower stresses ok. So, lower stresses and higher temperatures Coble Creep will dominate at again higher temperatures ok. Little bit more stress than the Coble Creep dislocation Creep will dominated higher stresses and lower temperature. So, at high temperature also it will be dominating, but it will go towards the lower temperature also ok.

So, at higher stresses and lower temperature, you will have dislocation creep ok. Only when you reduce the stress at higher temperature, the NH Creep will start dominating. So, if you see here as I am reducing the stress, at the same temperature the instead of dislocation creep I am started having diffusional creep ok.

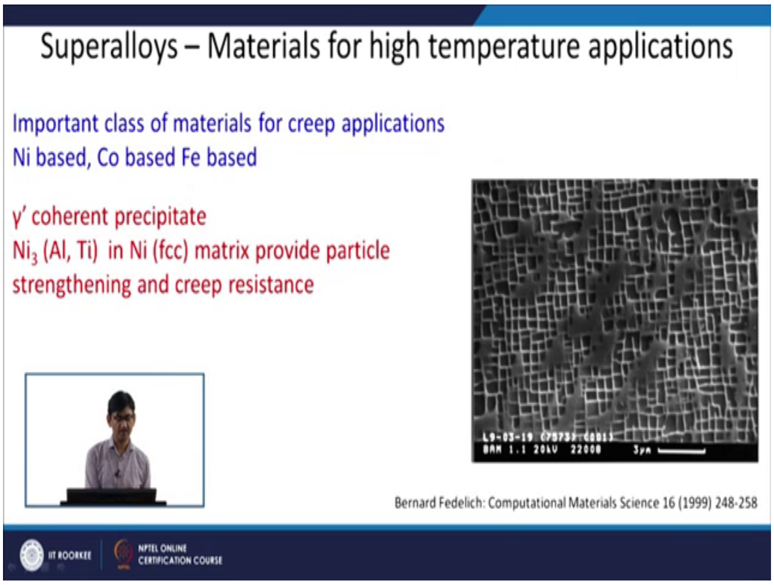
So, this is the whole different mechanise can be shown for a particular material in a simple map like this ok. To kind of find out that if in my material is grain going to be exposed to this temperature and it is going to be loaded by this much stress ok; what type of deformation mechanise are going to dominate, that we can find out.

So, once I know that it is will be dominated by dislocation creep; Then, I will design my material on microstructure according to that requirement; if I find out that it will be dominated by diffusional mechanise ok. Then, I will design my material or tailor my microstructure according to that requirement.

So, this will give me an idea that what material to be used ok; maybe I can go to for then another type of material which will have for which this diffusion this Creep mechanise are shifted to higher temperature. So, my material is going to be safe at that particular temperature ok. For example, if I find out that my material is going to be exposed to this stress and this temperature ok.

So, maybe I can choose another material for which all this mechanises are going toward the high temperature. So, my operating the service conditions are still within the elastic region. Super alloys are one of the example where the Creep ideas or the ideas from Creep deformation are used or the understanding of the Creep mechanise are used.

(Refer Slide Time: 33:04)



Superalloys – Materials for high temperature applications

Important class of materials for creep applications
Ni based, Co based Fe based

γ′ coherent precipitate
Ni_3 (Al, Ti) in Ni (fcc) matrix provide particle strengthening and creep resistance

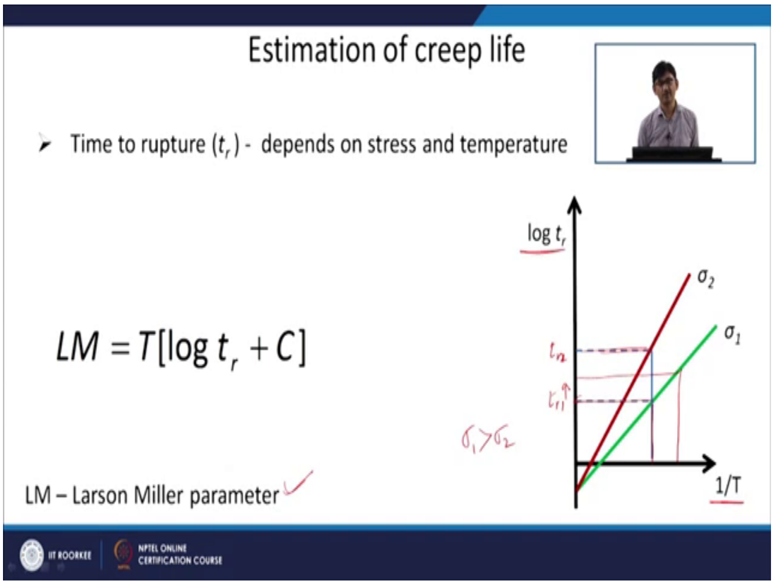
Bernard Fedelich: Computational Materials Science 16 (1999) 248-258

So, usually these super alloys are either Nickel based Cobalt based or iron based super alloys are available and Nickel based super alloys for example, the gamma prime coherent precipitate which is shown here by this cuboids ok. These cubes kind of nice arrangement of precipitate is there. So, this gamma prime coherent precipitate which is consists of nickel 3 either aluminium is there or nickel 3 titanium is there. In nickel fcc matrix provide particle strengthening and Creep resistance ok.

So, basically it provides an obstacle to dislocation movement ok. So, this kind of material can be used at higher stress condition and lower temperatures because it will be able to give a effective obstacle to the dislocation movement. So, wherever dislocation Creep is dominant we can use material like super alloy.

So, we can also estimate the creep life and one of the ways of estimating creep life is through parameter called Larson mirror parameter ok.

(Refer Slide Time: 34:16)



Estimation of creep life

- Time to rupture (t_r) - depends on stress and temperature

$$LM = T[\log t_r + C]$$

LM – Larson Miller parameter

So, basically the idea is like this, we want to find out that what is the time to rupture and it will depend on stress and temperature. So, you can see on x axis, we have plotted 1 by T here and on y axis, we have plotted log of rupture time. So, rupture times are in 2-3 order of magnitude will be there that is why it is plotted on log scale here.

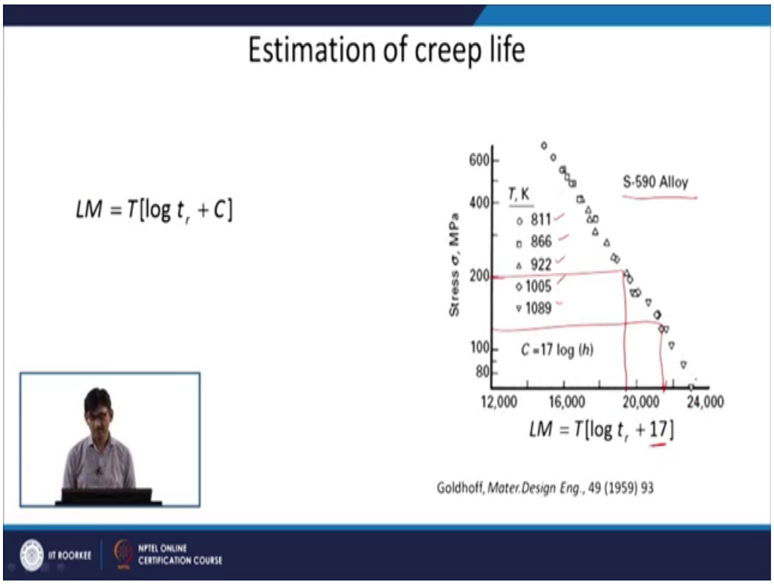
So, for example, if I do a testing at stress sigma 1; So, this will how this is how the curve will come between the tempre 1 by T and log t r. If I do another test for the same material at another stress level, you will get another curves. So, for each stress condition you will get one curve here ok. So, it is kind of difficult to get. So, many curves and kind of find a life of the component under Creep condition ok.

So, for example, if I am I am using this particular material at the condition where the stresses are going to be sigma 1 ok. So, this is the temperature and I am using my material at condition where the sigma 1 stresses are applicable on that. Then this will be the time to rupture. So, that will be my creep life. For the same temperature, if I am using the same material at stress which is sigma 2 ok; then, I will be having the rupture life is this one ok.

So, this is one life this another life you can called its t r 1 t r 2 let us say and t r 1. So, from here, I can tell you that the sigma 1 is more than sigma 2 here because my time to rupture is reducing as a function of stress.

So, sigma 1 is more than sigma 2. If you have even lower sigma value, the creep life will increase or if I change the temperature suppose for the same stress cycle if I inc reduce the temperature one if 1 by T is increasing here the temperature, I am reducing in this direction. So, if I reduce the temperature, you can again see that my creep life is increased ok. So, reduction in stress and reduction in temperature is going to increase your creep life in general. So, I can express all these data for each of these stress different stress acting on the system by Larson mirror parameter.

(Refer Slide Time: 37:05)



Estimation of creep life

$LM = T[\log t_r + C]$

Goldhoff, *Mater.Design Eng.*, 49 (1959) 93

So, this is what is plotted here for certain alloy that T is log t r plus 17. So, the this is some range for different material, you will have different constant here ok. So, for this material the constant is constant is 17 ok.

So, now the all the stresses are different stress data is plotted on one single curve here now at different temperatures ok. So, on x axis you have this Larson mirror parameter which is dependent on temperature. This is the Creep life t r time to rupture and some constant is there ok. So, now, if I know that my material is going to be exposed to this stress for example, 200 ok. So, let us say it is going to be exposed to 200 ok. Then, I can find out that what will be the Larson mirror parameter at that stress.

So, let us say it is going to be around if there is 20000, it must be around 19000 or 19500. So, here it will be 19500 temperature. We know that for which temperature, I am doing the test ok. So, that temperature will come here. So, I can find out the for this temperature and this Larson mirror parameters that what will be the time to rupture or what will be the creep life ok.

So, now if you want to if you think that the this is not suitable maybe I can try to redesign the my component and bring down the stress to some other level and again I can find out that what will be the time to rupture for a particular condition ok. So, the all the temperatures curve are plotted on one single curve here ok. You can see for different temperature all are falling in one single curve. So, once I know the stress, I can and the temperature on which I have to use this material, I can find out that what will be the time to rupture.

So, either I will manipulate the temperature or I will manipulate the stress to get more life out of the component or I can use a different material for which you will have a again and new curve and that can be used to have a higher creep life under the given stress and temperature condition ok. So, we can also do this quantification of the creep life and find out that which material or which service conditions will be appropriate for my component ok.

So, with that thank you and so, this is our lecture on Creep. So, fully we have covered the whole idea related to Creep and for in this particular lecture.

Thank you.