Nanotechnology Nanostructures and Nanomaterials:
Characterization and Properties

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Lecture - 43
Fracture and Creep

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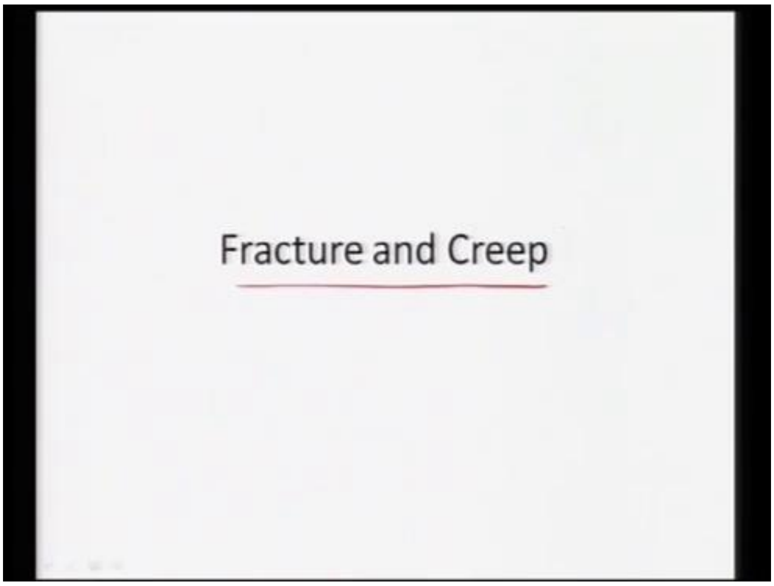

Fracture and Creep

In this lecture, we will learn about fracture and creep fracture and creep are the two distinct mechanical properties of a material which define how the material behaves since at an environment. So, like fracture is the fragmentation of the material into 2 or more pieces, whereas creep is the time and temperature dependent deformation of the material and will learn about these 2 aspects of material as we go along.

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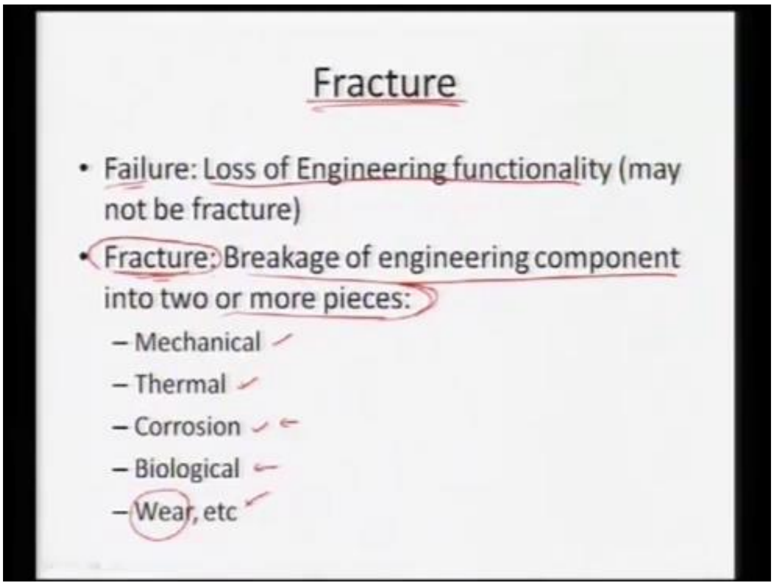

Fracture

- Failure: Loss of Engineering functionality (may not be fracture)
- Fracture: Breakage of engineering component into two or more pieces:
  - Mechanical
  - Thermal
  - Corrosion
  - Biological
  - Wear, etc

So, to define fracture before we define fracture we want I would like to say what failure is so failure is very much different than the fracture because failure is a loss of functionality. So, it like if I have a cycle I am riding a bicycle if the, if just the little there is a deformation of the cycle tyre I will know that I cannot ride the cycle anymore. So, that is a failure, for the failure of the functional there is no, the tyre is no more functional, so I cannot ride a cycle anymore.

So, that is called loss of engineering functionality it may not be fraction though this tyre is same tyre can be fragmented in 2 pieces still it is a failure. But, also it is fragmented of fracture, so we define fracture as a breakage of engineering component into 2 or more pieces and then any engineering process we do not want fracture to be catastrophic. So, it means we want fracture to always provide some indication that it is going to fails because if it fails while fracturing it can be very catastrophic in nature.

So, like say a material is been turned on a lathe machine and if the material fails without any indication that will be very catastrophic because it can hit any nearby operating personnel. So, in that case it might be very damaging, but if the component or material gives an indication that it starts deforming or it starts bending itself or starts loosening losing its shape.

Then we would get a idea that this material is going to fail and we can take precautionary measures, we can stop the instrument or the machine and then we can replace the component. So, that is why it is very important that we learn about fracture how material is going to fracture or how it is going to break a particular engineering component. So, the indication of micro engineering, indication will be very much helpful in altering or altering the microstructure and then basically being able to tap the exact requirements from a particular component.

So, in terms of manipulating the component and tailoring it for particular engineering need will be very helpful because now we can take care of factor of safety. So, we can also give the exact weight what is required for taking a particular load, so designing of a engineering component will become very helpful in terms of weight saving economising. So, the overall component while rendering the exact functionality that is expected out of that particular component and this fracture can be through mechanical load.

So, if I apply a very high stresses or very high load to the component which it is not designed for then the component can fail or it can fracture thermal loading. Now, if I can thermally load a particular component it can just basically fracture because at high temperature temperatures the strength of the material also starts degrading. So, depending on that it can fail again if I take that material and take it to very low temperature there even smaller impacts can fragment the material.

But, because the material would have gone undergone ductile to brittle transition temperature it means the component itself becomes highly brittle in nature. So, that can be the thermal aspect of it also it can be other aspect to the creep as I said at high temperature greater than point 4 times the melting point of the material. So, it can again lead to very lower strengths yield strength can be very low at high temperatures, so it cannot sustain those high loading and it can fragment.

So, fracture can also occur because of corrosion the corrosion can start eating away the material in case there is a pitting corrosion or very dramatic corrosion. So, the design strength of the component will not be its exact value because all the material has been damaged because of corrosion and it will not be able to take as much load as it is been designed for. So, in that case corrosion can also induce much more damage for a catastrophic failure or fracture again some biological entities can also lead to fracture.

Since, there are certain there is say a particular component is being placed where we have very high bacterial activity and that has start doing certain leaching of the material and in turn it will degrade the strength of the material. Then obviously the material, the material for which it was designed for is no more serving its purpose. So, it can again fracture again there if, there is there to there to articulate the surfaces one surface will start upgrading against other.

So, even where can cause sudden or traumatic fracture of one of the components or both of the components as well. So, we can see the fracture is very different from failure because failure is a loss of functionality it may not result to fracture. But, fracture is a final component like even after failure the component can basically fragment that is the next stage of failure or a fracture definitely means failure.

But, failure does not always mean fracture and fracture can be induced by many various input variables like mechanical shock or a thermal shock or corrosional corrosion of the material. So, it can be biological dimensions of material, it can again be wearing of material and there can many other components as well a combination of these or more can also induce the fracture.

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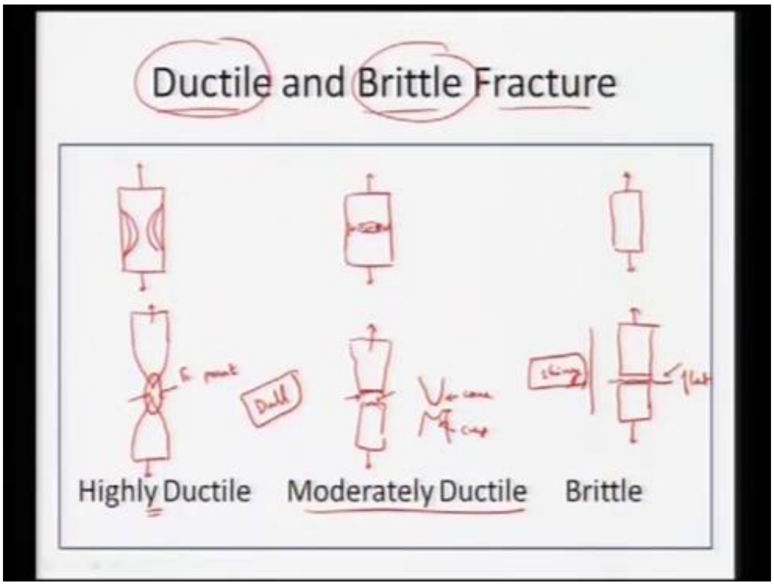

Ductile and Brittle Fracture

Highly Ductile

Moderately Ductile

Brittle

So, just to show a feel of how the ductile and brittle fracture can be induced, so why ductile and brittle fracture is why because if I am getting some indication. So, if a material fails very dramatically catastrophically like if I take a chalk piece and start I just shear it up bend it the material or the chalk piece will fracture in a brittle fashion. But, if

I take a aluminium wire I start bending it the aluminium wire will not break it will start deforming and I will have to, I will have to do the process of bending a many a times.

So, that it finally fractures, but in the process what I have done the material has undergone much more deformation before it has been fractured and that is very good for us. So, because now we are getting an indication that the material is going to fail and, now if the if the need arises we can always replace that particular aluminium wire some stronger material or newer material within certain design limits. So, that is a basic need of ductile and brittle fractured component, so we can design them accordingly in certain cases we want to work with brittle.

So, brittle material because of their very high strength because of even there, say optical properties or certain biological properties we would want to play with brittle materials. So, in that case also we need to some more impact much more toughening to it we will see how we can do that as we go along. But, in this in this slide I will just tell about the difference between a ductile and a brittle fracture, so what happens if I take small piece of material. So, I start putting a tensile loading, so I have a ductile material I can have a moderately ductile material and then I can also have a brittle material.

So, let me say the initial cross section of the all the 3 materials are same, so in a highly ductile material what will happen the material will start necking at certain stage. So, eventually what will happen it will fracture at a common single point, so this is this will be the fracture point in case of a very highly ductile material. So, we can see that the material will start deforming at some stage it will start necking just to accommodate the deformation and this neck will start going smaller and smaller.

So, finally what will happen will some area which is very weak and this point contact will occur in a very highly ductile material. Now, in case of moderated moderately ductile material what will happen that will start creating certain voids in between as soon as the material is been deformed the neck is occurring.

But, not to that large extent it will start creating to start some voids in between which will try to basically merge together and will get something called a cup and cone type of fracture. So, this region would have fractured, because many micro cracks will not become much bigger cracks and they will be more fractured to form this sort of a fracture. So, we will see some sort of a cone and a cup type of a fracture, so like we have a cone, so cone will appear more like this and cup fracture will be something like this.

So, we can see this is kind of a cone and this is a cup, so we can see this type of fracture in a moderated ductile material because in this case the necking is occurring to a very minor extent. But, it is occurring because of the cracks in between which is in case of brittle material there is no necking. So, material will fracture very flat, so will see that the surfaces very flat and apparently no deformation is occurred in the material apparently what is also you will realise the difference between brittle.

So, ductile fracture is the fractured surface will be very shiny, whereas these surfaces will be very pretty dull by when you see them. So, we can see in ductile fracture it can be a point fracture it can be cup and cone type of fracture. Now, the surface will appear pretty dull, whereas in case of brittle fracture we will see that the surface is pretty shiny and highly flattened edged.

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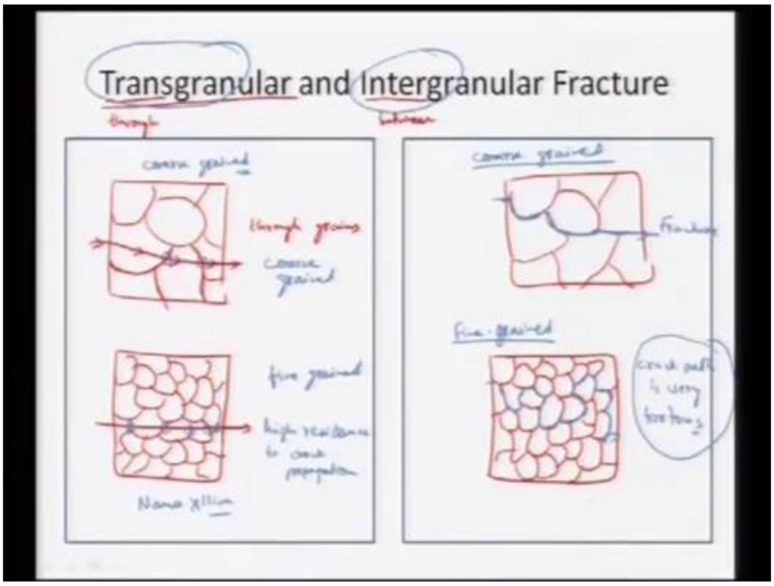

Transgranular and Intergranular Fracture

So, depending on that, the brittle fracture can again be transgranular or intergranular in nature and trans means it is through the grain intergranular means in between the grains. So, fracture can also be transgranular or intergranular, so if we can see a material will always have some grains a polycrystalline material you will see the multiple numbers of grains out here and there. So, we can see ain both the cases we can have some grainy material, so we can see that we have certain grains out there, so in a fracture what will happen the crack has to propagate from one end to the other end.

So, in a transgranular what is happening is it is going through the grain, so it is through the grains, this is in between the grains. So, you can see a crack once it is propagating it can propagate like this from this end to this end and eventually we have a fracture. So, the moment of crack from one end to the other end is through the grains and at room temperature the strength of grain boundary is much more stronger than the grain. So, grain boundary is much more stronger than the grain, so apparently if we have a nano crystalline material or it means if we have a material with very fine finer grain sizes.

So, in this case if we have very finer grain size then in turn what will happen, the crack has to encounter the grain boundaries more number of times. So, in process we will see here much enhanced strength of the material, so in this case we it was encountering grain boundary 1 and 2 and a coarse grain material. Whereas, in case of fine grain material or a nano or a nano material the crack is encountering grain boundary 1, 2, 3, 4, 5 times. So, we can see it is much more it is encountering grain boundary much many more number of times.

So, it will provide very high resistance to crack propagation high resistance, so we can see nano crystalline. Whereas, a coarse gradient coarse grained material will show very easy crack propagation, whereas in nano crystalline material we can see much more encountering of the crack path with respect to the grain boundary. So, we can see there will be very high resistance of the crack propagation in case when we have a nano crystalline material.

Similarly, for intergranular fracture also we can see if a crack is propagating in this case of intergranular fracture the crack will initiate from one side and then it will follow. So, let me also draw one for the nano crystalline, so I will see that in this case we have a very fine grain structure.

So, in this case we can see that we have very fine grain structure and then grains will be very I am drawing little more systematic or very self following structure. But, it will be very random in nature, so in this case of coarse grained material crack will initiate at one point and it will follow the grain boundary to finally fracture. So, this is the overall crack path in the case of coarse grain coarse grain material whereas in case of fine grain material or a nano crystalline material the crack will initiate at one point.

So, it will start following the grain boundary and it will start following the way it can follow may be somewhere and it will finally. So, in this case we can see that the crack path is very tortues and it means that the crack has to change its path very dramatically. So, in a coarse grain material is soon as the crack has initiated along a particular grain boundary it can progress through certain distance without getting affected without changing its direction.

So, that is for coarse grained material, whereas in case of fine grained material the grains are so fine that it has to come back to its original point changing its direction by say 180 degree. So, it was going down and it has to come up, so in a process it is getting much more resistance because of the path because if I if the crack propagating from left to right it has to go down. Then come up it is doing nothing but absorbing certain energy for maintaining its original path, so in turns we can, in turn we can see that the crack path is very tortues for a fine grain material.

So, we can see there is there is very high resistance for crack propagation in a fine grain material, so we can see that whether the fracture is either transgranular. So, whether it is intergranular of fine grain material will impart much more resistance to the crack propagation or it will make the correct path very tortuous. So, in turn the overall strength will be very high for a fine grained material in one more term the toughness also.

So, toughness of these fine grained materials also will be very high because, now these fine grained materials also realign themselves and they can absorb certain shock. So, overall strength and the stress part can recombine statistically to enhance the fracture toughness as well. So, generally fine grain material will have very high toughness in comparison to that of coarse grain materials as well, so that is what we just saw in a micro versus nano crystalline material.

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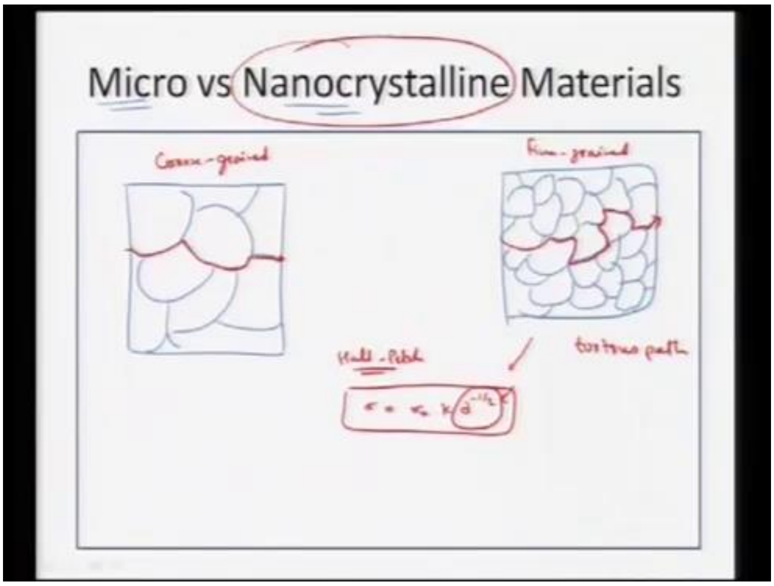

Micro vs Nanocrystalline Materials

So, we can see that in micro in a micro grain material we have much bigger grains, whereas in nano crystalline material we have very fine grains. So, that part we already observed that in a in a case of nano crystalline material the crack has to take a very tortuous path. So, in turn it can provide very high resistance to the crack path, so in this case the crack path is much easier listen this case it has to go here change its direction come back.

So, we will change its direction and get a very tortuous path also the strength of the material enhances as we go with lower and lower grain size this is giving by Hall Petch relationship. So, we have a we have a coarse grain we have fine grain material, so what eventually we are seeing in a coarse grain material the crack path is very easy it can follow through very easily.

Whereas, in fine grained material the resistance offered by the structure itself is very high and also the strength of the material for deformation also requires very. So, you mean enhanced strength because of its lower grain size, so that part is being true for the nano crystalline material that we can enhance the strength of the material via reducing the grain size. But, that is true until only say around 20 nano meter of grain size and below that inwards Hall Petch relationship also comes into picture.

So, that means that for grain size lesser than say around 10 or 15 nano meter the strength also starts degrading that is the overall deal with the micro and nano crystalline materials.

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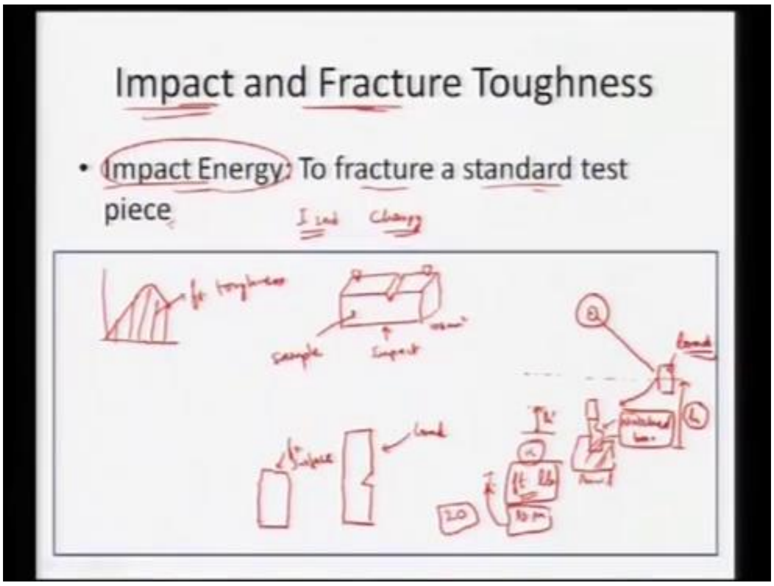

Impact and Fracture Toughness

- Impact Energy: To fracture a standard test piece

So, that eventually what happens is that the impact and fracture also is dictated by the grain size of the material like I said, like I said earlier the tortuosity is being increased. So, also the strength of the material is increased and at the same size the nano crystalline grain they can also realign themselves. Now, they can absorb much more shock and then they can impart very high impact energy or they can have very high fracture toughness the impact energy is nothing but it is defined as a fracture.

So, fracture fracturing a standard test piece the energy which is being absorbed in while fracturing a standard test piece. So, like we do it tensile test this is much more rapid form of impact of that particular test that we can achieve fracture very quickly. So, instead of doing the impact tensile test of loading the material and seeing the fracture this test can immediately fracture it. So, we can get something called a fracture material impact energy it can be identified using Izod testing Izod notch bar testing or Charpy.

So, Charpy testing in this case what is happening is we take a notch we develop a notch on in a material and that material is now, is now supported on this instrument. So, an impact is provided on the other side and then this material entirely fractures and that is thing is that particular sample is now also being tested in Charpy by using this instrumentation that we have load on one side. Then we have our sample which is sitting and then it will again have a notch on this side, so a notch bar specimen is on this side which is held on the enveland for a certain height.

So, this has certain mass this load it has certain mass, so what happens is this load is allowed to free flow and impact this notch bar. So, with certain height so there will be some absorption of this energy because we have certain load and it has certain height once it is allowed to flow or swing from one end to the other end there is loss of height. So, we had certain height and, finally we can also see some H dash, so there will be lowering of height because of the absorption of this energy by the notch bar.

So, in turn to this particular equation we can always find what is the overall energy which is being absorbed by the sample, so our sample is a notch bar. So, this is our sample and through that we can also see that what is happening in terms of the absorption of this energy. So, we have either Izod testing or Charpy bar testing, so this is a bar general rate is around 10.8 around 10.6 to 10.8 millimetre square sample and we provide a notch.

Then it is basically being fractured the top centre schematic shows the further Charpy impact testing and in this case we will have a notch 45 degree V notch which is around 2 millimetre deep. Now, it is the root radius of around 0.25 millimetre and the impact direction is shown along with, whereas the right hand schematic shows in which we choose a impact testing for a for a Izod testing.

So, both the both of these methods will give us the fracture surface, so this is what we can see that the overall impact it basically is to fracture the sample. So, this sample will fracture it where we wherever we have notch, so this load will start fracturing will fracture it along the notch and then we will see some fracture surface. So, the impact and fracture toughness can be measured by using Izod or Charpy testing and we provide a notch in the sample.

So, the load is shown with a certain height and then that load strikes the sample and there will be reduction of the height because of the absorption of the energy by the sample. So, by changing the height of this load we can calculate what is an impact energy that is been absorbed by the material it can be the provided either in Joules or foot pound 1 Newton meters. So, Newton meter come to with Joules or it can also be calculated as foot pound and generally energy which is being provided. Here, it is around 20 Joules or 15 foot pounds are basically the minimum requirement for a particular material for certain engineering applications.

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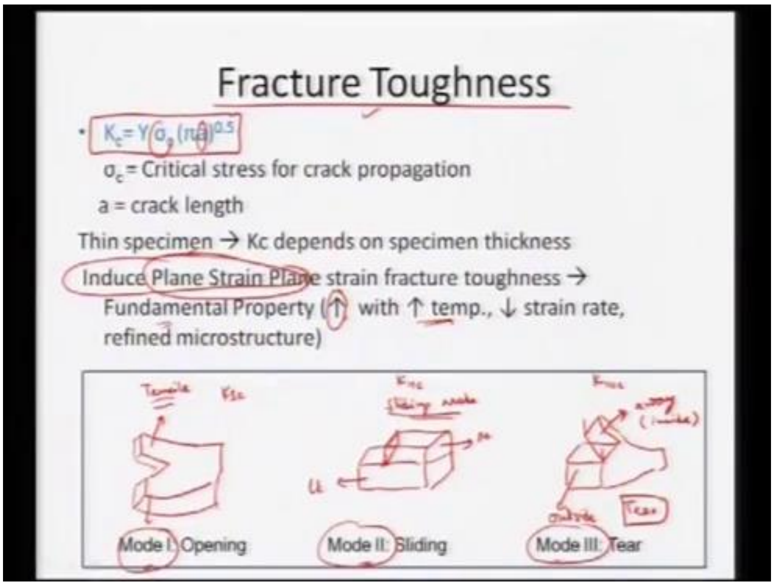

Fracture Toughness

- $K_c = Y \sigma_c (\pi a)^{0.5}$

  σ_c = Critical stress for crack propagation

  a = crack length

Thin specimen → Kc depends on specimen thickness

Induce Plane Strain Plane strain fracture toughness → Fundamental Property (↑ with ↑ temp., ↓ strain rate, refined microstructure)

Mode I: Opening   Mode II: Sliding   Mode III: Tear

Now, coming to the fracture toughness, so apart from impact energy is the fracture toughness is the very critical component of the material. So, as a material will be very highly tough it will have very high value of fracture toughness and fracture toughness is given by K C that is equal to Y.

So, that is a constant for a material and depending on the geometry sigma C is a critical stress for a crack required for crack propagation K is the crack length. So, K C is equal to Y sigma under root of pi C and generally we can see that the thin specimen. So, when we have thin specimen the fracture, toughness will start depending on the specimen thickness because nor the material can also deform along the third direction.

So, if we take a very thin material it can start deforming along that side, so the toughness also will be very different and if we do not allow the stream to be accumulated along thickness. So, we can what we can do we can enhance the thickness of the material for, now in that case it will restrict any deformation along the z axis or the third axis. So, by that we can also induce plane strain conditions and what plane strain condition do it becomes the fundamental property.

So, we can see that if we want to if you want to have a constant toughness for a material we need to have very high thickness of the material. But, of the crack notch should be much thinner than the thickness of the specimen, so that there is no deformation occurring in the third direction. Again, deformation of this can be defined in terms of plane strain as mode 1 or mode 2 or mode 3 and we can see that the mode one opening is more like this.

So, we can take a sample with certain thickness we can have, so we can have only the opening modes. So, mode 1 is also called tensile mode or the opening mode, so we can see that it is just the tensile mode or opening more it can also be sliding mode. So, we can have, this is called as sliding mode this second mode is called sliding mode in this the top piece is being taken on the right hand side. So, this thing is on taken being taken on the left hand side along the notch, so this is called a sliding mode third mode can be a tier mode.

So, we can see that in this case what is happening is, so in this case we can see that this part is being taken away from each other. So, it is going towards inside this plane and this is going outside the plane. So, in this plane it is called a tear mode, so we can obtain the under this plane strain conditions when we have, when we limit the deformation along the third axis. So, what we can do we can do this fracture can evaluate the fracture toughness via tensile mode sliding mode or the tear mode.

So, we can call it mode 1, mode 2 or mode 3 toughness, so we will call them K 1 C, K 2 C or K 3 C for these 3 different conditions also fractures toughness. Now, also it is a fundamental though it is a fundamental property it basically increases with increasing temperature because all with increase in temperature the material is much more it can deform very easily. So, it can absorb much more energy, so it can provide a higher value of fracture toughness as we increase the temperature also it will increase.

But, as the lower the strain rate because as we increase the strain rate that is very minimal time for material to adjust itself or to align or equilibrate with the surroundings. So, in that case as we start increase, increasing the strain rates, the fracture toughness of the material decreases dramatically. So, the third case is the refined microstructure as we talked about once we were nano grained, nano grained material. So, what it can do, it can provide it can provide enhance strength as well it can accommodate much more strain into the material.

So, in turn it can provide very high fracture toughness to the material, so we can see that fracture toughness is fundamental property. So, it will increase with increase in temperature or it will increase with decrease in strain rate or it will increase when we have a very refined microstructure. So, that is the trait of a material, so once we have a very fine microstructure or a nano structured material. But, it generally shows very high fracture toughness in comparison to that of micro or a conventionally or conventional material which has a very big grain size. So, fracture toughness is also one of the important properties of the material eventually what can also happen.

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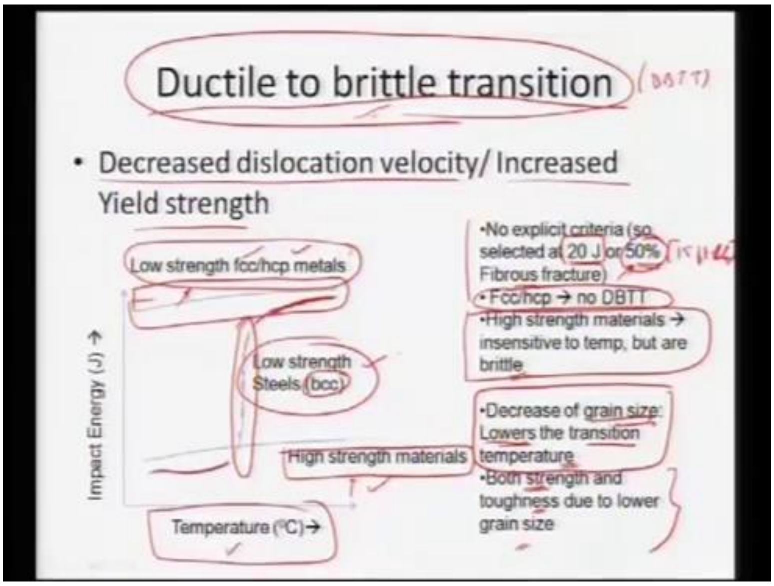

Ductile to brittle transition (DBTT)

- Decreased dislocation velocity/ Increased Yield strength

- No explicit criteria (so selected at 20 J or 50% Fibrous fracture)
- Fcc/hcp → no DBTT
- High strength materials → insensitive to temp, but are brittle
- Decrease of grain size: Lowers the transition temperature
- Both strength and toughness due to lower grain size

We can also observe a ductile to brittle transition and that occurs the brittle fracture generally occurs because of decreased dislocation velocity. Now, dislocations cannot accommodate the stress because the rate of strain is pretty high or it means once you reduce the temperature the dislocation cannot move that easily. So, also the material has increased its yield strength so in turn it cannot accommodate, thus yielding of the material. So, in turn we can achieve a, so we observe very brittle behaviour of the material generally for low strength or F C C or H C P material.

But, they generally show very higher impact energies and, but it do not show any change of this impact energy with temperature. So, it is also called ductile to brittle transition temperature ductile to brittle transition temperature, so we do not see that transition. So, in case of low strength F C C or H C p materials, whereas high strength materials also do not show any variation in impact energy with temperature. But, they eventually their highly brittle, so that is the problem with these high strength materials, whereas B C C materials.

But, they show transition format high temperature they are at high temperature they are very ductile, whereas at certain point they undergo a transition. So, in which suddenly from brittle ductile material they become highly brittle, so that is the problem with B C C materials. So, this concept came into existence because of during World War 2 when many naval ships while they were sitting in the sea they broke into 2 pieces these materials, the ferritic steel which had enough strength at room temperature.

So, they were listened to the sea and because of the temperature of that zone the ship just broke into 2 pieces. So, that initiated the study of what happens at this load temperature why these ships are failing into more than 2 pieces. So, it is because of load temperature and essentially we can see that there is no, so that was the concept of ductile or brittle temperature transition and eventually we will see that there is no character criteria.

So, that when this transition is occurring, so that is being selected as 20 Joules or 50 percent of fibrous fracture or it is also 15 foot pound of energy that they can be absorbed. So, we can see when the impact energy is around 15 to 20, 15 foot pounds or 20 Joules we can call that as a ductile embedded transition temperature. So, at what temperature that particular thing is been observed or we can also relate it to 50 percent or 100 percent fibrous fracture.

Also, in this case D B T T is given by the 50 percent fibrous fracture, but once it is being initiated we can take it down to say even 100 percent fibrous fracture as well. So, we see here an F C C and H C P be around seeing any ductile to brittle transition temperature and they generally are low strength materials. But, they show very high impact energy and high strength materials also they are insensitive, but they are inherently very brittle. So, coming back to the microstructure of the material when we have a nano crystalline material we are seeing decrease in the grain size.

So, that will allow much more deformation even at much lower temperatures because, now grains can realign they also have very high strength. But, in turn they can have very high toughness or it means they can survive or they can retain this high impact energy of 20 Joules even at much lower temperatures. So, decrease in grain size it also lowers the transition temperature that is very good, because now the material can be operated even lower temperatures.

So, that occurs because of both enhancements in the strength as well as toughness due to the lower grain size. So, this is this is one more functionality of the nano crystalline materials that they can show enhanced toughening in such conditions as well. So, we can see this phenomenon of ductile to brittle transition temperature how it differs from material to material.

Now, like in this case of low strength F C C materials it has very high impact energy low high strength material they again show non dependence on the temperature of impact energy. Whereas, B C C material, they show undergo a transition and to load this transition is very is very much required. So, that can be achieved via controlling the grain size, so we can reduce the grain size and then we can achieve enhance toughening.

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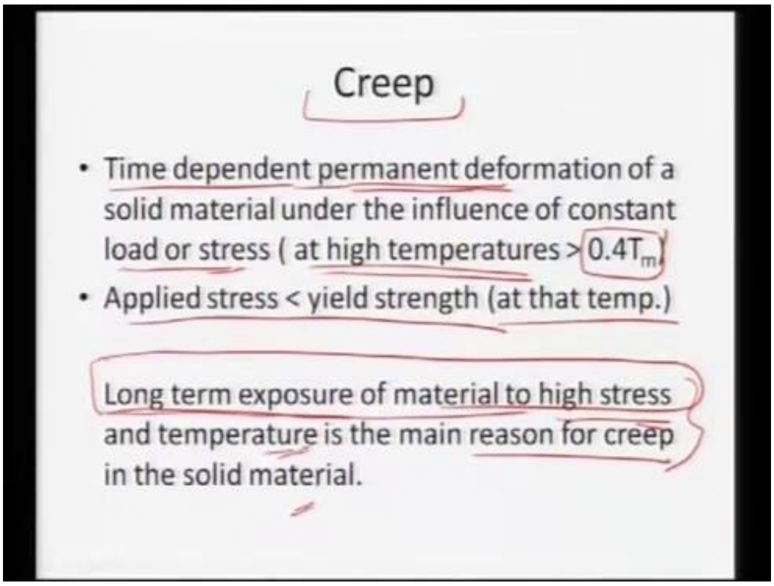

Creep

- Time dependent permanent deformation of a solid material under the influence of constant load or stress (at high temperatures > $0.4T_m$)
- Applied stress < yield strength (at that temp.)

Long term exposure of material to high stress and temperature is the main reason for creep in the solid material.

Now, coming to another deformation criterion which is called creep, creep is a time dependent permanent deformation of a material. But, it is under the influence of constant loading of stress which is pretty low much low than the yield strength. But, at pretty high temperatures, the temperatures are ranging greater than point four times the melting temperature of the material.

So, we can see creep is a time dependent permanent deformation of a solid material under the influence of load or stress which is much lower than the yield strength at room temperature. But it occurs at very high temperatures which is to the order of greater than point four times the melting temperature. So, we can see applied stress is pretty less than yield strength at that temperature and this basically occurs. So, that long term exposure of the material because of high stress and temperature is main reason for the creep.

So, if we keep a material at high temperature high enough temperature for long enough duration and that material will undergo some changes in the, it will deform permanently. So, that is the cause for the deformation of the material and that is not very desirable because it will change the shape of the component. Now, that might lead to the sacrificing the safety of the component, so that in that case we can see that the creep also needs to be controlled by enhancing its strength. So, we can neutralize certain design criteria and we can avoid long term exposure of the material to high stress and temperature to avoid the creep.

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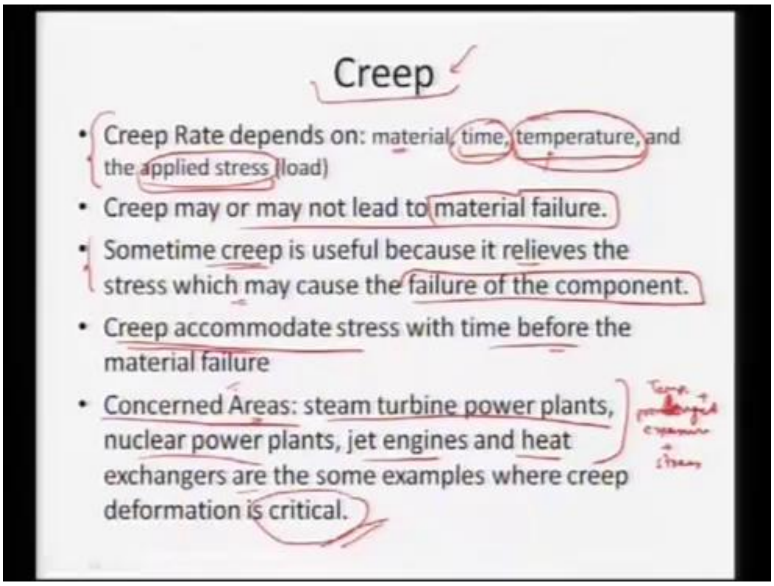

Creep

- Creep Rate depends on: material, time, temperature, and the applied stress (load)
- Creep may or may not lead to material failure.
- Sometime creep is useful because it relieves the stress which may cause the failure of the component.
- Creep accommodate stress with time before the material failure
- Concerned Areas: steam turbine power plants, nuclear power plants, jet engines and heat exchangers are the some examples where creep deformation is critical.

Now, again in the creep, creep rate will depend on the material kind of material we have, so if we have very high strength material the creep will be delayed the time of exposure. So, if we keep the material for long enough time, if we expose it for very long enough time the creep deformation will be pretty much high temperature.

Now, again if we keep the material at very high temperature the creep rate will be very dramatic, will be very high and the material will deform very rapidly applied stress. So, again it also depends on the kind of loading that is being incurred on the material, so if we have a very high applied stress the material will undergo very high rate of creep.

So, we can see the creep is dependent on many parameters such as material its microstructure the time of creep or time of exposure temperature at which the creep is occurring. So, even the applied stress on which this loading is been provided to the material though creep is though creep induces deformations it may or may not lead to material failure.

But, the creep deformation can be very margin it can be very minimal, so it might deform the material, but may not lead to eventual failure as well. So, sometimes creep is very useful also because if a material has undergone it has say inculcated much stress because of certain processes. Now, once we heated to high temperature for long enough duration it can relieve those stresses, because nor the yield strength of the material has been reduced nor it can release its stresses.

So, which might have incurred during the processes or even during the even enough functionality or when the material is been utilized using the service. So, that again can reduce that relieve, the stresses and that can again avoid the failure of the component in that sense sometimes creep can be little bit useful. But, it has to be in a controlled fashion, so creep accommodates stress with time before eventually the material fails. So, again the concerned areas because once we have a creep it starts accommodating much more strain or it can accommodating, starts accommodating stresses.

So, the concerned areas which can which are affected by this creep are steam turbine power plants nuclear power plants jet engines heat exchangers. Basically, some places where we can have some temperature for prolonged exposures and some stress that is incurred on material. So, like we have steam turbine power plants nuclear power plants jet engines height heat exchangers, so here we are we are talking about certain temperature. So, certain duration soon on which had particular component is been operated and also the stress which the component has to resist.

So, in those, under those three conditions we can see that it can always induce some deformation in a material. So, because that it is very favourable for a very high temperature around greater than 0.4 times the melting temperature there is some stress or loading. So, also there is enough time for the material to respond to that, so in that case creep can become very critic. But, also in this case we have to control the creep by designing proper designing proper selection of the material also a calculative.

So, what is a temperature, what is a time and what is a stress developed that is acting on the on that particular component. So, in that case we can utilize certain design concepts of controlling the microstructure as well. So, by altering the microstructure it can also control creep in certain sense or by controlling the stress or temperature, we can control the creep, so creep has its own features we can see that.

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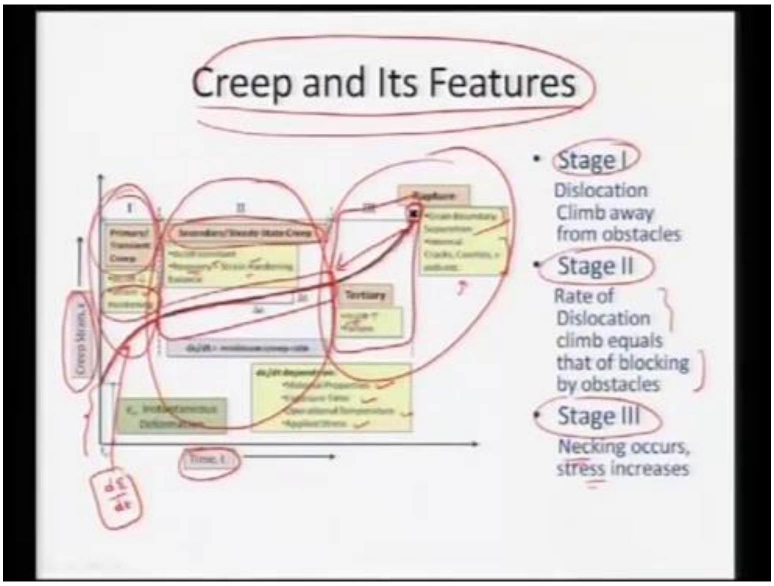

Creep and Its Features

- Stage I
  Dislocation Climb away from obstacles
- Stage II
  Rate of Dislocation climb equals that of blocking by obstacles
- Stage III
  Necking occurs, stress increases

The creep can be divided into 3 stages it can be stage 1, stage 2 and stage 3 and stage 1 is called primary or transient creep. So, we can see in first stage what is happening is we have we have an instantaneous, initially as we apply the loading we have some instantaneous deformation. So, that inculcates in the material, so as soon as we apply the load it will have certain strain that instantaneously develops and as soon we. Now, as soon as the time increases what we can see the creep rate, now starts decreasing and in this case what is happening.

So, the dislocation climb is occurring which is away from the obstacles and also the strain hardening is occurring in a material that starts reducing the creep rate. So, the creep rate is giving by the ratio of creep strain with respect to time, so d epsilon by d t that basically starts, now reducing in the first stage.

So, it is occurring away from the obstacles and we can see the creep rate starts decreasing and there is instantaneous of some strain hardening also occurring in a material. Now, that provides enhance resistance to the creep, whereas in second case what is happening it is called secondary or the steady state creep. So, in this case we can see the creep rate is almost constant it is more like a straight line and in this case what is happening the recovery and the strain hardening they sort of balance each other.

But, in first case we had, we had higher rate of strain hardening in case of second stage what is happening the recovery and strain hardening. So, they balance each other or the rate of recovery instant hardening is very similar, so we can see here is the rate of dislocation climb equals that of, that blocking. So, that occurs the obstacles and this is nothing but the minimum creep rate and this is a prolonged situation this is a dominant factor which is basically been incurred in a second stage, in the second stage.

So, that dictates how much is the lifetime of the material and again d epsilon by d t, it will depend on the material property is exposure time. So, what is the temperature, that is the stress, so we by controlling the microstructure also we can obtain a very high creep resistance material and in this creep. So, basically the grain boundaries are very harmful or deleterious, so that is where deformation really occurs, so by incorporating nano crystalline material that will have very high creep rates.

So, by increasing the grain size we can have much lower creep rates because, now grain is much more stronger than the grain boundary at where high temperatures. Now, in third case what happens the necking starts the stresses also increase the grain boundary separation will occur on all that. So, tertiary creep is generally very rapid and this duration is also very short, so as soon as a tertiary stage starts the dimension of the material also enhances very dramatically. So, also we can see that the creep rate also starts increase very dramatically and leads to eventual failure or rupture.

So, that occurs by grain boundary separation there will be formation of internal cavity is cracks voids and so on. So, that has damaged the material to very large extent, so we can see the creep primary stage we have lowering of the strain, lowering of the creep rate because of strain hardening. But, in second case we have a balance between the strain hardening and the recovery and third stage we have very rapid enhancement of the creep rate. So, eventually leads to rupture, because of the internal defect generation such as cracks cavities and voids.

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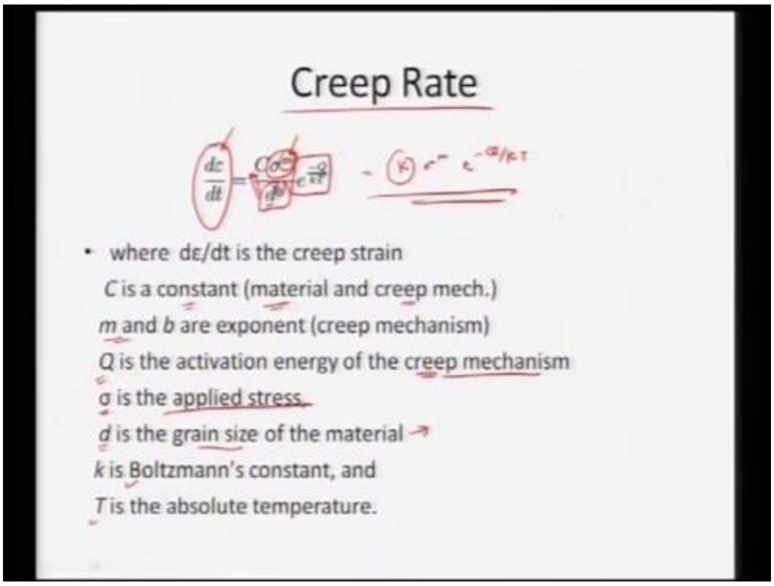

Creep Rate

$$\frac{d\varepsilon}{dt} = \frac{C\sigma^m}{d^b} e^{\frac{-Q}{kT}} = K \sigma^m e^{-Q/kT}$$

- where dε/dt is the creep strain
  - *C* is a constant (material and creep mech.)
  - *m* and *b* are exponent (creep mechanism)
  - *Q* is the activation energy of the creep mechanism
  - σ is the applied stress.
  - *d* is the grain size of the material
  - *k* is Boltzmann's constant, and
  - *T* is the absolute temperature.

Now, the creep rate is basically been given as d epsilon by d t it is the function of the sigma that is applied stress with respect to also the temperature. So, as soon as the, as the temperature is high and stress is high the creep rate, the creep rate is also very high it can also be given as K sigma power m e power minus Q by Q T so this can be constant. So, this is a constant which is a combination of C by d raise to be, so we can see that C is a constant which depends on the material and the creep.

So, creep mechanics how the creep is really occurring m and d are the exponents, so we can see m and b are the exponents. But, m is the strain exponent b is the grain size exponent Q is activation energy of the creep related to the creep mechanism. So, depending on which creep mechanism is active we have a corresponding Q or the activation energy is related to that sigma is the applied stress.

So, as we have very high stress this exponent will dictate what is the material response to that particular stress applied stress level d is the grain size. So, as we have a very low grain size the overall value of this d b will be very low and eventually the resistance will also be very low because that that is in the denominator. So, higher the value of d lower will be the creep rate, so we can see that for a nano crystalline material the grain size has to be very higher.

But, the grain boundary area has to be very minimum, so for this particular case, and K is a Boltzmann constant T is the absolute temperature. So, in that case we can see that nano crystalline grains do not serve as a good resistors for the enhance creep rate, so to restrain the creep we always need to have a varying coarse grain material.

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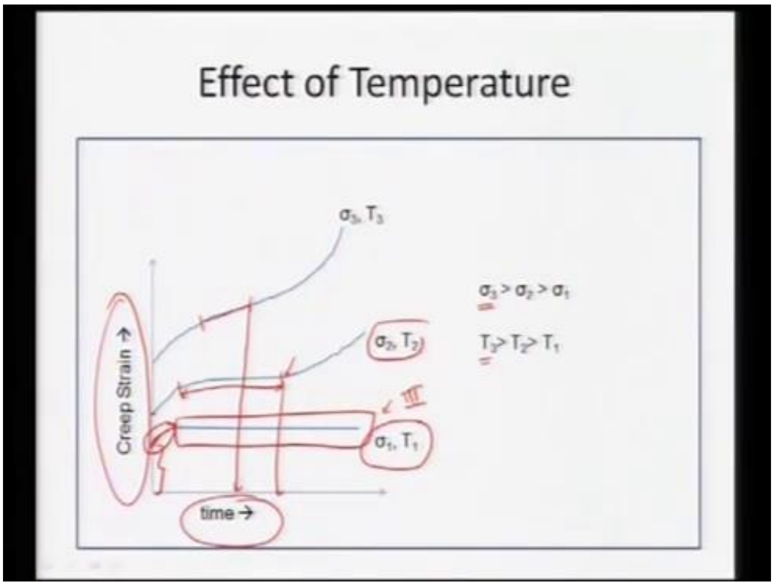

Effect of Temperature

$\sigma_3 > \sigma_2 > \sigma_1$

$T_3 > T_2 > T_1$

So, we can see the effect of temperature and the stress can be given as like this, so we can give define creep strain along the y axis and time along x axis. So, we can see that when we have load stress and temperature our second region or the steady state creep region is very long. So, also we have awe have a particular instantaneous strain that is also much lower, but as soon as we increase the temperature and time. So, the region the instantaneous stress also increases also the region in which we have a stationary creep the second stage creep also is now reduced to very smaller region.

So, that that part we can see with the region starts decreasing with the increase in the stress or the temperature. So, that is the effect of temperature and stress with respect to the creep rate also the damage is now to very large extent because, now third stage has started very quickly. So, in this stage third stage has not started yet in this case it has started at this particular time, whereas in this case it has started much earlier.

So, that will lead to very eventual very raid failure of the component, so as we have very high stress level or very high temperature that will lead to a very eventual failure at much rapid rate. But, now sometimes the extrapolation of data also is very much required because if we do creep we might require e as to complete the test and that becomes impossible.

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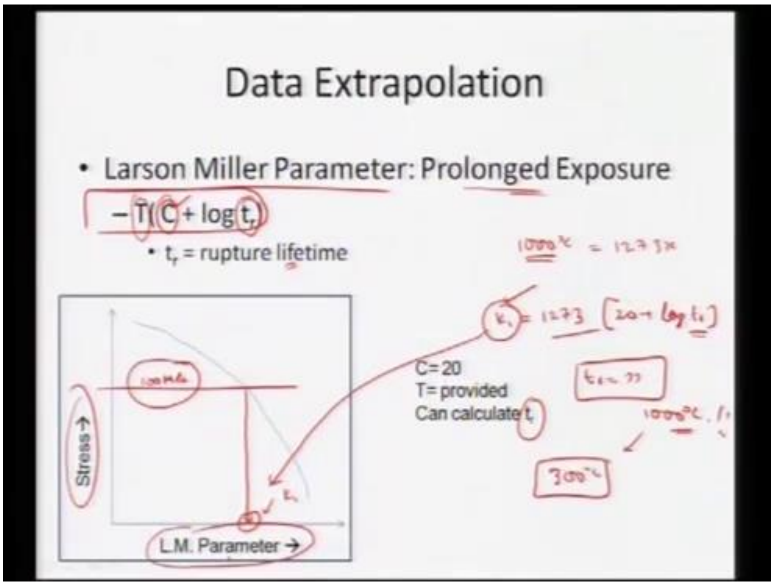

Data Extrapolation

- Larson Miller Parameter: Prolonged Exposure
  - $-T(C + \log t_r)$
    - t_r = rupture lifetime

C=20
T= provided
Can calculate t_r

So, there is a Larsen Miller parameter which can take account of prolonged exposures or enhanced creep rate at enhanced at a elevated temperatures. So, once we know what is a Miller parameter for a, for a particular material we can also calculate what is the stress or the rupture lifetime of the material at certain temperature. So, the Larson Miller parameter can be calculated for certain stress values, so we can see when the fracture is occurring.

So, for a particular stress value say if you want to have a particular stress value say 100 m p a, we can get corresponding Larsen Miller parameter. So, for a particular strain level or stress level we can keep calculating the Larsen Miller parameter for a particular temperature. Now, once we know that we have a stress of 100 m p a, it is giving to such and such Larsen Miller parameter, now we know this term.

So, if you want to what will be the rupture lifetime, say in this case we had we want to utilize at the temperature of 1000 degree centigrade or 1273 Kelvin. Now, once we know what is the Larson and Miller parameter say it is the value of K, C is only 20, so we can always calculate what the rupture time is. So, we can see Larson and filler parameter in this case is k one which equals temperature of 1273 Kelvin, C is 20 plus log of t r.

So, K 1 is known from this particular Larson Miller parameter it is already known, so K 1is known everything else is known what we can find we can identify tar at 1000 degree centigrade. So, once we do the tests at high temperature we can always correlate them with the Larson Miller parameter and from that we can also identify say what will be the fracture time or the lifetime of this component.

Now, 300 degree centigrade and if we actually go about testing this component at 300 degree centigrade we might require at least 4, 5 orders of magnitude high time. So, then the, then the material which is filled at 1000 degree centigrade, now utilizing this Larson Miller parameter. Now, we can back calculate and we can find the rupture time using this Larson Miller parameter, so that is the using utilizing the Larson miller parameter.

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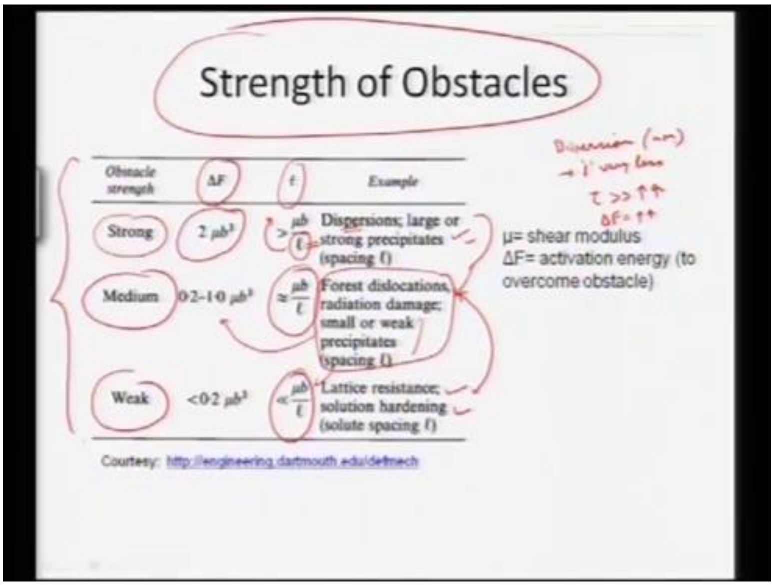

Strength of Obstacles

Obstacle strength	ΔF	τ	Example
Strong	$2\,\mu b^3$	$> \frac{\mu b}{\ell}$	Dispersions; large or strong precipitates (spacing ℓ)
Medium	$0{\cdot}2\text{-}1{\cdot}0\,\mu b^3$	$\approx \frac{\mu b}{\ell}$	Forest dislocations, radiation damage; small or weak precipitates (spacing ℓ)
Weak	$< 0{\cdot}2\,\mu b^3$	$\ll \frac{\mu b}{\ell}$	Lattice resistance; solution hardening (solute spacing ℓ)

μ= shear modulus
ΔF= activation energy (to overcome obstacle)

Dispersion (nm)
→ ℓ' very less
$\tau >> \uparrow\uparrow$
$\Delta F = \uparrow\uparrow$

Courtesy: http://engineering.dartmouth.edu/defmech

Also, this strength of obstacles also comes into picture, once we have a activation energy for overcoming the obstacles the shear what is required for creating the shear for utilized for this creep. So, what we can see the overall obstacle strength, it will be very strong from dispersion, so once we are nano crystalline materials. So, also there is some precipitation at nano scale that can eventually induce very high activation energy. So, it means the creep process can be deterred or it can be slowed down to very dramatic extent when we have nano precipitates.

But, once you hired the dislocations forest dislocations or we can have very weak precipitates that will lead to lowering of the activation energy of a required lower load stress for the shearing. So, the movement of the grain boundaries for this creep and once the obstacles is pretty low we require very low lower shear stress. Now, for causing this creep there will be very lower lattice resistance or there will be lower of solution hardening. So, in that case we can observe that the spacing between the precipitates of the dispersions is also very critical.

So, once the spacing is very near, it can induce very high, it can induce very high resistance to the creep of the material. So, we can have obstacles strength which can be strong weak or medium, so we can see the obstacles strength it can be very strong. So, once we have dispersions order of couple of nano meters also how well they are spread apart, so they are very nearby to each other.

Now, it means l is very less, so this force the shearing force required for their moment is also very high and in turn activation energy is also dependent. So, that also will be very high and we can get very high optical strength because of those precipitates or dispersions. So, this is very critical, once we have nano faces which are present or nano precipitates or nano obstacles very hard, hard obstacles which are present for reducing the grain boundary movement.

But, even the grain coarsening, so in that terms we can use the creep as a material, so because we will have some creep, we have some pinning agents. So, such as, such as very fine dispersions of ceramics this can be there present in a very soft matrix, whereas this is the creep deformation in the material.

So, that is how we can enhance the creep resistance of the material by incorporation of very fine ceramic particles to resist the, resist the deformation. So, due to creep and this obstacle strength can vary depending on what sort of obstacle is being is resisting the creep deformation.

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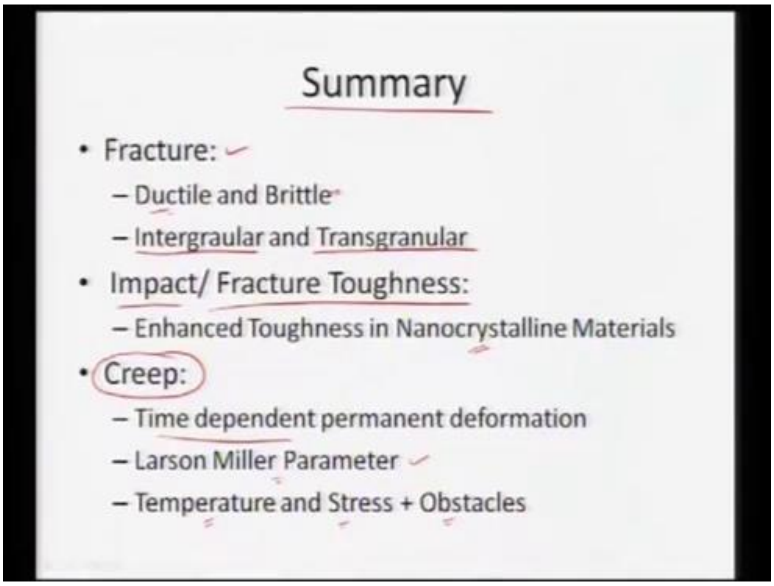

Summary

- Fracture:
  - Ductile and Brittle
  - Intergraular and Transgranular
- Impact/ Fracture Toughness:
  - Enhanced Toughness in Nanocrystalline Materials
- Creep:
  - Time dependent permanent deformation
  - Larson Miller Parameter
  - Temperature and Stress + Obstacles

So, in summary we can see that we have a fracture which can either be ductile or brittle and that depends on the microstructure of the material. So, if we have very fine microstructure that can induce much more strength and strain that can be accommodated in the, into the material before it fractures. So, also we can, we also observed that the intergranular and transgranular fracture can also occur in a brittle material. But, how a nano crystalline grain structure will assist enhanced tortuosity of the crack and enhancing the toughness thereby and impact, and fracture toughness, again we can see.

So, that because of enhanced strength and deformation in the material we can also achieve very high fracture toughness in case of nano crystalline material also there may be 3 different modes. So, that can be opening mode sliding mode or the shearing mode for achieving this fracture toughness and a plane strain condition. So, that becomes the minimum value of fracture toughness and that is independent of the thickness of the material because of that.

Now, if you have a thin material fracture, toughness can start depending on the thickness to avoid that we can also induce plane strain conditions. So, in that we can also see the nano crystalline materials will have much more fracture toughness in comparison to the micro grain structure materials coming to creep. So, creep is a time dependent permanent deformation of material which occurs at very high temperatures greater than 0.4 times t e m and stress levels much less than the yield strength.

So, then we have Larson Miller parameter to basically correlated the ruptured time at different temperature. So, if you have if you have wanted to do a test which is kind of impossible or very impractical that can be also evaluated using Larson Miller parameter. So, that dictates that it is the role of temperature and stresses and obstacles and inducing certain creep resistance to the material.

So, we can play with the microstructure, we can play with the temperature, we can play with the stress or we can also play with the obstacles which are present in the material. So, the exposure time to eventually control the creep rate and design a perfect material for its resistance. So, with this I end my lecture.

Thank you.