Materials Science and Engineering

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Lecture – 34
Fracture: Part II

Hello friends' continuing with our discussion on topic of Fracture. This is the second lecture on that ok. So, continuing with that we discussed about the Griffith criterion for brittle material ok, and we said that failure stress will be given by a relationship like this from Griffith theory.

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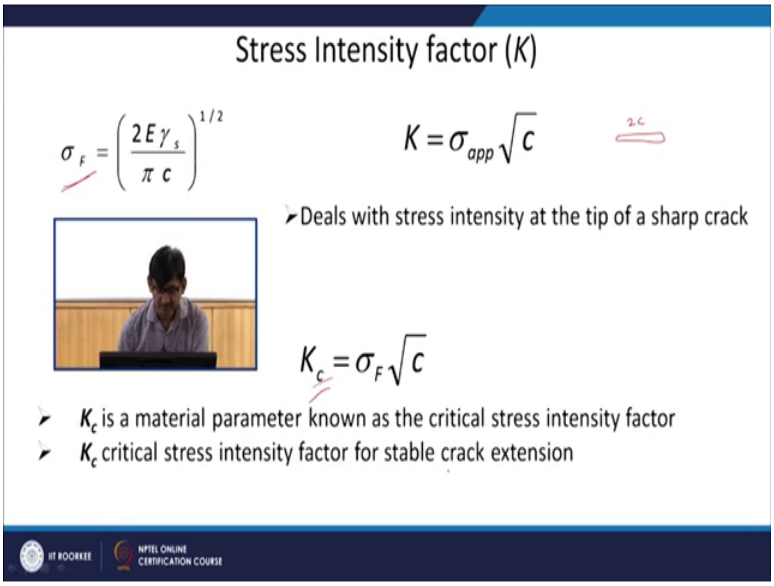

Then, we also said that in ductile material, because there will be some plastic deformation ahead of the crack. This actually stress will be more while we are talking about ductile material; that means you will need more stress to continue the crack or propagate the crack ok.

So, it is always better to design your material or whatever you are the structure you are designing considering only the considering it as a bitter brittle material so that you are always going to give a conservative estimate you will be always within the say safe limit ok. Now the problem with the Griffith equation here is that you have a parameter which is the surface energy the gamma s and it is very difficult to kind of find out this in all kinds of material, if you change the composition these energies will change ok.

So, for each material finding out this energy is always going to be difficult; so instead of that; another proposed idea is that, we can calculate a parameter called stress intensity factor ok. And, what inter stress intensity factor says that? K is dependent on the; whatever is your applied stress under root of the crack length ok.

So, if it is the crack within the material it will be the total will be 2 C ok. So, half of that for inside crack if it is a edge crack; already we will take the total length as C. So, it deals with the stress intensity at the tip of a sharp crack ok. Now you can also define a critical intensity factor in this ok. So, this will be when the stress is sufficient to start the fracture. So, it is sufficient to start the crack propagation.

So, as a Griffith criterion has already assumed; that we believe that there are going to be small defects cracks inside the material. So, when the material fractures basically, these cracks are going to propagate ok. So, we want to find out a stress which is sufficient to propagate these cracks. And for that; we can define a critical in intensity factor and with that will be now we have a remove change the sigma applied to sigma F; that means, the stress where the fracture is going to take place and this is again the crack length.

So, this is a; K c s critical stress intensity for a factor for stable crack extension ok. So, instead of doing this analysis using surface energy, we can do an analysis like this and we can find out the critical intensity factor for a given material. So, your value of K or K c will depend on type of loading.

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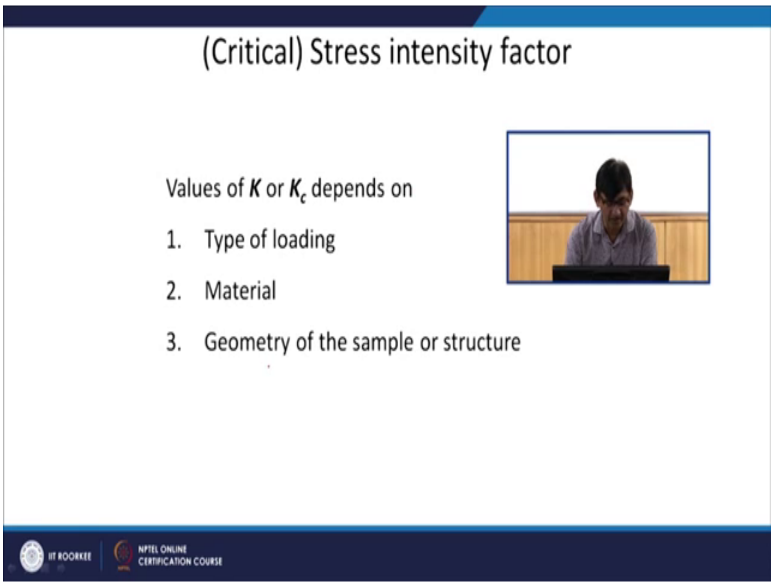

Of what type of loading I am giving material ok. So, for each material I can find out the stress intensity factor critical intensity factor and geometry of the sample or structure ok. So, what is the geometry of the structure is there ok.

We will look into detail of all these three parameters. So, the first one if you see this is a three modes of loading ok. So, mode one is what we call as tensile mode ok. So, if a edge crack is there and you are applying.

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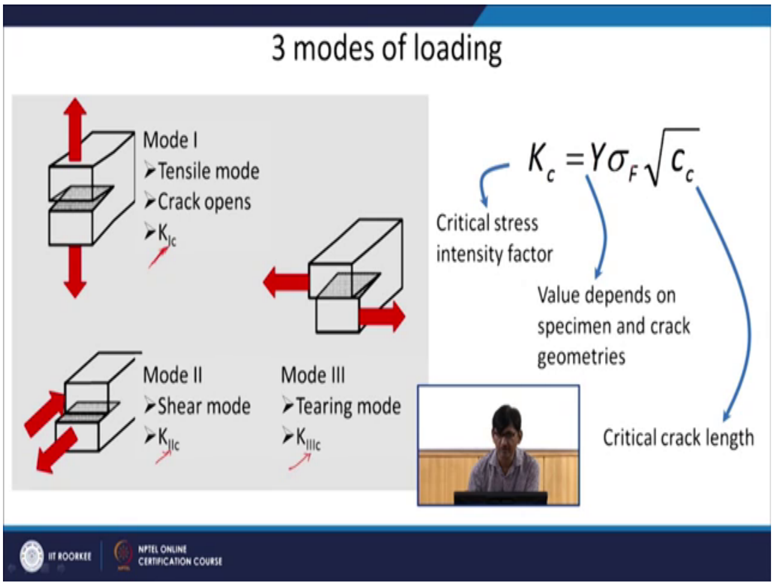

A tensile stress over that ok; so, it is called a crack opening kind of mode. So, whatever crack is there it is going to be open by application of this tensile stress.

Just a comment here that compressive loads are not that critical in case of fracture ok, because when you are applying suppose; there is a crack also when you are applying a compressive stress. Actually, you are closing the crack ok. So, it is not going to propagate in tensile mode only it will propagate, that is; why you will not see a compressive mode here only a tensile mode. Then the second mode is the shear mode. So, basically I am sharing the material where the crack is there ok. So, when the mode 1 is there, then we critical intensity factor will critical intensity factor stress intensity factor will be called as K 1 c, because we are doing it in mode 1.

So, which mode we are doing that also, we can include in the definition here. Similarly, mode second when it is a shear mode then it is a mode 2 ok, then I will call it as K 2 c and then if it is a tearing mode. So, it is a mode like this. So, instead of shear mode like this it is kind of tearing mode ok. And then it will be mode 3. So, K 3 c will be written.

Usually most important is K 1 c, which we will use in all the design practices ok. So, if you want to consider this geometry of the loading and geometry of the specimens ok. Actually, I can modify the equation here now ok. So, it will be critical stress intensity factor equal to a factor which deals with the value depends on the specimen and crack geometries ok.

And this is your critical crack length and sigma F your as I told you the fracture stress ok. So, a stress at which the fracture takes place or the crack propagation becomes stable, if a very sharp crack can be made in a material. So now, how we are going to use this particular parameter? So initially what we will do is we will introduce a crack in the material ok.

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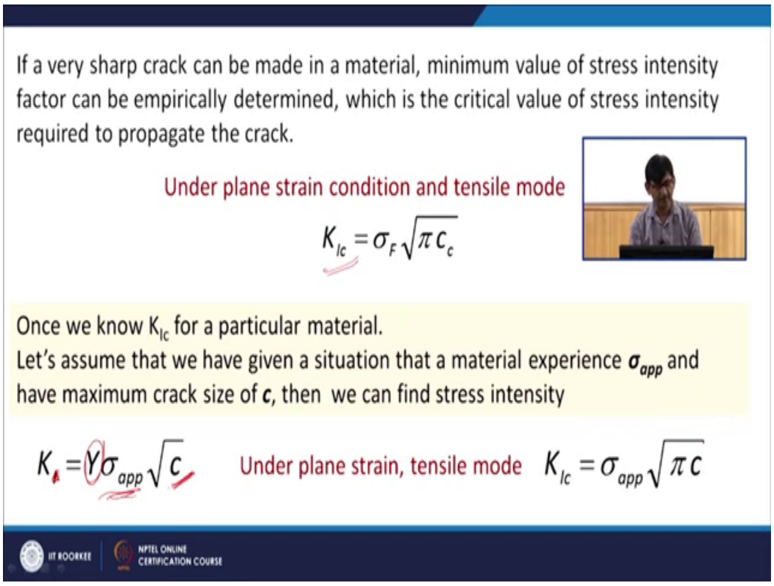

So, suppose you give a material to me ok; and ask me to find out the; that, what will be the critical intensity, stress intensity factor for this material? So, what I we will do is? First, we will make a specimen introduce a crack of a known length which we have already introduced ok; which we can easily measure. So, that crack length we will always already introduced in the material and then we will do test to find out that at what stress it is going to fracture ok. So, when I do that; so, under plane strain condition and tensile mode which is K 1 c. So, I will find out that for a particular crack length; what is your going to be the fracture stress.

So, by doing this kind of experiment; empirically I can determine that what will be the critical value of stress intensity factor ok? So, for a given material I will get that; now once I get that, now I am using this material in practice ok. So, there in that practice wherever I am applying this material, there will be some applied stress by doing some non destructive testing. I can also find out that; what are the typical crack or defect present in that material.

So, by knowing this applied stress which you have found out from your design and finding out; this crack length from some entity kind of analysis evaluation ok. And using whatever geometries, we are using if we are doing it in plane strain condition under tensile mode. then Y will be under root pi ok. I can calculate that, what will be the stress intensity factor under mode 1.

Now, if this stress intensity factor is more than K 1 c, then I have to either change the applied stress or I have to redesign the my structure or I have to do certain processing to the material to reduce the defect size. So, if K 1 is more than K 1 c, if K 1 is less than K 1 c for the this given applied stress and the whatever defects are there in the material.

Then, I can say that this is a safe mode and I can use this material; under this stress condition with the given flaw size. So, I guess you understood that, how we are going to use this stress intensity factor to find out the? Whether; I am going to or whether I will be able to use a certain material with certain crack length under certain applied stress and by comparing the critical stress intensity factor with the stress intensity factor. We have calculated for a particular condition.

So, in books I found that there is lot of confusion regarding these equations ok, I have done I whatever I have followed here is that: K 1 the 1 is your tensile mode and in plane strain condition and c is your critical. When we are talking about critical so, when we are talking about critical this stress should be the fracture stress and the under root pi term comes only when I am using K 1.

As you can see here also; I am using K 1. So, let us say, I am not going to use K 1 here ok, and I will be using only K; so Y when I put Y as under root pi, then I will use it as K

1. So, under plane strength tensile mode ok, this is what I will get? And I can compare with the stress intensity factor which I am calculating and find out whether I can use this for a particular application or not.

So, as I told you that in general I will write it as K equal to Y a sigma applied under root C. So, if it is a crack length center crack with length 2 c, in an infinite plate. So, under plane strain condition so, one I can always use, because one is for plane strain sorry tearing mode oh sorry tensile mode ok.

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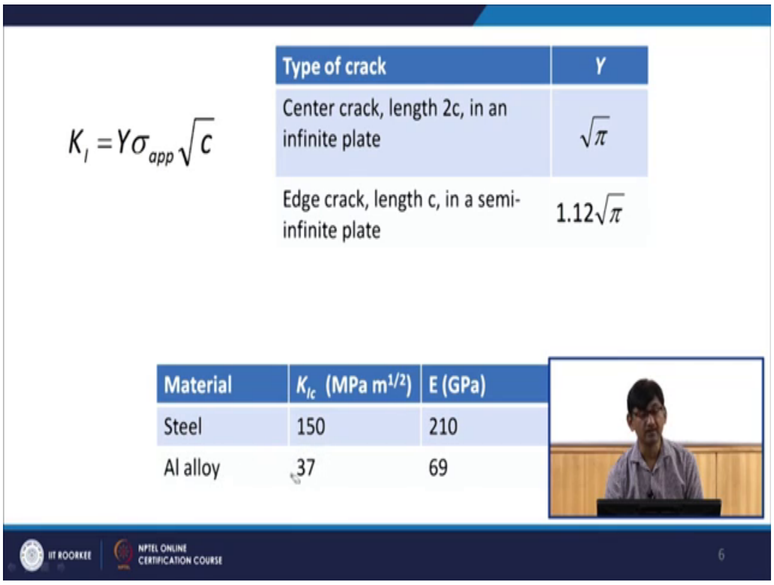

So, one is for tensile mode. So, I can use that and why I will put only according to what kind of crack is there. So, if it is a center crack within the material a through crack with length 2 c, in an infinite plate. So, it is a plane strain condition for infinite plane the condition for deformation will be plane strain for an another set of conditions Y will change.

So, it is edge crack. So, then I will use a factor like this ok, and then there are some values for the; critical stress intensity factor for the steel it is around on 50 mega Pascal per meter under root meter. Actually now it is under root meter and aluminum alloy it is around 37.

There Young's modulus is also given here; now what are the common fracture modes ok? So, if you see the there are different fracture modes already we have seen once in the previous slide also.

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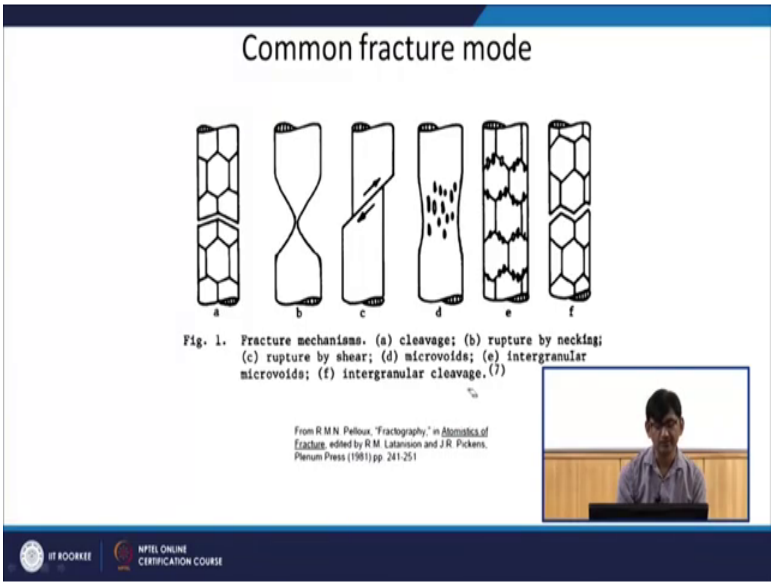

Just to recap here so, in this case the crack has going through the grain ok. So, and this is what we call as cleavage fracture through the through the crystallographic plane basically, the crack goes through the crystallographic planes.

So, as you can see a certain plane is preferred. So, it is going through that in that plane may be oriented in a different way in next grain. So, the crack has kind of there is a divergence or diversion of the crack in that next screen, but the crack will go through the grain ok. So, in this case the it is a trans granular fracture. Another fracture which is a ductile fracture can be there be through necking process. So, it is making and later on it will fracture, when the diameter of the material become very small, then this is the rupture by shear process under plastic deformation.

Again then there is a micro wide coalescence. We will see these when we will discuss the ductile fracture ok, then there can be voids on the grain boundary ok. So, then it is inter granular micro voids or inter granule granular cleavage. So, in this case now the crack is going through the grain boundary in this case the crack was going through the grains. So, a crack can also go can go through the grain boundary then it will be inter granular cleavage.

So, now we will look at different type of fractures. So, first is brittle trans granular fracture ok; that means, through the grain. So, when you have a.

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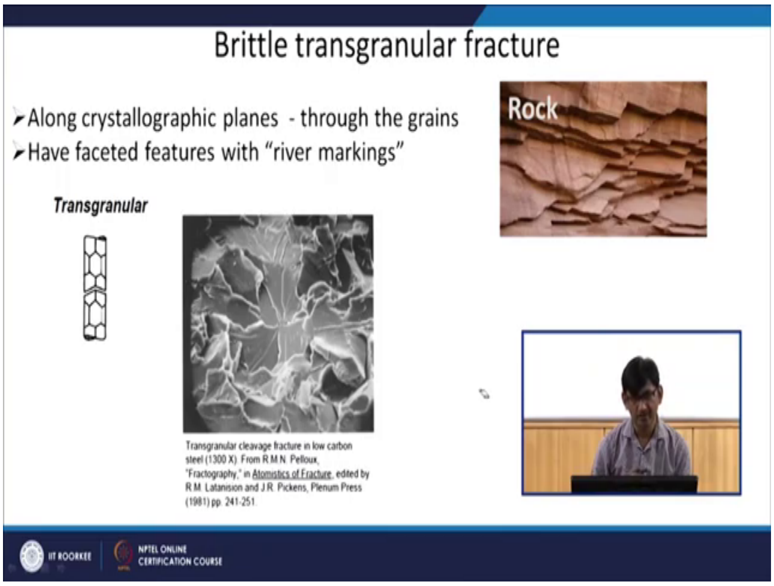

Brittle trans granular fracture ok; the crack is propagating along the crystallographic planes or through the grains and usually it gets you get a faceted feature with river markings faceted feature, because the crack is going along a certain plane.

So, you get one facet in another grain the plane may be oriented in a different way. So, the; you get another facet and. So, on and usually at micro score scale you can see this kind of fracture very nicely on a some rock, if some fracture is taking place or there is some crushing of the rock is taking place as you can see very nicely, these kind of a facets are there on the rock sample at a macro scale ok; this is a scanning electron micrograph of fracture sample again you can see the facets. So, one facet one facet and when wherever the grain boundary may be or wherever the crack is going into another plane ok, you get this kind of river marking; so it kind of it where the crack has changed it path ok.

There you see this kind of river markings ok. So, it is like tributaries to a main river that is how they come and then they join the main river ok. So, that is why it is called river marking then a brittle fracture can also happen inter granular ok; that means, the crack will propagate through the grain boundary.

So, in this case you get a granular appearance because it is going through the grain boundaries. So, the shape of the grain is actually what you see very nicely on the fracture surface if you want to compare this kind of fracture with anything.

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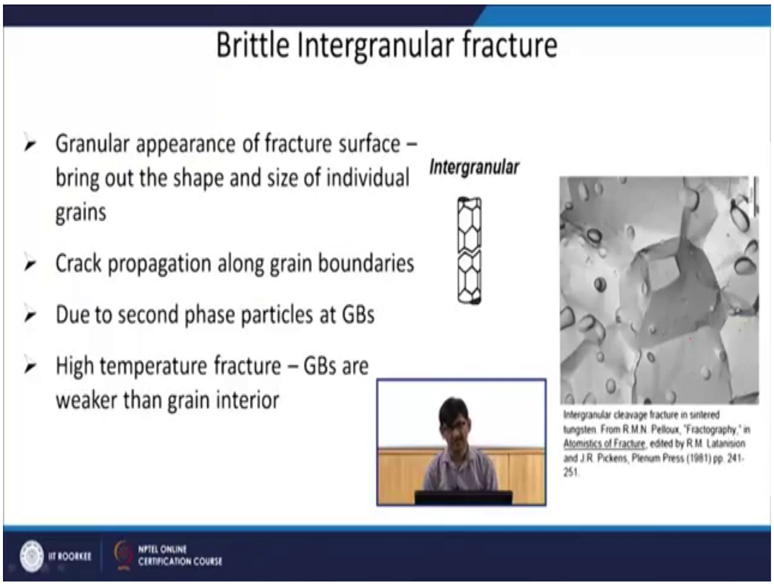

Which you see in a day to day life you take a thermocol ok, those white packing material in which you get all these electronic equipments your monitor and so, on.

You just fracture in fracture that thermocol ok, just break that thermocol and whatever the surface you will see that is; how you will see a inter granular fracture. So, those individual thermocol grains that is; what you will see? And in that the fracture is, actually taking place between the two balls of thermocol ok, and that is what you will see very nicely this kind of fracture feature.

So, in this case the crack propagates along the grain boundaries you usually; why it takes place. Suppose you if you remember, we discuss when we were discussing about steels that in hyper eutectoid steels and the cementite form on the prior austenite grain boundary. So, it is kind of a continuous network. So, if you have this kind of microstructure the cementite is a brittle phase and if any crack nucleates it is very easy to propagate the crack through this cementite network ok.

Because this cementite network is on prior austenite grain boundaries; you will see a nice granular type of fracture features ok. So, this is if you have on grain boundary a continuous network of a second phase, then the crack will may sometime can propagate through grain boundary.

In high temperature also, this grain boundary fracture takes place, because at high temperature grain boundary is weaker than the grain ok. And they are already quite easy to separate at high temperature ok. So, the crack propagates through the grain boundary, when you have high temperature fracture ok. In some cases not always so, in high temperature fracture also you will see this kind of a fracture feature; sometime it can be mixed mode also you can get inter granular you can get trans granular ok.

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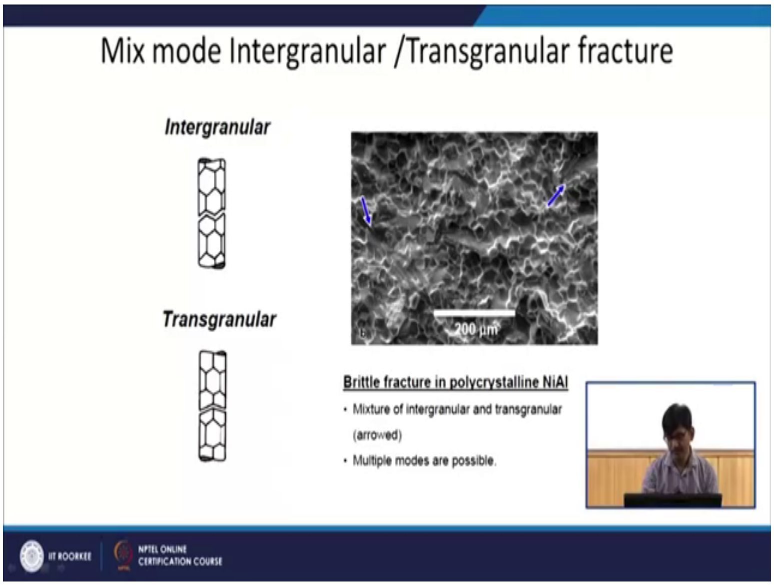

So, you can see these are all with faceted features ok, you can see a faceted feature here also ok. So, there can be some time mixing of two different fracture modes also because in practice things are not very simple ok. You have very complex stress system material is experiencing different stress state at different places.

So, the fracture can also be of different type and if there are two multi phase material some phase will deform by it not crack by trans granular mechanism other phase may fracture by inter granular mechanism. So, you can get a mixed mode type of fracture features on the surface. Now coming to the ductile failure or ductile fracture this is this happens.

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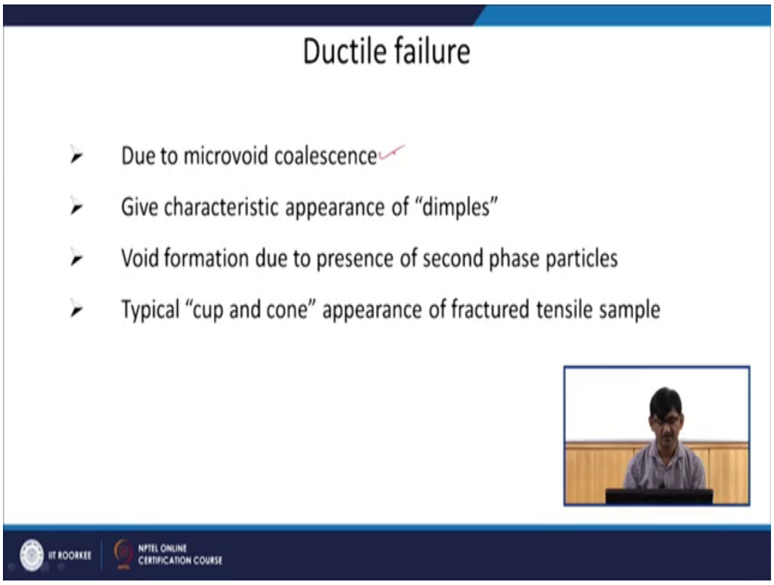

Due to micro void coalescence. So, we will see, what do we mean by that? Give characteristic appearance of dimples, actually this is what we call what features which we see on the; for ductile fracture ok. We say that these are dimples it looks like dimples wide formation due to presence of second phase particles and typical cup and cone appearance of fractured tensile sample.

So, this we have already earlier also discussed that you get this kind of a cup and cone type of fracture. So, if you have a ductile material and you do the tensile test you get this cup and cone fracture appearance whereas, if it is a brittle you will have a separation of two of the sample in two parts and almost the fracture micro features of the fracture surface is flat ok.

So, what happens in this micro void coalescence? Ok basically when you are deforming and suppose.

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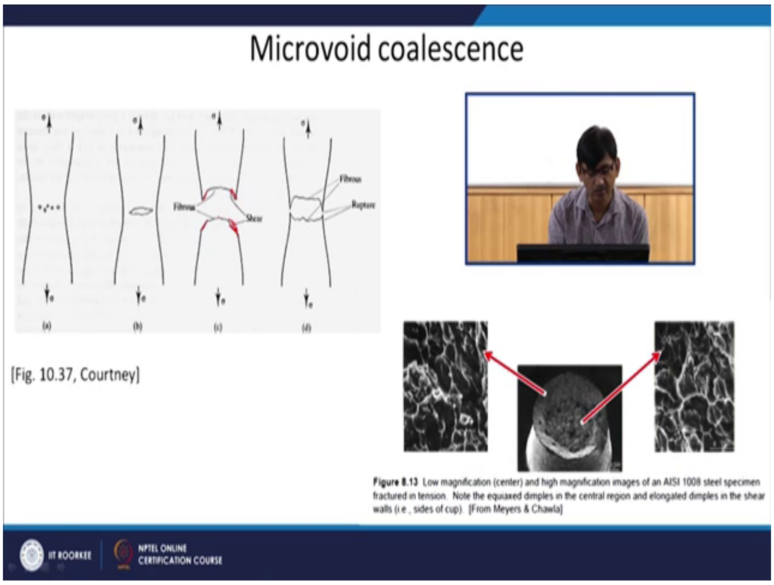

A necking starts at some point ok. Now, there will be some this kind of micro voids which will be forming on the inside the sample ok, why this micro void form ok. Suppose you have some inclusion in the material, let us say inclusion or precipitate or whatever and you are deforming. Now the mechanical properties of the precipitate will be different than the matrix ok. Usually precipitates are all very hard compared to the matrix.

So, matrix is soft it can deform whereas, the precipitate will not deform ok. So, when you have suppose this is my precipitate this is my matrix around it my matrix is able to deform, but precipitate is not deforming and there is an interface here isn't it. So, what will happen if it is able to deform it will try to separate from the; my matrix will try to separate from the precipitate, because it is able to deform whereas, precipitate is not deforming it is kind of a solid inflexible precipitate within the grain.

So, what will happen now? You have initiated voids at the interface and these voids. Initially, these voids will be very small micron sized small voids and when you keep on increasing the stress, because of the necking there will be the stress will be concentrating in this region what will happen that? These voids will grow and they will start connecting with each other ok, that is; what we call as coalescence ok. So, first voids will form the small voids micro voids, then they will kind of connect with each other and you will get region within the material which is now already separated.

So, remaining material on the outside is remaining there ok, and that will fail in a shear mode you can see this is typical 45 degree shear surface as I told you already that, when you have unaxial tensile at 45 degree you will get maximum shear. So, when the material is already separated from within the remaining part will shear out, and at 45 degree almost ok. So, you will get a fibrous appearance here, because of those micro void and their coalescing with each other and the shear on the outside and this is, what is going to give you a cup and cone type of fracture features.

So, you can see that there is a flat region and then, there is a raised region here which looks like a cup and in this case it looks like a cone ok. So, this is how the whole deformation takes place? So, now, because of this micro void formation and coalescence ok, the typical fracture feature which you see in ductile material is called dimples ok. So, these are individual dimples and you can also see that.

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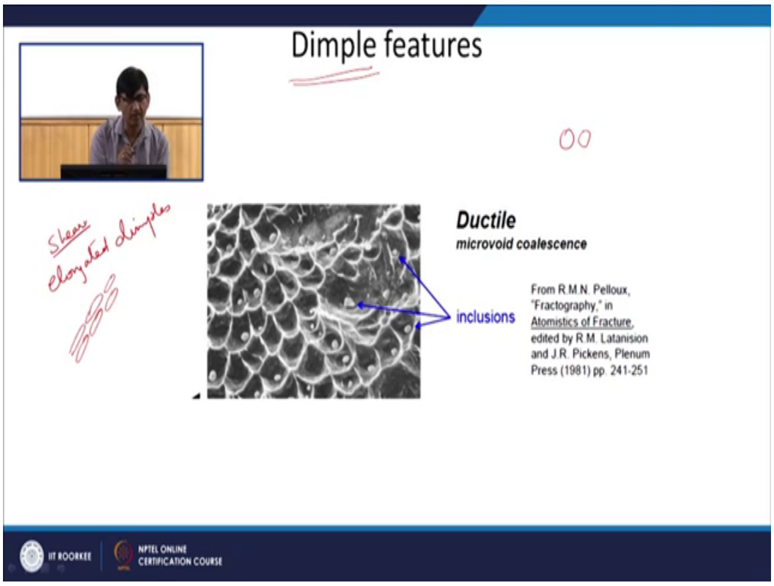

There is a precipitate sitting within the these dimples; that means, that the micro void might have nucleated there, then it is it was growing another micro void nucleated for this precipitate that is also growing and locally there is kind of a shear between the two of these holes. So, you have one micro void like this. Another micro void like this and when the material is whatever material is remaining between them ok, that is very thin small volume of material that will shear out.

So, because of that you get this raised portion here. So, this is a typical dimple fracture. So, if it is under tensile mode simple tensile mode, then it will look like a acquiesced dimples. Suppose the same thing is failing under shear mode which we see in cup and cone at the at the extremities of the sample ok. So, this same dimples will under shear mode will get elongated.

So, it will look like this ok. So, instead of acquiesced you will get a elongated dimples elongated dimples, when you have a shear mode ok. Now there is another problem with few materials and that is that they behave different under different mode at different temperature ok.

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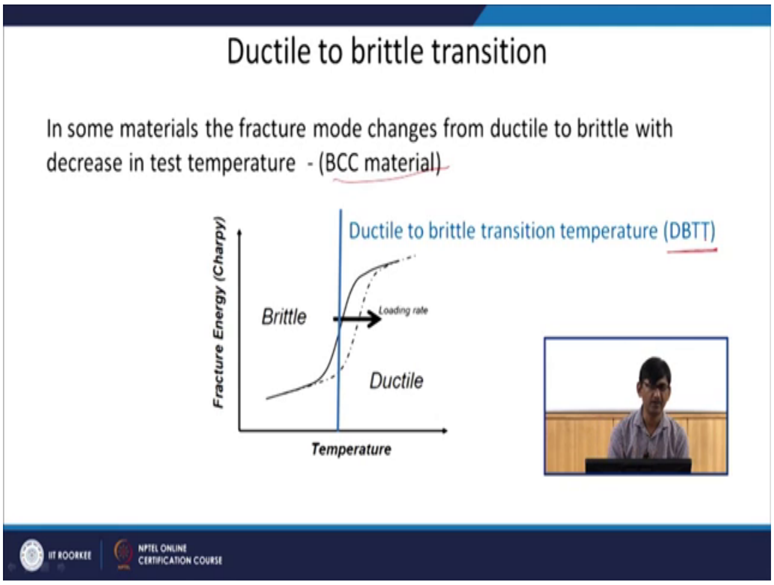

So, this is what we call as ductile to brittle transition. So, in some material the fracture mode changes from ductile to brittle with decrease in temperature and especially BCC materials are susceptible to this ok.

So, by if you see the; this is fracture energy; that means, how much energy is absorbed by material during the fracture process. So, at high temperature it is behaving in a ductile manner ok. So, ductile is always safe for example, if I have any kind of impact ok, if it is a ductile material it will only give a dent it will not break into two parts ok.

At low temperature it starts behaving as a brittle material. So, now, any impact on the structure it may fracture into or there may be a initiation of crack. So, with temperature and that is, what happened with the titanic ok, because the material which was used under the; when it was going through that Atlantic sea ok. Atlantic sea the temperatures and I think it was winter.

So, the temperatures were low ok. So, in that temperature the material was behaving in a brittle manner they might have done testing of this material, but they might have done testing at room temperature or little bit higher temperature. So, there the; material was behaving like a ductile material. So, they use that material ok, but when it went into the Atlantic sea and when, because of in the night the temperatures of the water must be low.

So, at that temperature it started behaving like a brittle material. So, the when the ice berg hit the ship it instead of just giving it a dent ok; what it did is? It is initiated the crack in the; in the structure of the ship and that crack, then started propagating and then you had the, that accident.

So, now the then of course, lot of material research took place people took care of that problem. So, at least they can bring the transition temperature to very low temperature which are you will not find in under the service condition ok. So, this kind of research keeps going on as you face some problem or other ok.

So, the temperature at which this transition take place takes place is called ductile to brittle transition temperature DBTT ok. So, basically we have to take care of DBTT for any material. So, when you develop a new material we you have to do testing at room temperature, high temperature, low temperature and the different loading conditions static low quasi static loading means way at very slow strain rate.

High strain rate testing which we call as impact ok, we can depending upon the application if it is not going to see any higher temperature. We will not do any higher temperature testing of that, but suppose you are developing an automobile material ok, I will test it under quasi static condition to design the structure, but I will also test under impact loading ok, because under the crash condition there should not be any fracture. In the sense that it will fracture like a brittle material, I want to it to absorb maximum energy by deforming plastically and that is what we will see in the next slide ok.

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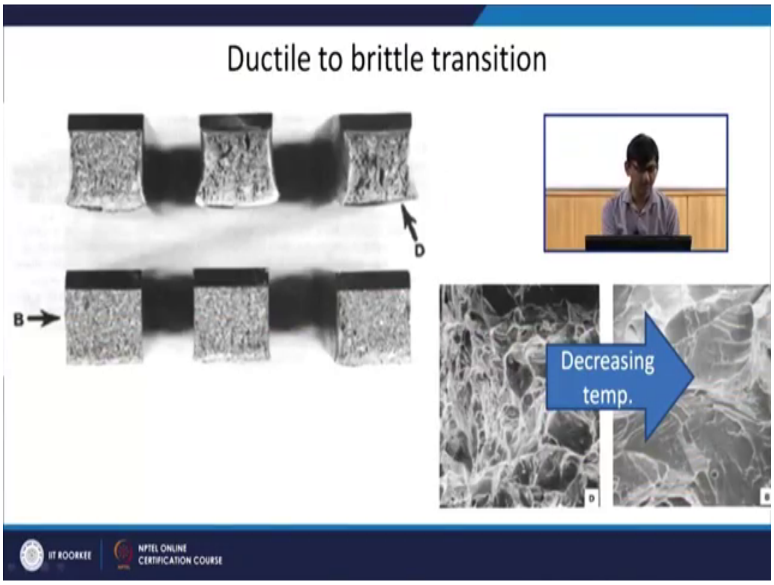

So, this is that ductile to brittle transition. So, the sample tested at different temperatures. So, at high temperature it behaves like a ductile material and at low temperature it will behave like a brittle material and the fracture morphology also changes, so as a function of decreasing temperature. So, here you can see that it is a ductile fibrous kind of appearance whereas, in this case you have faceted and river markings are there.

So, the; for the same material the fracture morphology has changed from ductile to brittle ok. Now this is just one slide on the impact testing that is one of the important aspect of any material development especially, for automobiles as I was telling you.

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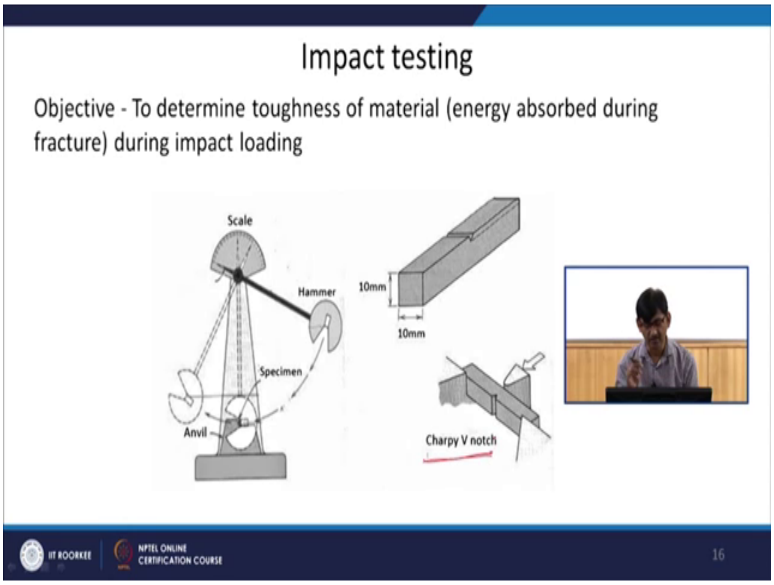

So, basically our objective here is to find out, what is the energy absorbed during the fracture? Ok. So, maximum energy absorbed is what we want ok. So, there is one type of test which is called Charpy V notch test and this is the arrangement for the atom you create a pre crack kind of condition already here by providing a notch here so that the stress will be concentrated in this region only. So, it is kind of trying to simulate that already there are flaws present in the material. And, if you have an impact loading how much stress it is going to absorb? So, and to do the test a very simple apparatus is there. So, you have a very high a hammer with lot of weight is there you take it to certain height.

So, now it has some potential energy and then you remove that so that it takes a swing here. So, that potential energy will convert into kinetic energy. So, at this point you will it will have maximum kinetic energy and it will hit the sample and then it will go on the other side. So, whatever is energy absorbed in this fracture of this sample that much less energy will be there for it to swing to a certain height ok. So, that height difference will give you the idea about, that how much energy is absorbed in this process? So, this is a typical impact testing. So, with that our fracture part is kind of covered.

So, we have discussed about brittle and ductile fracture, we have discussed about the Griffith theory and we have discussed about the stress intensity factor which we can use to design our structures ok. And if there is going to be any fracture from the fracture surface we can find out that what type of fracture took place whether it was ductile or brittle.

Thank you.