Materials Science and Engineering
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Lecture – 33
Fracture: Part I

Hello friends. Today's lecture will be on Fracture. So, after we do if you remember the tensile curve we start from elastic deformation then we go into the plastic deformation range and plastic deformation range you have uniform deformation ok. And then you have a necking and then no uniform deformation and at some point you will have fracture in the material ok. So, we want to understand these phenomena of fracture that what does it mean and does it depend on that different materials in different materials do we have different type of fracture mechanisms ok, so all those things we would like to see.

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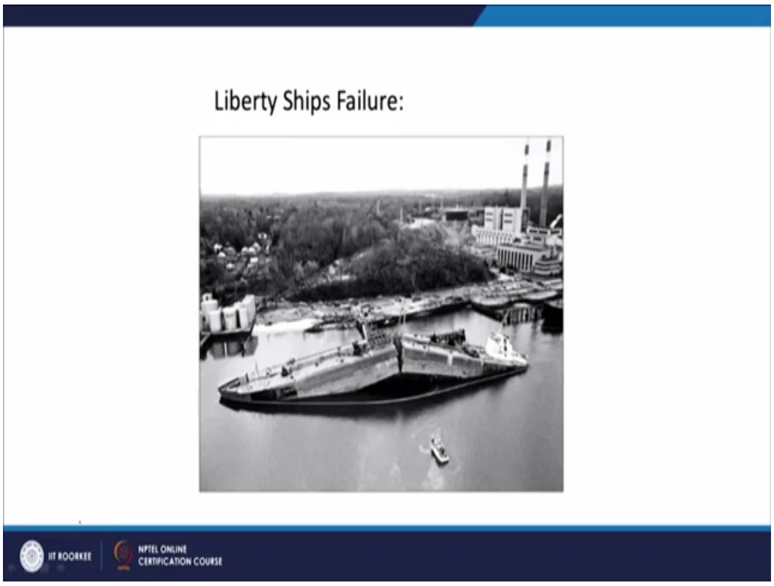

This is one of the some very famous photographs to bring out the importance of understanding of fracture, our and actually importance of materials also these are some ships which were made in world war second these are called liberty ships and most of this ship failed like this, you can see the fracture the ship has fractured into two parts ok, I completely two part it has fractured and the big ship like this just fractured into two parts is a kind of a very difficult thing to understand ok.

So, people found out that there were problems in the material there were problem in the fabrication and so on and lot of improvements took place after that. In fact, titanic also if you see it was a kind of a fracture problem only that the material was not of good quality, lot of carbon used to be there in the steel at that time and when the iceberg hit the titanic ship ok.

So, it hit fractured instead of they having a ductile fracture or ductile deformation it actually fractured in a brittle manner ok. And then once it is the crack started it under the massive load of that ship and that propagated and the whole ship got again I think divided into two parts ok. So, types of fracture if you want to see there can be two type in which we can divide one is brittle ok, brittle is a is a very difficult and problematic kind of fracture because you do not get any warning. So, once it starts and then it will go at a very fast rate so you can say it is a fast fracture also.

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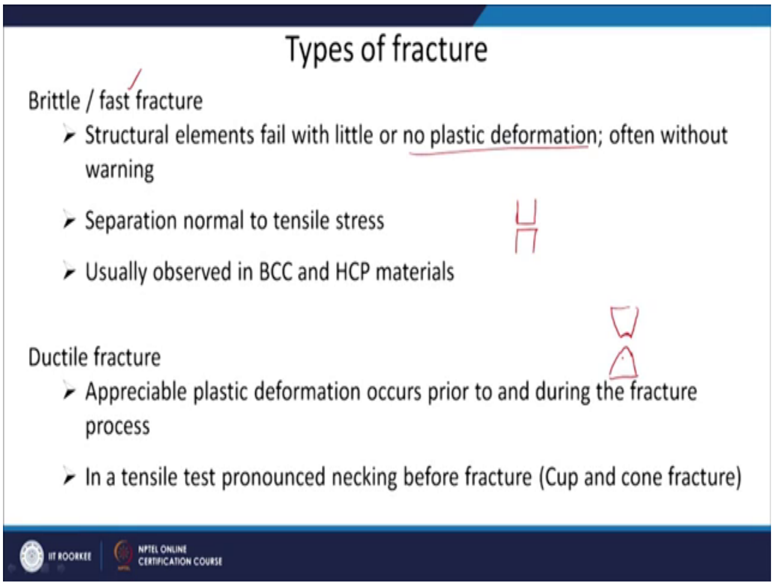

So, brittle fracture in this you do not have any plastic deformation or very small plastic deformation and that is why there is no warning ok. So, you will not know when you have reached the, the fracture stress of the material whereas, as you when you are plastic deformation it will take lot of time in getting deformed and then go into the fracture mode ok. And before that you will actually be able to see that something is deforming out of shape.

So, separation in this case is normal to tensile stress it is kind of a de cohesion between the two atom. So, all the atom bonds kind of break and usually observed in b c c and FCC material, FCC because it is very ductile FCC structure materials are ductile you do not see there in bcc also you will see only at very low temperatures at normal room temperature you may not see it ok

So, there is effect of temperature also here and HCP of course, you will see this kind of fracture brittle fracture ductile fracture you will have appreciable plastic deformation which occurs prior to or during the fracture process in a tensile test pronounced necking before fracture cup and cone fracture. So, when we do tensile test also we will clearly be able to tell you that which one is a ductile material which is a brittle material depending upon how they are getting fractured.

So, in if you do a tensile test of brittle material, just taking the gate section actually your material will divide into two parts ok. And the fracture has taken place normal to the tensile stress, where is, in case of ductile material the material will actually neck first and in this also there is a kind of a very nice geometry to that ok.

So, in one case it will be a cup and in the other part it will be a cone ok. So, it separates like this so it is called a cup one cup and cone fracture, fracture mode depends on different parameters. So, you can have as a function of material.

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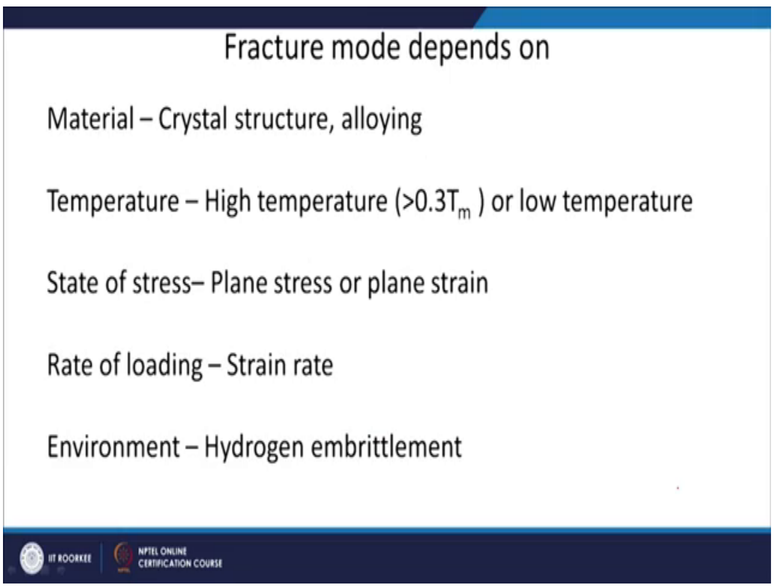

So, crystal structure or alloying already we have seen that different crystal structure and behave differently temperature as I told you that the temperature plays very important. So, in bcc material as a function of temperature it will either show as a brittle fracture as a brittle material or fracture as a ductile material ok. So, temperature plays very important role here state of stress whether it is a plane stress condition or plane strain condition rate of loading strain rate ok.

So, if it is high strain rate then sometime material have a fracture is a brittle material, if you are doing the same test on the same material, but it has lower strain rate it will fracture in a ductile manner environment. So, basically corrosion and hydrogen is there hydrogen embrittlement is there. So, depending upon the environment the fracture will change in some cases a ductile material will fracture like a brittle material because it has already corroded ok

So, all this factors will determine the fracture modes, so if you kind of want to see the whole.

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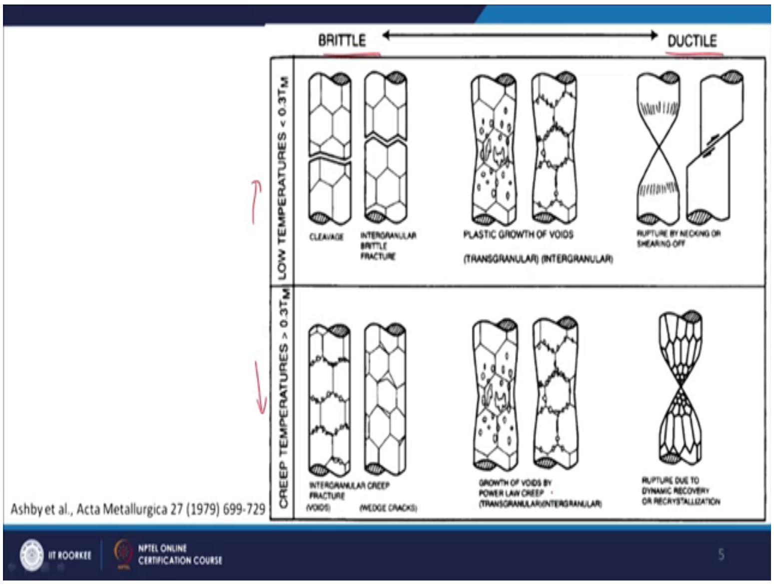

Kind of a overall scene or overall difference between different fracture mode ok. So, you have brittle here and ductile here ok. So, this is brittle here and ductile here and this is at high temperature at this is at low temperatures ok, at low temperatures in brittle material you will have a fracture like this where the crack is going through the grain ok.

It is a cleavage fracture we say or you can have intergranular brittle fracture. So, you can see is see in this case the crack has gone through the grain boundary. So, it is called intergranular and this will be call as intragranular, then you can have plastic growth of voids, so you can see some voids are forming within the grain here ok. So, within the grain it will be trans granular or intra granular and between two grains it will be intergranular ok. So, avoid can be at the grain boundary or voids can be within the grain and this voids will then grow then they will connect with each other and the material with fracture. And this is for ductile material rupture by necking of shearing off. So, you can see that necking is taking place and at the end you will have a fracture here as a point fracture or cup and cone fracture or you can have shearing in form of shearing at high temperature again you have will have formation of voids at the grain boundaries ok.

So, it is intra granular fracture through formation of voids or there can be formation of wedge at the grain boundaries then it is called wedge cracks growth of voids by power law creep another when we will see creep you will see again this type of fracture taking place or it will be through necking as we saw and the low temperature also ok. Now, coming to the brittle fracture it is easier to understand the brittle fracture first ok, so we will first look at the brittle fracture so.

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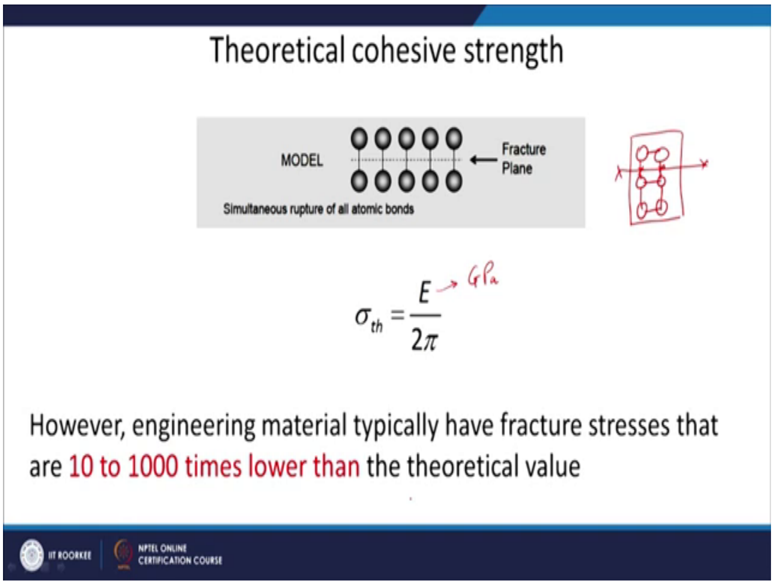

Coming to before coming to that let us see what will be the theoretical cohesive strength. So, basically what is we are saying is when we have fracture. So, suppose this was the material initially of course, you had atoms here and there was atomic bond between them ok. So, when I am saying that it is fracturing into two parts ok, so it is fractured here ok. So, basically I am breaking these bonds between the atoms and then it will be in the material will be in two parts.

So, I can kind of get an estimate that what kind of stress is required to do this breaking of all the bonds ok. So, if you I take up material of this size let us say there will be like millions of atoms and millions of bonds that that I have to break to take into two parts ok. So, suppose the atoms are there then there are bonds between them this is a fracture plane and I am simultaneously rupturing all the atomic bonds for fracture to take place.

So, if I want to do that as the theoretical calculation the derivation I am not giving here you can look in the book for example, by book by on mechanical metallurgy by deter. So, sigma theoretical will be equal to e by 2 pi, it is similar to what we saw earlier in case of shearing also that when I want to share all the atoms at one go I have to break all the bonds ok, create new bond and by that I will slip it by one atomic distance and what was the stress required to do that.

Similarly, here now in this case I am breaking all the bonds between the atoms simultaneously, and this is the strength or stress required to do that that is equal to Young's modular key divided by 2 pi young modulus already we know for most of the metallic material it is in the range giga Pascal, but the engineering material when we try to find out the fracture stresses these are around 10 to 1000 times slower than the theoretical value already we have seen that it is usually in mega Pascal or something. So, maybe 2 or 3 order of magnitude difference between what we get from theory and what we see in the experiments ok.

So, again in this case also there must be some something in the material which is bringing down this strength of the material ok. So, in case of plastic deformation shearing we say said that the defect is dislocation that defect is dislocation which is bringing down the theoretical shear strength of the material ok, in this case also we are going to have some defects and this defects are called cracks.

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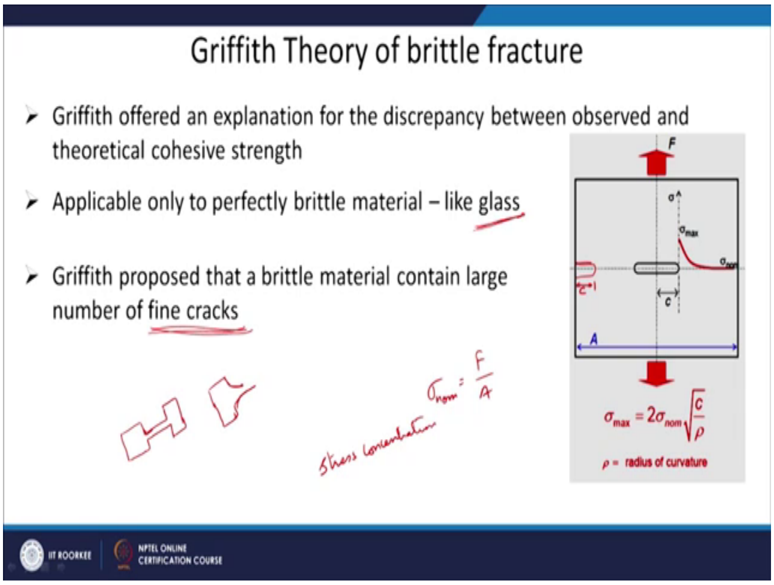

So the reason for bringing down this theoretical strength is that there are fine cracks present ok. So, first time it was proposed by Griffith ok, so and he proposed that for brittle materials because fracture process is very easy to understand in brittle materials because there is no plastic deformation; so only the separation between the two materials through breaking of the bonds without any plastic deformation.

So, Griffith offered an explanation for the discrepancy between observed and theoretical cohesive strength of course, what he offered was only applicable for brittle material like glass not even brittle metals it is brittle material like glass and Griffith propose that brittle material contained large number of fine cracks ok. So, what happens when you have large number of fine cracks for example, one crack is shown here in this figure you are applying a force f ok. So, the stress on the system will be given by sigma with that say we call it is as nominal stress that is force upon this is the area of cross sectional area of the sample ok. So, nominal stress is only force upon per unit area ok.

Now, when you look if you have a crack in the material what will happen is that locally the stress will be very high where the crack tip is there and this is called stress concentration. So, wherever you have sharp some discontinuity like this, you are going to have a very high for the nominal stress which you are applying the locally the stress will be very high ok. And that is why if you remember when I was discussing the tensile test also I said that when we prepare the sample tensile sample we do not prepare it like this ok.

The reason is this sharp corner will impose or we will give rise to stress concentration and the locally the stress here will be very high. So, this kind of sharp corner like this will act like a crack here ok. So, instead of that what we do is we give, kind of the curvature like this and to minimise the stress concentration ok. So, what will happen is that where the crack tip is there the stress is very high, so this is my sigma max ok.

And as you go away from the crack tip the stress is equal to whatever you will get from the force per unit area and the dimension of the crack is also defined here. So, the total dimension is 2 c ok, we will if it is inside crack we will take only the half of that that is c if it is a surface crack suppose it can be here. Then we will just take the whatever is the total length of the crack which is going to be c ok. So, if it is inside crack then whatever crack length is there half of that, so we will always say that it is 2 c.

So, half of that will be c if it is surface crack then we will just take the c here ok. So, sigma max will be equal to you can have an expression also here it will be equal to 2 sigma nominal and 2 under root of c by rho I think that.

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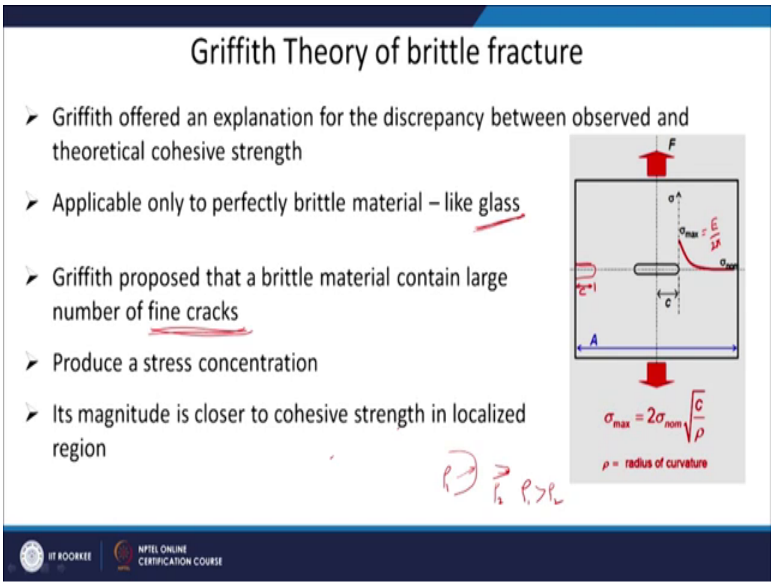

So, when you have fine crack it produces a stress concentration and its magnitude is closer to cohesive strength in localized reason. So, what will happen that the over all the stress is very small ok, and we are seeing that the material has fractured at this is stress the locally the stress will be very high that can be close to the cohesive strength of the material. So, locally here it will reach what we have calculated for given material. So, sigma max can reach e by 2 pi locally where is what you are measuring it is on the sigma nominal that is why you feel that it is fracturing at very lowest stress ok.

So, as you can see this sigma max depend upon the crack length. So, if you have a larger crack length then the stress will be also be higher the stress concentration at that crack length will be higher ok. So, it will be easier for you to fracture the material if the crack is sharp the radius of curvature is small ok. So, for a blunt crack the radius of curvature will be more for a sharp crack the radius of curvature will be small ok. So, because it is coming in the denominator ok, so let us call this rho one this rho 2, so row 1 is greater than rho 2.

So, when my rho is or crack is getting sharper and sharper this value will be smaller and smaller. So, my because it is in the denominator the sigma max value will be even higher ok. So, bigger crack and sharper crack you make the sigma max even higher you will have a higher local stress, and it will be easier to fracture the material ok. So, over all the stress is much lower than the local stress ok, so this is what you have ways we discussed in the.

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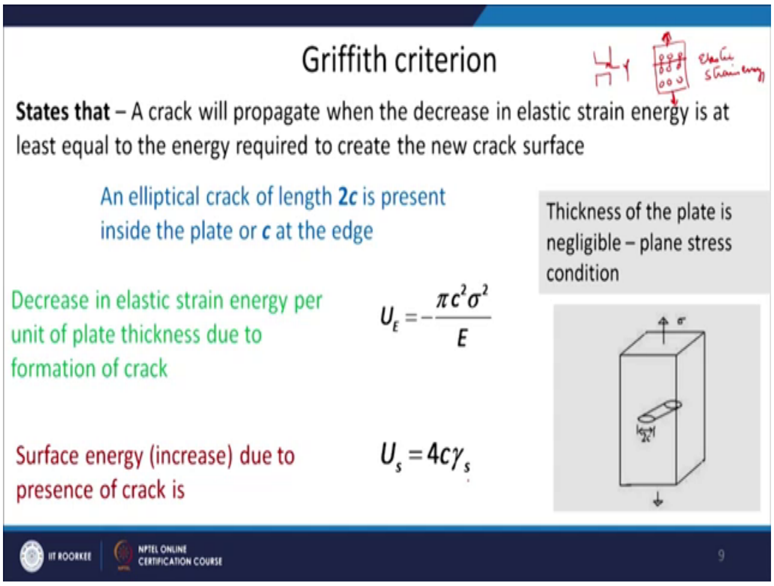

So, Griffith criteria propose that or states that that are crack will propagate when the decrease in elastic strain energy is at least equal to the energy required to create the new crack surfaces ok. So, what will happen when you have suppose material there are atoms here and you are applying a stress on the system ok.

So, all the bonds are under stress conditions. So, there is a elastic strain energy, if you are not applying any stress the atoms at the equilibrium condition at minimum potential energy. So, when I am applying any stress on the system all these bonds are now stretched. So, they will have some elastic strain energy, so they will have some potential energy associated with them ok.

So, when you create a crack, so basically you are breaking the bonds here. So, you are releasing this elastic energy my atoms are again going into the relaxed state and this bonds are now broken. So, there is not going to plane any elastic energy, but the problem is that when I fractured the material I am creating two new surfaces. So, there will be some surface energy associated with this is with this which is called gamma ok.

So, my strain energy is release, but I am creating two new surfaces. So, that is what he proposed that a crack will propagate when the decrease in elastic energy, whatever is the decrease in elastic energy due to the breaking of bond is at least equal to the energy required to create the new crack surfaces when it is equal to the energy surface energy of the two new surfaces. So, suppose crack of length 2 c is present inside the plate or c at the edge and.

We are taking the thickness of plate is negligible, so it is a plane stress condition ok. So, for that the decrease in elastic energy per unit of plate thickness due to formation of crack is given by a relationship like this, u e pi c square sigma square by e and surface energy increase due to presence of crack will give you new because of two new surfaces the this is surface energy now, it will be equal to 4 c into gamma s and the total change in potential energy due to formation of crack will be.

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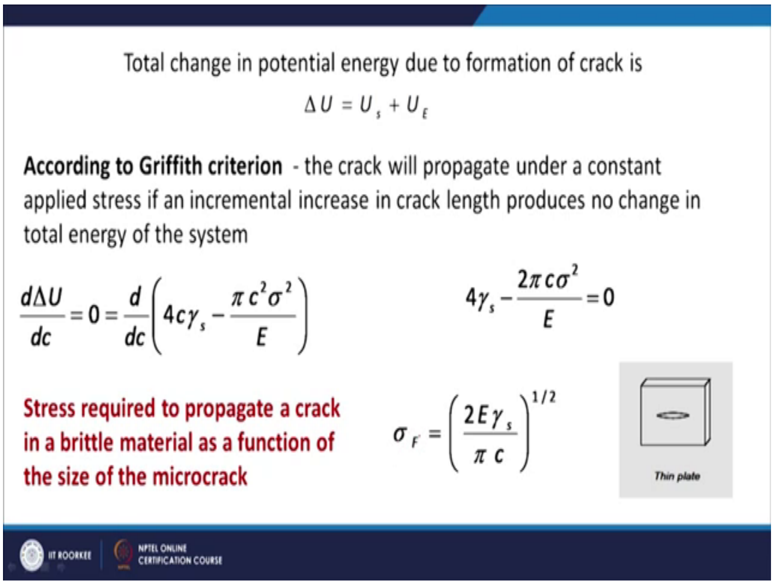

Delta u the change in potential energy, so u s plus u e, so according to the Griffith criteria the crack will propagate under constant applied stress if an incremental increase in crack length produces no change in total energy of the system. So, when I am increasing the crack length if there is no net change in the energy of the system the crack will be a stable crack and it will propagate ok. If surface energy is high then it will not propagate, because creation of surface energy makes the total energy of the system will increase if the elastic energy is higher than the surface energy then; obviously, the crack will be a stable crack.

So, the minimum criterion for stable crack is that at least they are both these two energies are equal or there is no net addition of energy during the this process of crack propagation if the energy is negative it is it is it is it is even better ok, but at least it should be there should not be any net addition to the energy to the system ok.

So basically, the change in energy delta u as a function of increase in the crack length that should be 0; so d by d c of this particular equation, so u s you are adding the energy ue is you are you are taking out the energy by breaking the bonds. So, that is why the negative sign is here and what will be the change in that as a function of change in the crack length ok. So, simple differentiation you have to do, so it will d by dc of four and gamma s will be constant.

So, it will be dc by dc, so it will be four gamma s minus all this things will remain constant. So, this is c square, so it will become 2 c the 2 pi c gamma sigma square by e equal to 0 and that will give you the required stress for fracture it will be 2 e (Refer time: 23:00) gamma s upon pi c to the power half ok. So, this is the stress required to propagate a crack in brittle material as a function of the size of the micro crack ok.

So, if the crack is bigger you will have small fracture stress the fracture will take place at a small stress for a thick plate plane strain condition the equation will be something like.

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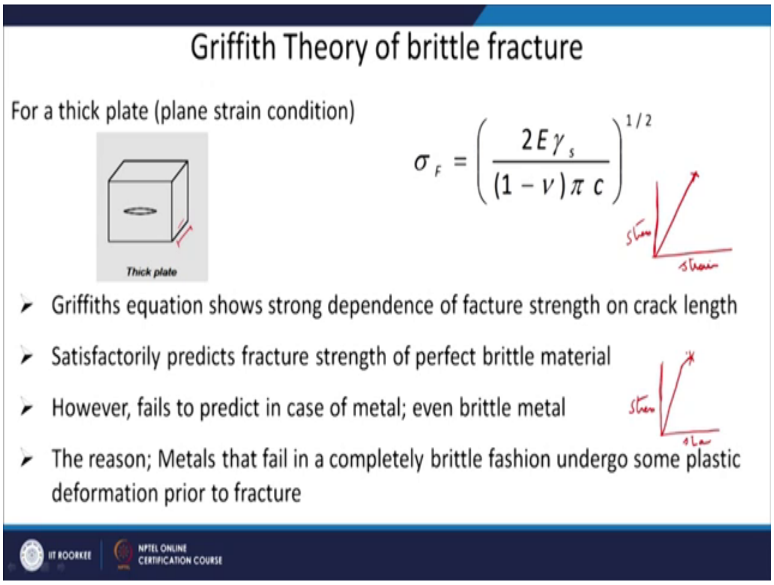

This slight change from the previous condition, so a 2 e gamma s by c. So, 2 e gamma s by 1 minus new pi c, so there is a additional contribution of poisons ratio here because we are considering the thick plate ok. So, thickness is more in this direction ok.

So, it is a plane strain condition and for that we will consider the poisons ratio also here. So, Griffith equation shows strong dependence of fracture strength on crack length ok, it is said it is able to predict satisfactorily fracture strength of perfect brittle material; however, fails to predict in case of metal even brittle metals the reason metal that fail in a completely brittle fashion undergo some plastic deformation prior to fracture ok.

So, this equations are valid only for perfectly brittle material in the sense if you see a stress strain perfectly brittle material. So, it is this is stress this is strain. So, for a perfectly brittle material it will fracture without any plastic deformation. So, it is it will takes place in the elastic range only that is why you see we are using poissons ratio here ok. So, this whole analysis of Griffith criterion or Griffith theory is for the elastic range only or elastic deformation only, so there is not going to be any plastic deformation.

Whereas, in metals for any metal though it may be a brittle metal if you see the stress strain curve it will be something like this plastic part small elastic part, some plastic deformation will always take place locally and then it will fracture. So, this deformation plastically kind of modify this whole analysis and that is why it is not able to predict very well in case of metals brittle metals the reason is this as you can see that we said that where the crack tip is you will have.

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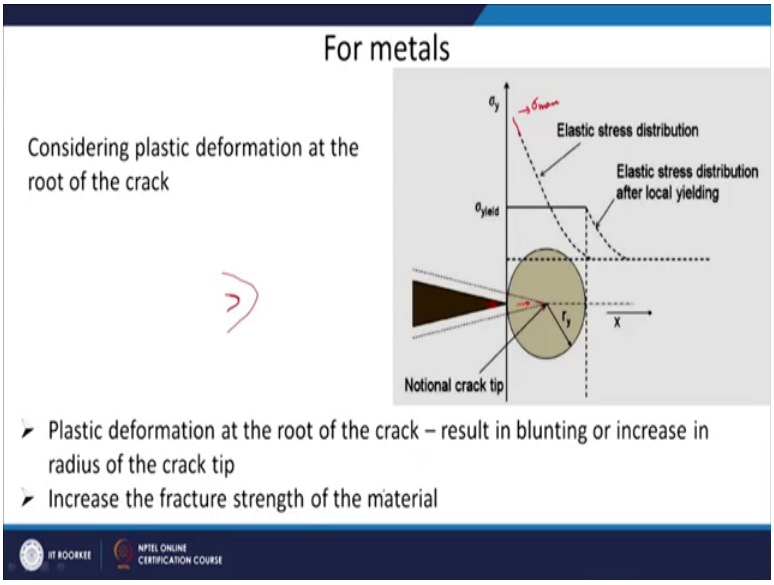

This is very high ok, so your sigma max is going like this. So, this is the elastic stress distribution just we saw this is my crack tip and because of that is my stress increase in stress next to the crack tip, but in my metals where there is some plastic deformation what will happen as soon if suppose this is my yield stress of the material ok, then what will happen as soon as this is locally the stress go beyond that instead of restraining the bonds what will happen is there will be shearing of bonds basically shearing of the planes, so material will shear.

So, instead of this stress going beyond that what will happen is locally the material will deform and instead of this stress distribution you will have a stress distribution like this it will not go beyond the yield stress elastic distribution after local yielding will be like this and you can understand that by modifying the crack tip. So, instead of crack tip like this the overall notional crack tip can be something like this. So, actually what we have done is we have increase the this is this was the radius of curvature now the radius of curvature is increased it is blunted the crack tip.

So, instead of very sharp crack tip now you have a more blunt crack tip ok. So, and if you remember the expression which we use the rho comes in the denominator. So, if your radius of curvature is increasing then the maximum stress in front of stress also will come down ok. So, plastic deformation at the root of the crack result in blunting or increase in the radius of the crack tip and that increases the fracture strength of the material. So, now, it will fracture at a higher stress.

So, thank you this we have covered the basically the fracture introduction and we have you seen the Griffith criterion. So, in the next class we will conclude the fracture lecture and we will see that how you can do the analysis in case of slightly brittle metal for the crack. And we will also see that how the different fracture will look like the ductile in brittle fracture when we look it into the microscope.

Thank you.