Introduction to Materials Science and Engineering
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Lecture – 142
Ductile to brittle transition

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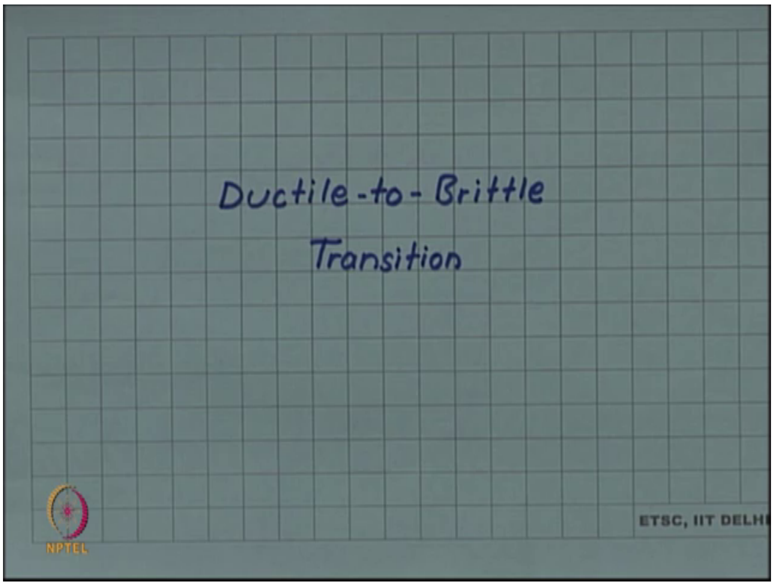

We will talk about Ductile to brittle transition. We have seen the brittle behavior and ductile behavior of materials.

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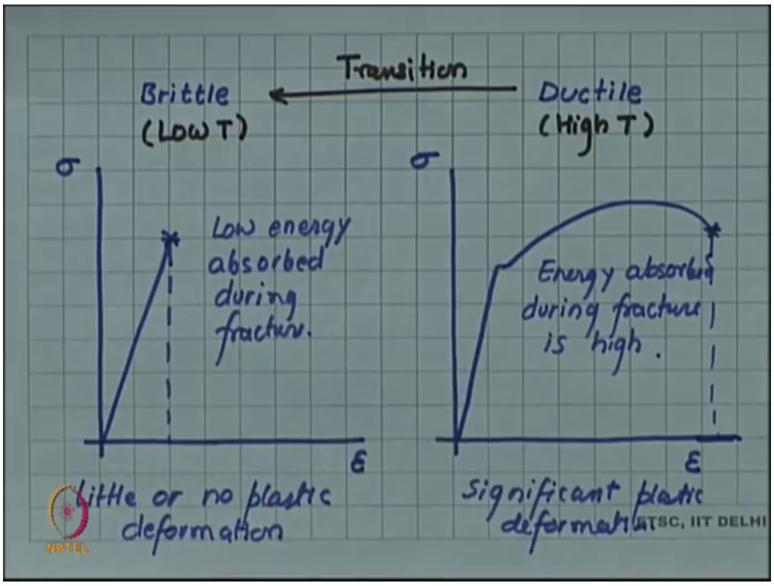

So, for example, here we have a stress strain diagram and we see that for a brittle material the stress strain diagram may be more or less straight line because there is little or no plastic deformation. So, the failure the fracture happens in the elastic regime. So, the entire deformation is elastic. So, little or no plastic deformation; whereas, for ductile there is significant plastic deformation

If you look at it in terms of energy, we see that energy is the area under the curve, energy absorbed for fracture is the area under the curve and that area will be significantly larger for a ductile material than for brittle material. So, this is low energy absorbed during fracture, here energy absorbed is high fracture is high. Sometimes it so happens for some materials that a material which is ductile at a higher temperature may become brittle at a lower or room temperature. So, there may be a transition from ductile to brittle behavior where ductile behavior is normally at higher temperature and brittle behavior is at a lower temperature.

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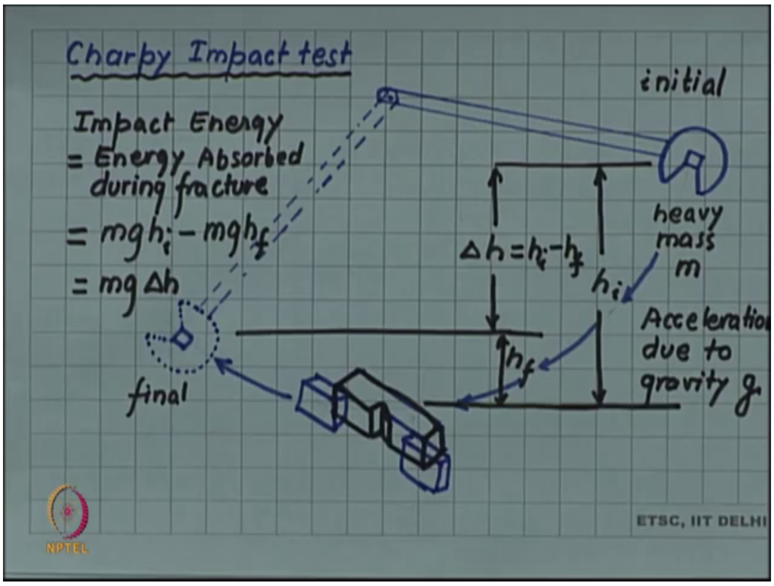

To one of the methods by which this ductile to brittle transition is studied and illustrated is the so called Charpy Impact test. So, let us look at what is involved in this test. In this test, we have a sample a rectangular sample, you can see there is a cross section is rectangle, this cross section is a rectangle cross section, sorry, this is a square section and it is a long rectangular specimen, but on one surface, it has this notch on one surface this notch is present and then the sample is held with supported at two ends and from behind it is a horizontal sample and from behind it is struck by a very heavy pendulum. So, this is a heavy mass.

So, if we if this pendulum is released from a high height let us say this is the level of the sample and this is the level of the pendulum. So, the height of the pendulum above the level of the sample is h i, this is the initial height, this is the initial stage of the pendulum. Then when this pendulum is released, it will it will follow this path and will strike the specimen and the experiments are set up such that the experiments in the sample breaks. After breaking the pendulum will continue its motion on the other side and rise up to a height a final height. So, this is the final situation; which will rise up to a final height h f.

Now if the sample was not present, then the pendulum will swing to the same height on the other side as it was released by the energy conservation. So, this means that now since it is rising up to a much lower height h f, there is a difference in the initial potential energy and the final potential energy. So, let us write that difference in energy that is what is called the impact energy. The impact energy is energy absorbed in fracture is energy absorbed during fracture.

Now, you can see that the initial energy of the pendulum; what if mass is m and the acceleration due to gravity due to gravity is g, then the initial energy will be m g h i, but the final energy is only m g h f. So; that means, this difference is what has been observed absorbed by the sample during fracturing. So, this will be mg delta h where delta h is the difference between these two heights; h i minus h f. So, this is a very simple test, you release the pendulum break the specimen and let the pendulum swing to a final height h f, the difference in the potential energies of initial and final gives you how much energy has been absorbed in the fracture of the material.

This fracture energy can be studied as a function of temperature if we keep the sample at different temperature. When this test is conducted it is found for let us say steel.

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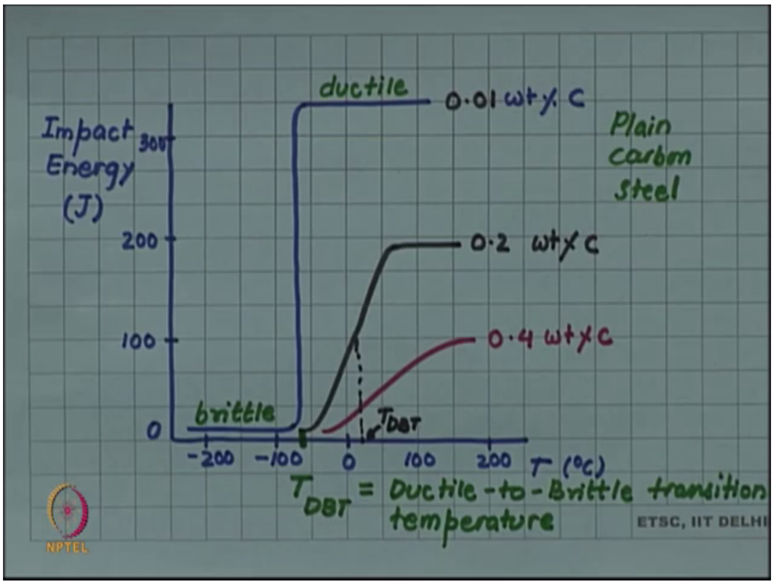

So, this is this is plain carbon steel all of them with different carbon concentration. So, for very low carbon concentration, let us say 0.01 weight percent carbon you can see that the energy absorbed was very high on the higher temperature side, but then suddenly at around minus 75 degrees Celsius or so, the energy absorbed became very low and remains to that lower value at still lower temperature.

So, when the energy absorbed was very high, remember, energy absorbed is high during the ductile fracture and energy absorbed is very low during brittle fracture. So, this means this represents a ductile behavior whereas, this represents a brittle behavior and a transition is happening at this temperature which we will call the ductile to brittle transition temperature T DBT, ductile to brittle transition temperature.

If you increase the carbon concentration, let us say 0.2 percent; still the transition is there, but then you find that the transition is not sharp as sharp as in the low carbon steel, but is much more gradual; also you find that although it is showing the ductile to brittle transition, even the ductile part the energy absorbed is not as high as for 0.01 weight percent carbon.

So, energy absorbed in the ductile regime is also reducing and this is what we know from our previous discussion that as you increase the carbon concentration the brittleness increases. So, the fact that the energy absorbed is decreasing is indicating the enhancement in the brittleness of material as carbon concentration is increasing. Then for this the ductile to brittle transition temperature will be taken as somewhere in the middle of this transition zone. So, this will be the DBT for 0.2 weight percent carbon.

Now if it is 0.4 percent the transition has become even gradual and for very high carbon concentration there will be hardly any very significant change from as a function of temperature. So, we can see that the ductile to brittle transition temperature increases as you increase the carbon concentration, but it also increases the brittleness of the steel.

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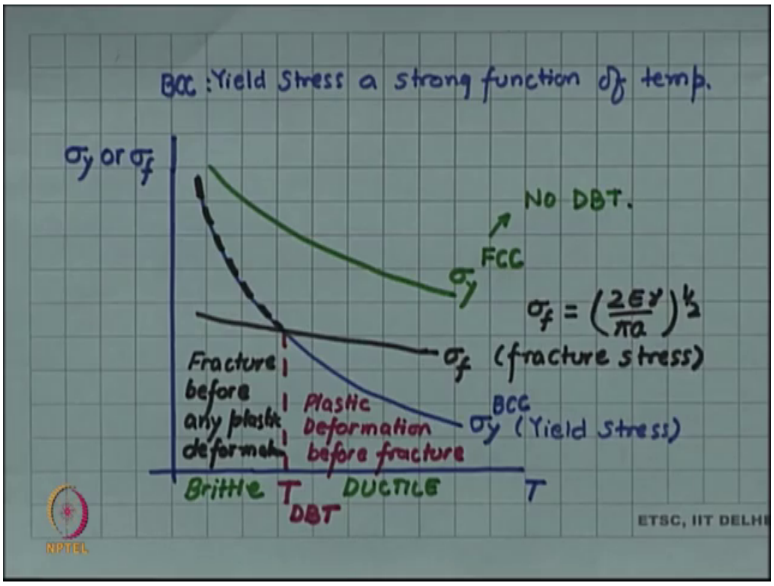

One way to look at this transition is this; let us plot the yield stress sigma y. So, sigma y is the yield stress and sigma f is a fracture stress and we are considering a situation where the yield stress is a strong function of temperature this is the case for BCC materials. So, yield stress a strong function of temperature for BCC solids. So, this will be yield stress for let us say, BCC and we are assuming the fracture stress is not so sensitive to a temperature. So, which will mean if you remember from Griffith's analysis, we had sigma f is equal to 2E gamma by pi a, where E was the Young's modulus and gamma was surface energy. So, Young's modulus and surface energy, if they are not very strong function of temperature then this may be the situation.

So, if this is the situation, then the two curves are intersecting at a given temperature, here temperature at which they are intersecting. On the higher temperature side you see yield stress is lower than the fracture stress. So, here yielding will proceed plastic defer yielding will proceed fracture. So, plastic deformation precedes fracture, plastic deformation before fracture. So, this means this regime is the ductile regime this regime is ductile, but below this temperature below this temperature you have fracture stress less than the yield stress.

So, fracture will happen before plastic deformation. Of course, if fracture is happening before plastic deformation this part of the curve is not accessible experimentally. So, this is either theoretically estimated or just an extension of the curve above this temperature. So, this is I that is why I am trying to make it dashed. So, this is not accessible; however, now since fracture is happening before any yielding is happening, then this part is brittle this domain of temperature material will behave in a brittle fashion. So, then this temperature is the ductile brittle transition temperature. In some situation, it may happen in some cases that you have a material in which the yield stress is not a strong function of temperature.

This happens in the case of FCC materials; FCC materials in general do not show a very strong dependence of yield stress as a function of temperature. So, there may not be any intersection between yield stress and the fracture stress. So, they will not show any ductile brittle transition, so no ductile brittle transition.

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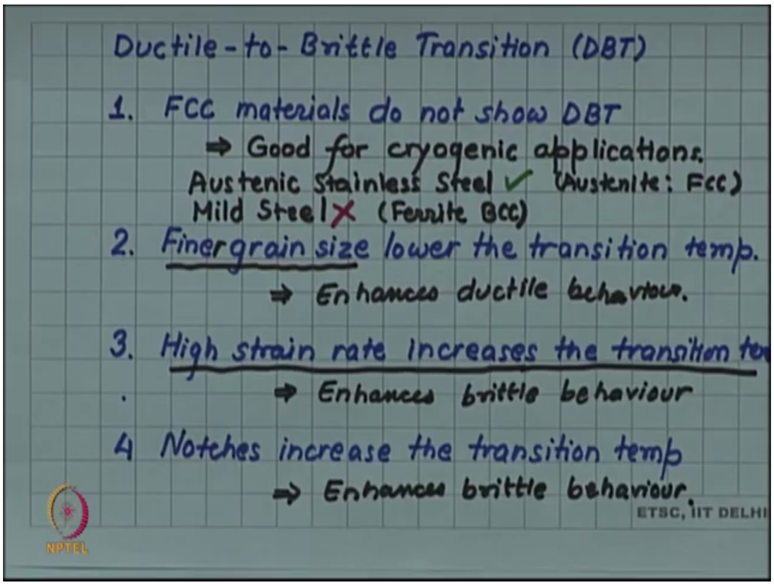

So, let us look at some of the facts about ductile to brittle transition. So, FCC materials do not show DBT, ductile brittle transition. So, they are very good these materials are good for cryogenic applications, good for cryogenic applications. For example, stainless steel austenitic stainless steel will be good for low temperature application, but a normal mild steel will not be because authentic steel has austenite and which is FCC.

Mild steel is not good for cryogenic applications because mild steel will have ferrite which is BCC and we have seen, it undergoes a ductile to brittle transition. Another factor in ductile to brittle transition is the fine grain size. The finer the grain size lower is the grain finer is the grain size, lower is the transition temperature. So, the DBT temperature is lowered, if you have fine grain size, this is a good news because this means that it is increasing the domain of ductile region and for engineering application ductility is required; as engineers, we wish to avoid brittle materials as far as possible.

So, finer grain size lowers the transition temperature. So, material with fine grain size is a good thing from ductile to brittle transition point of view. Then high strain rate increases the transition temperature. So, which means it increases the brittleness. So, high strain rate enhances brittle behavior. In the similar way, when if we go back, we write here that this enhances ductile behavior and if notches are present in the material that also increases transition temperature that is it enhances brittle behavior. We have seen that notches also give a stress concentration.

So, in any case, the presence of notches and presence of high strain rate is not good from engineering point of view and should be avoided as far as possible and if they are present, we should take care of their presence carefully in our design.