Mechanical Behaviour of Materials

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Lecture - 42
Mechanical Testing - X

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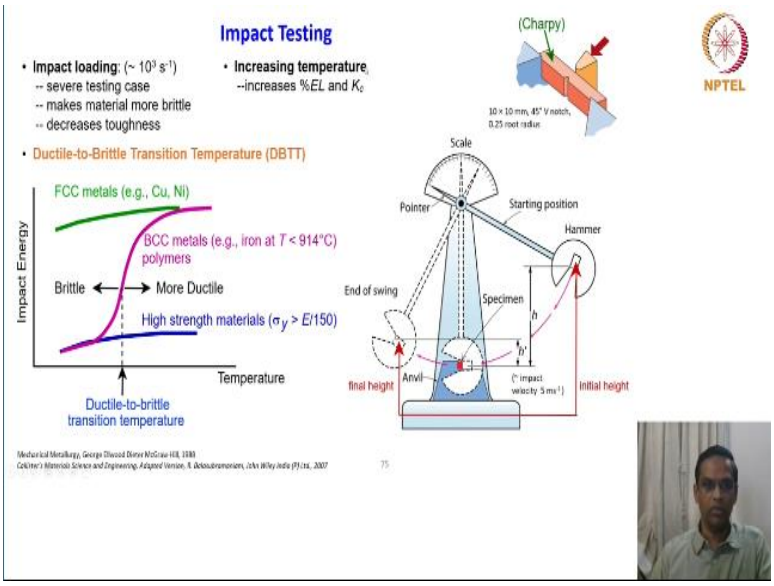

Hello, I am Professor S. Sankaran in the Department of Metallurgical and Materials Engineering. Now, we will move on to another basic mechanical testing called impact testing, very important industrial setup and very old testing methodology especially after the grand failure of liberty ships and another catastrophic failures which, I mentioned in the beginning of the course, this test becomes quite popular to assess the ability of the material to undergo brittle fracture and so on.

So, basically it is a fracture test we are yet to get into that subject, but then we are looking at the mechanical testing. So, I just want to complete this before we go to the other topics so what is this impact testing? So, this is the setup where you have this you know hammer, the sample is kept in the anvil here fixed and then hammer which and what is the sample dimension? This is the sample dimension this particular experiment or test is called it is popularly known as the charpy impact test.

And this is a charpy specimen and this is geometry it is kind of a 3 point loading setup. The sample dimension is typically 10×10 mm^2 and with the notch in the center it is about 45˚, the root radius is about 0.25 mm. So, which can be characterised or cross checked with the shadow camera and so on. So, the sample is kept in this anvil and then the hammer is going to bang the sample with the impact velocity approximately 5 ms^{-1} and then you can always calculate the initial height and the final height so on. I mean to arrive at this numbers and what is that you get so you just look at the result what do you get out of this test is impact energy versus temperature. So, at various temperatures this experiments are carried out and then formula, the plot will look like this for an FCC metals like copper and nickel and for the high strength materials especially (σ_y>E / 150). So, the impact energy is going to vary with the temperatures like this and for a FCC metals and for example polymer which is typically a polymers and iron they are all going to show very different behaviour, it is a S curve as compared to other materials, they are going to exhibit this kind of impact energy has function of temperature. And what is interesting to note here is the materials like you know BCC metals and polymers, they show something called you know that ductile to brittle transition temperature. So, this is very important it is a characteristic of these materials and then we will see how we are I mean would not understand this. So, we have the background from this and this particular temperature is called ductile to brittle transition temperature DBTT popularly called as characterized as a DBTT. And what happens is the material will behave, you know from up to this I mean this temperature it shows the transition from I mean ductile to brittle transition temperature that is called. So, the temperature is getting lowered so it becomes brittle so that is quite important test, so why these materials behave like this and why some materials behave like this? So, we need to understand this. Typically impact loading is now order of $10^3 s^{-1}$. So, we have seen these numbers in the previously, the one table I have shown all the various, you know rate of loading right from the tensile to impact to very high strain rate test and all.

So, this is in the order of $10^3 s^{-1}$, this is also come into the category of severe testing and this kind of test makes material more brittle and decreases the toughness. Of course with the increase in temperature the percentage elongation increases, energy absorption also increase and of course the K_c that is a stress intensity factor which we will see later also going to improve.

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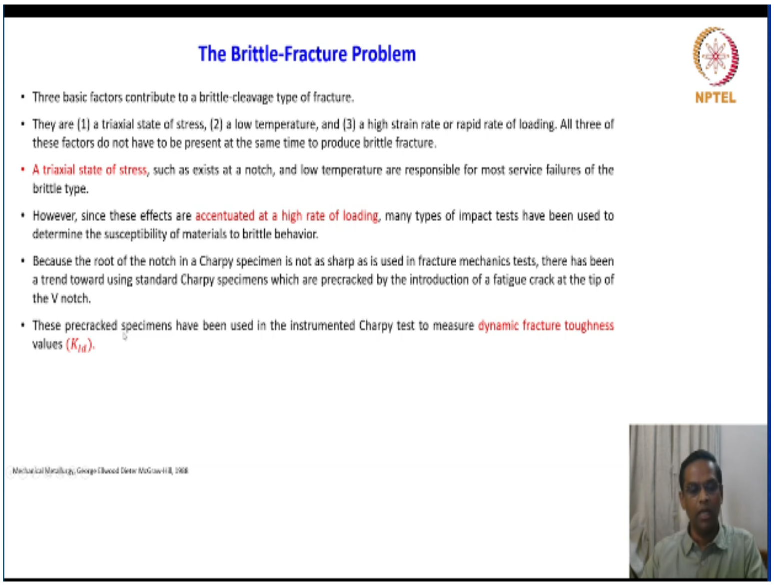

What are the important points to note the impact testing came because of the brittle fracture problem like I just mentioned. three basic factors contribute to brittle cleavage type of fracture. What are those? They are the triaxial state of stress, a low temperature and a high strain rate, rapid rate uploading. All three of these factors do not have to be present at the same time to produce brittle fracture. So, even any one of these factors will cause the brittle fracture, the triaxial state of stress you know what is it now you have sufficient backup understand this, low temperature that is what just we seen as we have said in the previous slide that then we will see why it is so in a minute and high strain rate also make some material brittle. A triaxial state of stress such as exists at a notch because please remember we are making a notch in the charpy test specimen and the low temperature are responsible for the most service failure of the brittle type. So, in general a notch that is why we simulate this notch in this test, so notch is a stress concentrator. So, similarly the low temperature, these combinations are it could be either individual or a combination is responsible for the most of the failures. However since these effects are accentuated at a high rate of loading many types of impact test have been used to determine the susceptibility of materials to brittle behaviour. So, this is a kind of an acid test to check whether the material is going to behave or it is going to failure by a brittle fracture. Because the root of the notches is in a charpy specimen is not as sharp as it used to be in the fracture mechanics test there has been a trend toward using the standard charpy specimens which are precracked by introduction of the fatigue crack at the tip of the V notch. See the 0.25 mm root radius is a standard charpy impact test which is normally practiced in most of the industry in R and D sector.

But, what happens is and people believe that this 0.25 root radius is not a true fracture; I mean the root radius is not sharp enough to assess the fracture toughness of the material, so how are we talking about fracture toughness here? We see now. These precracked specimens have been used in the instrumented charpy test to measure dynamic fracture toughness values which is K_{1d}.

So, instead of making 0.25 as a root radius, if you make a very sharp crack using fatigue loading and then again you know break this specimen under this test condition you will generate the data and then determine the parameter called dynamic fracture toughness, is very useful information. So, that is why the precrack specimens are being used.

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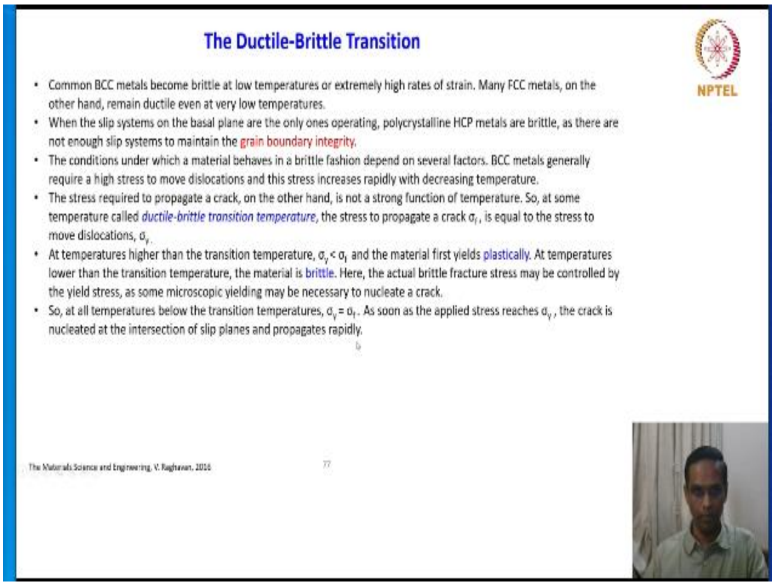

Now, let us look at little more fundamental aspects why this material behave very differently different material behave differently. Common BCC metals become brittle at low temperatures or extremely high rates of strain. Many FCC metals on the other hand remain ductile even at very low temperatures. These particular aspects we have repeatedly seen in the previous lectures. We have seen in there are two locations we have seen what is that when one occasion we said that the yield strength of BCC metal is temperature dependence of the yield strength of BCC metal and that is one end the other end is we looked at the Peierls-Nabarro of force in the very beginning there also we talked about the stress required to move a dislocation in FCC lattices and the BCC lattice. These are the two aspects we have to recall and the temperature dependency of yield stress in BCC metal that also will the same, they are all will account for this behaviour. That means, these are the properties which are responsible for these kind of metal to brittle transition temperature because the BCC is the Peierls-Nabarro of forces very high for lattice like BCC as compared to FCC. So, this is one of the primary reasons. When the slip systems on the basal plane are the only ones operating polycrystalline HCP metal are brittle so, this is also known to us, when we say brittle behaviour suddenly we can also connect them to you know materials which has got a very restrict to slip systems or restrict to number of slip systems rather that is HCP, as there are not enough slip system to maintain the grain boundary integrity this aspect also we know we understand it very clearly, how the limited number of slip system will have a problem with grain boundary integrity and so on. We have looked at a slip and the deformation mechanisms elaborately you have a sufficient background to connect all this terminology. The conditions under which material behaves in a brittle fashion depending upon several factors, BCC metal generally require a high stress to move dislocation and this stress increases rapidly with the decreasing in temperature. The stress required to propagate a crack on the other hand is not a strong function of temperature. So, at some temperature called ductile brittle transition temperature, the stress to propagate a crack that is σ_f is equal to the stress to move the dislocation that is σ_y. So, it is a very straight forward aspect, how to understand this. At temperature higher than the transition temperature that is σ_y is less than σ_f and the material first release plastically. At temperatures lower than the transition temperature the material is brittle.

Here, the actual brittle fracture stress may be controlled by the yield stress as some microscopic yielding may be necessary to nucleate a crack. So, at all temperatures below the transition temperatures when $\sigma_y = \sigma_f$. As soon as the applied stress reaches sigma y the crack is new nucleated at the intersection of slip planes and propagates rapidly. So, this way of understanding is also helps, then why these materials behave like this.

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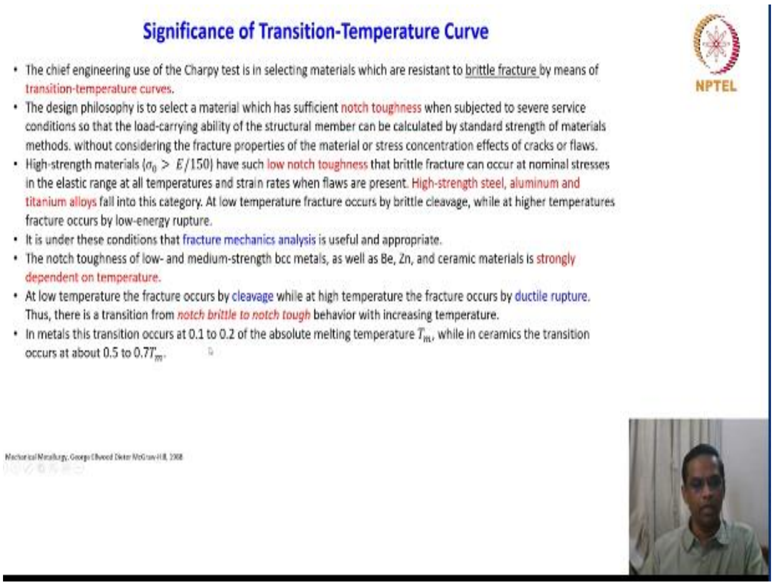

And what is the significance of transition temperature curve, the chief engineering use of the charpy test is in selecting the materials, which are resistant to brittle fracture by means of transition temperature curves, that is the primary use. The design philosophy is to select the material which has sufficient notch toughness when subjected to a severe service condition so that the load carrying ability of the structural member can be calculated by standard strength of materials method without considering the fracture properties of the material or stress concentration cracks or flaws. So, what does it say, see gives a rough idea before getting into, you know getting into very detailed strength of materials analysis or fracture toughness estimation which we are going to see very soon. So, this is a simple test, but gives lot of you know fracture related problem, fracture mechanics solution. It gives a very rough estimate of fracture mechanics solution. High temperature materials which is σ_0 is greater than E / 150 have such low notch toughness that brittle fracture can occur at nominal stresses in the elastic range at all temperatures and strain rates when flaws are present. High strength steel, aluminium and titanium alloys fall into this category. At low temperature, fracture occurs by brittle cleavage while at high temperatures fracture occurs by low-energy rupture.

It is under these conditions that fracture mechanics analysis useful and appropriate. I will just not elaborate here we are only talking about impact testing, we will discuss in detail, when we get into fracture mechanics analysis. The notch toughness of low and mediums and BCC metals as well as beryllium, zinc and ceramic materials is strongly dependent on the temperature this we know already.

At low temperature the fracture occurs by cleavage while at high temperature the fracture occurs by ductile rupture. Thus there is a transition from notch brittle to notch tough behaviour with increasing temperature. So, we are kind of you know accounted for, why the ductile to brittle transition is shown by some of the materials and how the other material behave under this high impact loading test that is all. In metals this transition occurs at 0.1 to 0.2 of absolute melting temperature T_m while in ceramics the transition occurs at about 0.5 to 0.7 T_m.

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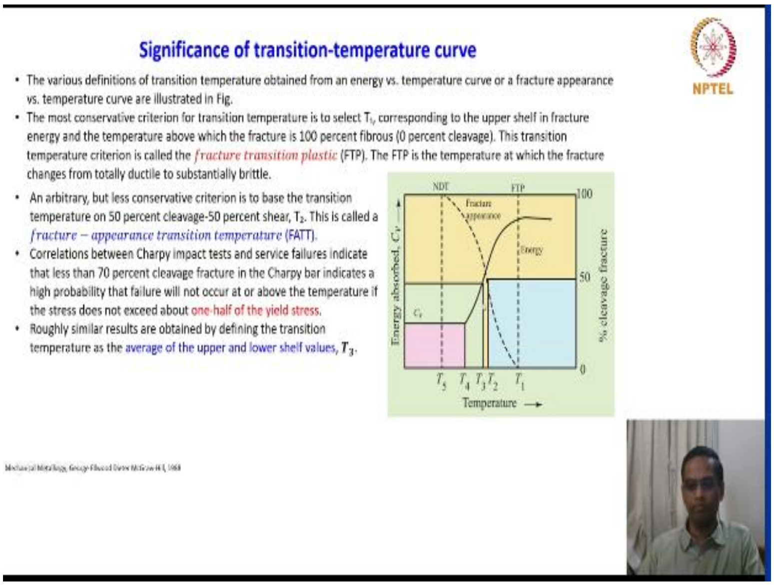

So, what is the significance of this transition temperature curve, the various definitions of transition temperatures obtained from energy versus temperature curve or the fracture appearance versus temperature curve are illustrated in the figure. You see, since I said the test is quite simple people have known adopted different terminology to identify the fracture behaviour of materials.

So, let us look at this plot it is quite interesting, this is the energy absorbed called C_v versus temperature and then you have this ductile to brittle transition S curve, but here you can see that there are so many divisions T_1, T_2, T_3, T_4, T_5 and then there are different regions demarked like you know NDT, FTP and so on. And then see NDT you are going to see all the nil ductility temperature fracture you know, what is that depending upon the fracture appearance, the temperatures are defined, we will see one by one. The most conservative criterion for transition temperature is to select T_1 corresponding to the upper shelf in the fracture energy. So, this is an upper shelf so this is T_1 we are talking about, so this is upper shelf and this is lower shelf and the temperature above which the fracture is 100% fibrous that is 0% cleavage. This transition temperature criterion is called fracture transition plastic that is FTP. The FTP is the temperature at which the fracture changes from totally ductile to substantially brittle. So, this is one very conservative criterion, instead of looking at you know in the middle like the generally shown in the BCC metals, but these are all different criterion for which you know these temperatures are chosen. So, the FTP falls in the upper shelf of the curve, so below this it is considered brittle and about this it is considered this ductile. An arbitrary but less conservative criterion is to base the transition temperatures on 50% cleavage and 50% shear that is T_2 a better criterion so this very conservative criterion.

So, T_2 at least takes care of 50% cleavage and 50% shear this is called fracture appearance transition temperature called FATT. So, this particular T_2 wherever it goes it is called FATT fracture appearance transition temperature. Correlations between charpy impact test and service failures indicates that less than 70% cleavage fracture in charpy bar indicates a high probability that failure will not occur at or above the temperature if the stress does not exceed about one half of the yield stress so, this is all some thumb rules it will keep to predict the material behaviour. Roughly similar results are obtained by defining the transition temperature as the average of the upper and lower shelf value, this is T_3, see it is almost like the middle of this curve.

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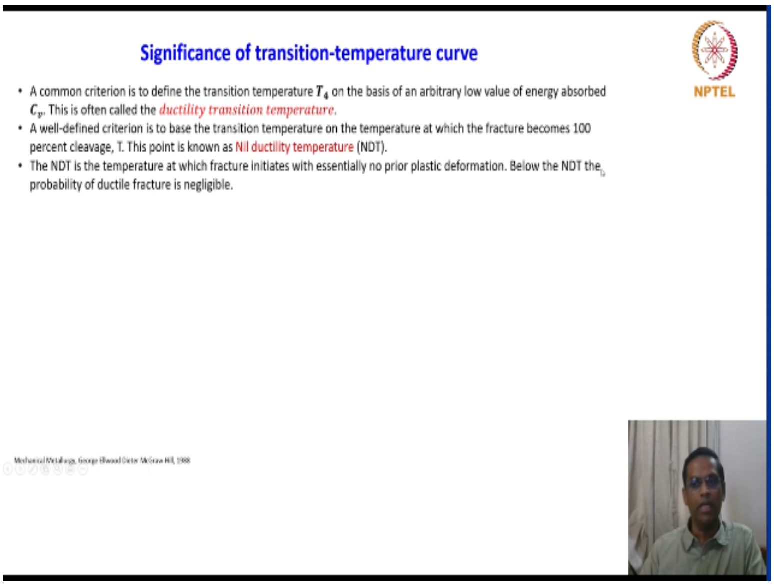

A common criterion is to define the transition temperature T_4 on the basis of an arbitrary low value of energy absorbed C_v. This is often called the ductility transition temperature; T_4 is the ductility transition temperature. And then another well defined the criterion to base the transition temperature on the temperature at which the fracture becomes 100% cleavage. This point is known as nil ductility temperature, so what is that this is nil ductility temperature. The NDT is the temperature at which the fracture initiates with essentially no prior plastic deformation. Below the NDT the probability of a ductile fracture is negligible.

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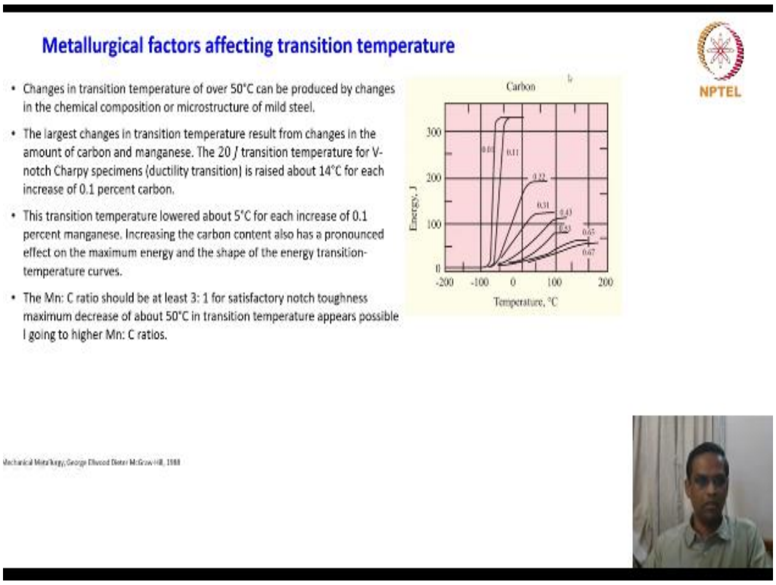

Just finally what are the important metallurgical factors affecting the transition temperature very important. Changes in transition temperature of over 50˚ can be produced by changes in the chemical composition or microstructure of mild steel, this is just one example. So, what is the message by tweaking the chemical composition or by doing a proper alloy design or microstructure that is proper pre-treatment, you can have a control of transition temperature with the order of 50˚ magnitude you can control. Other than that it is in tensions, that is what it means so this is a typical energy versus temperature plot. This is for the as a function of carbon how this the DBTT curve changes this is a very popular diagram which is given most of the textbooks. The largest changes in the transition temperature result from changes in the amount of carbon and manganese we are now talking about with respect to steel alone, we are not going to any other material because this is very you know popular material and has been used for by many decades and steel is the work as material. So, the 20 joules transition temperature for V-notch charpy specimen ductility transition is raised about 14˚ for each increase of 0.1% carbon. So, every 0.1% of carbon addition then you see that there is a 14˚difference. This transition temperature lowered about 5˚ for each increase of 0.1% manganese. Increasing the carbon content also has a pronounced effect on the maximum energy and the shape of the energy transition temperature. So, this is interesting not just the values the total shape of the curve itself is changed with the alloy chemistry especially carbon manganese which is discussed here. The manganese is to carbon ratio should be at least 3 is to 1 for satisfactory notch toughness, maximum decrease of 50˚ centigrade in transition temperature appears possible in going to higher manganese ratios. So, this is one typical example, where the chemical composition controls the transition temperature. So, I think with this I will stop here and I think we have covered most mechanical testing, I mean which is very common and then we will now move on to high temperature deformation. Thank you.