Basic Construction Materials
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Lecture-07
Materials Engineering Concepts-Part 4
Mechanical properties (cont'd.)

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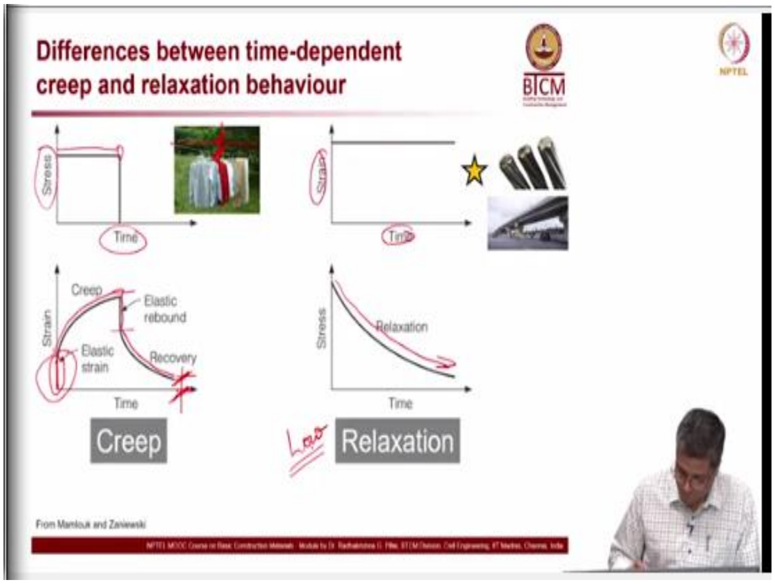

Now, another behavior which is related to creep or which is happening parallel to creep is a relaxation behavior. Now, before we talk about relaxation which is on the right side, I will talk about the creep which is on the left side of the slide first. So, let us focus on the left side. What you see is the first graph is a time versus stress. Now, what it means is, the stress is constant over a period of time.

This is an example you can see clothes hung on a string. Now here, the load of all these shirts, you can assume that to be this, because of that there is some stress acting on the string. Now, at one point it is unloaded, you take the cloth off but that is fine, so let us say this load is applied and here you have an elastic strain. The moment the shirts are put on the string, you have some strain which is immediate strain.

The string which was horizontal, immediately it will sag, that is an indicative of the elastic strain. Now, the cloth is already there and if you leave the cloth for some time period, then the string will still experience some deformation, this is the creep deformation. I know that you do not put the cloth for more than a day, but this is just an example to show you, which you can probably relate easier.

Assume that this cloth is there continuously on the string for every day, for months. Then you will see that the deformation or the length of the string keep on increasing or the sagging is more and more. I am talking about this height, this gap, that is going to be more and more. Then, when the load is removed it will come down, so you will recover some part of the strain, that we call elastic rebound.

Mainly, this portion, elastic strain, most of that is recovered. Then you will also have some more recovery which is elastic plus the plastic recovery, that is this portion here. And some point over here, there are some region which is, I mean some of the strain which is not recovered at all. That is permanent deformation. This you cannot recover. That is the permanent deformation you are talking. That is about creep.

Now let us talk about the relaxation, here strain is constant as a function of time and not the stress. Strain is constant as a function of time. Now, when strain is constant what is happening? Stress is coming down. So some realignment happens within the material and because of that the stress experienced by the material comes down. In other words, the material cannot take anymore load as expected. And this has become a big problem when you talk about pre-stressed concrete.

Example you can see here, one picture I have put on the right side, where we use this pre-stressing steel strands and then you have a, this is used on large concrete girders etc. Now, pre-stressing strand - when you pull it, you pull the strand and then anchor it and leave it, so that the concrete will be under compression, that’s the idea. Now when you pull the strand, the strain or the extension which you provide is constant.

So, let us say, you are pulling the strand and the strain at that moment in the beginning is almost same after some time also. In other words there is no reduction in the strain because the length of the girder remains same. Now strain is constant but if there is a realignment or some changes happening within the material of the strand or steel, then it will lose the stress. And if it loses, then we can call it, the strand has relaxed and it will not be able to provide the same stress as it was giving in the beginning.

And when that happens, the prestressed concrete's capacity will reduce. So, the pre-stress loss should not happen. More on this, you will understand when you get to courses on structural design etc. But the material behavior, very very important for pre-stressing strand is, it should be of low relaxation. The strand should be of low relaxation, you should look for this. It is very, very important when we talk about pre-stress concrete.

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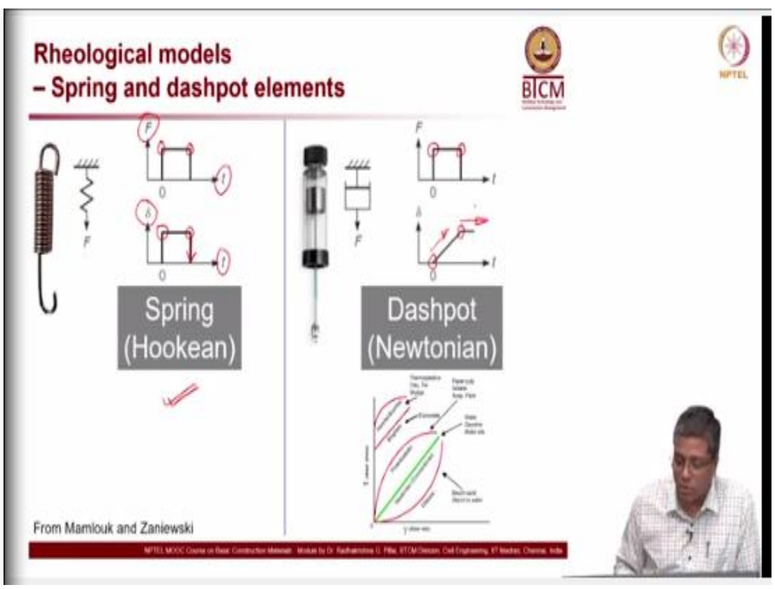

We talked about elastic behavior, we talked about viscous behavior. Now let us see how we can model this. Elastic behavior - you have seen many times we can model by using Hooke's law. Spring constant, you have seen that also, here you can see a load F is applied as a function of time, the deformation. The moment the load is reaching this point, the deformation is also at that point, I mean it experiences the same.

But when the load is released, this point deformation also becomes 0, it comes down to 0. So this is a pure elastic behavior. When you talk about viscous behavior, you see the load F is applied F and at that moment, the deformation is 0 but it slowly increasing. And when the load is removed, at that point there is a deformation and that deformation stays constant, it does not come down as in the case of spring.

So, these are 2 different basic elements which can be used for modeling viscoelastic behavior. Elastic behavior on the left side and viscous behavior on the right side. Now we how do we combine these to model a viscoelastic behavior? Let’s see that.

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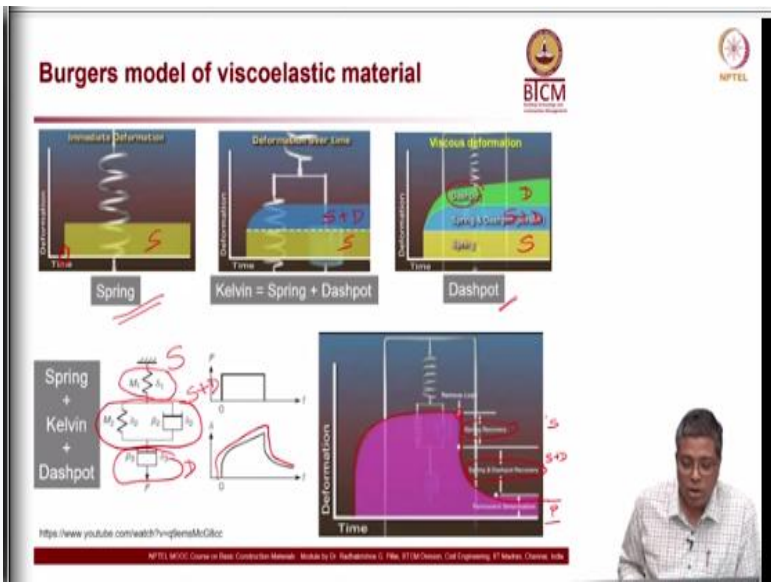

So, here is an example I got it from one of the youtube video, you can watch that video, very interesting, link is given at the bottom left. These are some snapshot from the video. So you can see on the first image, that is a spring model, you can see the spring. So, the yellow region is the graph corresponding to the spring model. So time t0 is this. Before I go into the graph, let me show you what this model looks like.

So, this is a spring model here, and then you have a spring and dashboard placed in parallel which we call Kelvin model and then you have a third one, which is a Dashpot model. So, these are Spring, Kelvin and Dashpot put in series. Now the first one on the top left is the deformation due to spring model or immediate deformation.

Second one is Kelvin model, which has spring and dashpot, the blue region is because of the viscous flow. So, you can see at the background of this curve, you have spring plus dashpot. Now, the third one is of the viscous deformation, which is only the dashpot, this green one. Let me correct that, second one is spring plus dashpot in the blue over here. And here, it is only D and spring plus dashpot and this is spring.

So, I am just keep on adding to the top, first I talked about the yellow, which is only spring and then I talked about S + D also added to that then on top of that D is also added. So, over here in the bottom left S and the second one is S + D and the third one is D, this is just a summation of all 3. That is what you are seeing on this graph here, which is very similar to the graph in the previous slide, this one.

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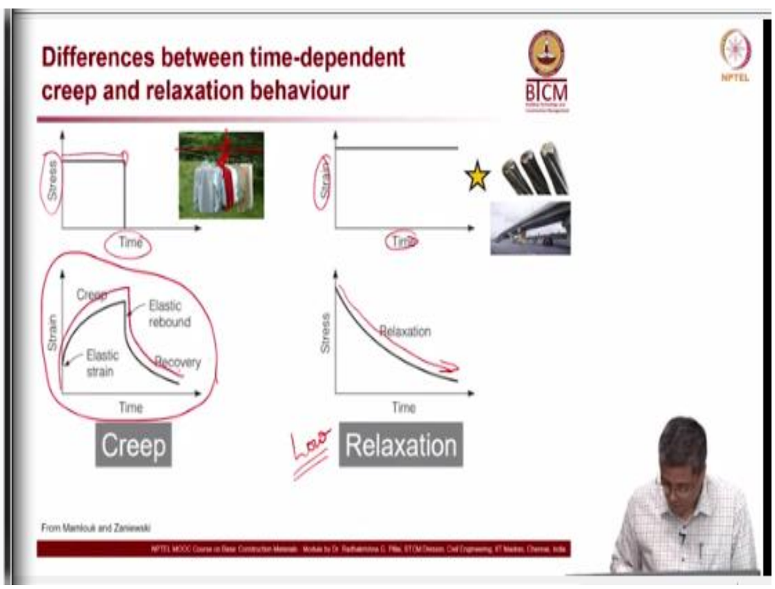

So, the creep graph here, it is very similar. You can see the shape, trace the shape of this, it is coming something like this. Now the same thing is here also, you can see this graph, it goes something like this and then comes down and then levels. Now here you can see the load is removed at this point and then you have spring recovery and then you have spring plus dashpot recovery and then you have permanent deformation.

This is permanent deformation, this is spring plus dashpot and this is spring. That is about the Burgers model of viscoelastic behavior.

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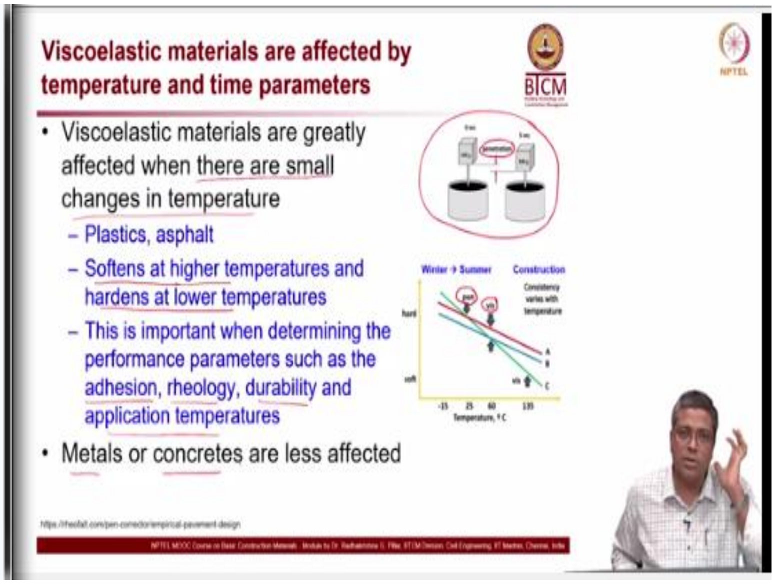

Now, this viscoelastic behavior is also dependent on the temperature and time, loading etc. So, when there are small changes in temperature, that's also affecting the behavior of these materials. Mainly it affects the plastics and asphalt materials and the material gets softens at higher temperature. I mean that is our anticipation like something when it is hot, it flows far easily, when it is colder, it will be difficult to make it flow. And softens at higher temperature and hardens at lower temperature.

So, look at the graph on the right side bottom, you can see these soft, hard and as the temperature increases, the material becomes from hard to soft case. And, in reality how do we look at this temperature increase? When winter, temperature will be low, in summer temperature will be high. This is during service, this happens during service, every year it happens.

Now there is also a case where these materials experience much higher temperature, that is during construction. You will be actually heating the asphalt or bitumen to make it flow during the construction. So, that time, during the high temperature of even at this temperature, the material will be very, very soft. It will be very soft or it will flow easily, whereas in winter it will become very hard.

Now imagine a road which goes through a region where the climatic variation is significant, very cold in the winter and very hot in the summer. So how do you set this material so that for both winter and summer, the softness or the viscosity is in the reasonable limit.

So, you will have to look at the temperature range which is in service and during the temperature range, whether the material is having sufficient viscosity or not. It should not be very, very fluid. It should be viscous enough, so that it does not flow easily. So, these parameters are important when you talk about adhesion, rheology, durability and many other things during temperature.

So, the temperature at the construction site or the ambient temperature conditions for the material throughout the year must be considered before you select a material. So, the picture on the top over here is basically how these typical asphalt materials are tested. So, this pen here is the penetration, this is a test which we do in asphalt, we will do this test again in some other class.

But, in penetration, you basically take a needle and put it through the asphalt and you see how much is the depth of that penetration. So, if the material is more fluidy or less viscous it will penetrate more. So, we will put some limits on how much it should penetrate. This is how it is handled in the construction site. And vis is viscosity, we will put a limit on viscosity also. So these are the approaches by which we control these properties of various materials.

Now last point on this slide, metals or concretes are relatively less affected because of the temperature. I am not going to say it is not affected, it is affected but relatively less.

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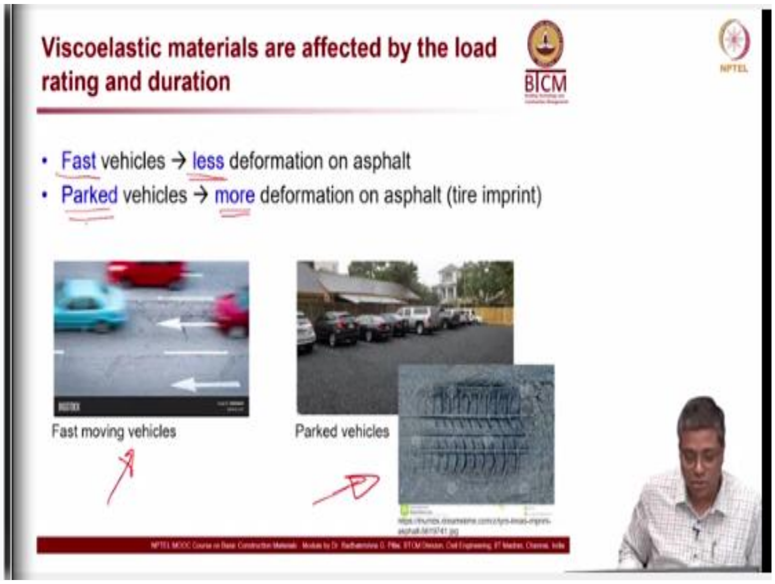

We will show some example on that also later. Now viscoelastic materials are affected by the load rating and duration. You can see here fast vehicles, when the vehicles are moving very fast as shown in this picture, the deformation is less. When you have a parked vehicle, you will see more deformation like you see in the marking here. You can see imprint of vehicles, if you imagine you park during the summer and there is some bleeding also on the road, the tar bleeding or the bitumen bleeding, you will see imprint of your vehicle's wheel and that is like, when you say the vehicle is parked, the duration of the load application is more. The time, the duration is more and hence you see more deformation on asphalt even though the weight of the vehicle might be less. In other words you can even have an imprint even if it is a cycle for example, but on the fast moving vehicles even at a higher load you will not see as much deformation, that is what you have to look at.

So, you have to look at the time duration and also the value or the magnitude of the load, both are important to consider when we think about deformations here.

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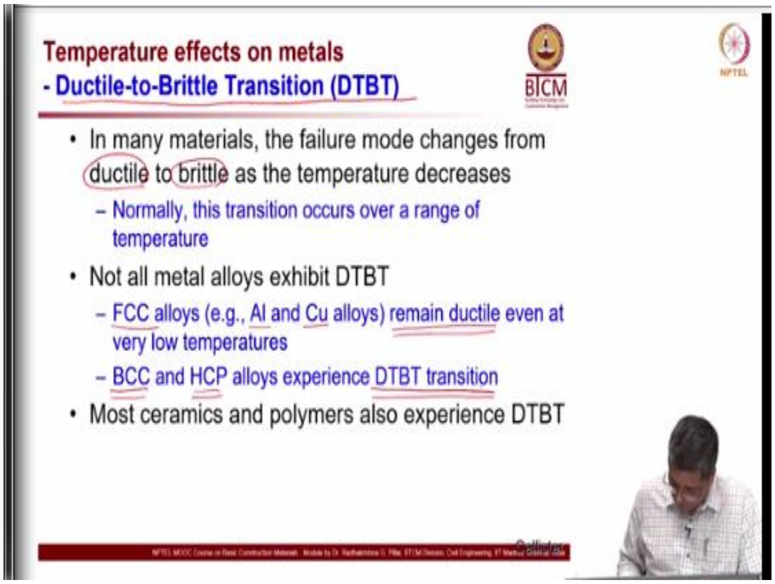

Now, another behavior which is mainly for metals due to temperature effect is the ductile to brittle transition. In the previous to previous slide, the last point I mentioned was metals can also have some influence because of the change in temperature. So, this is on that. So, in many materials the failure mode changes from ductile behavior to the brittle or from ductile failure to brittle failure as the temperature decreases.

Now normally this transition occurs over a range of temperature, it is not sometimes it happens in 5 degree change or something. We are talking about larger range, I will show a picture on the next slide. Now in what type of metals this happen?

In FCC alloys (aluminum, copper alloys), it does not happen. That means they remain ductile even at very low temperature. But when you talk about body centered cubic or hexagonal crystal structures, you have DTBT transition which is very common. Now most ceramics and polymers also experience DTBT.

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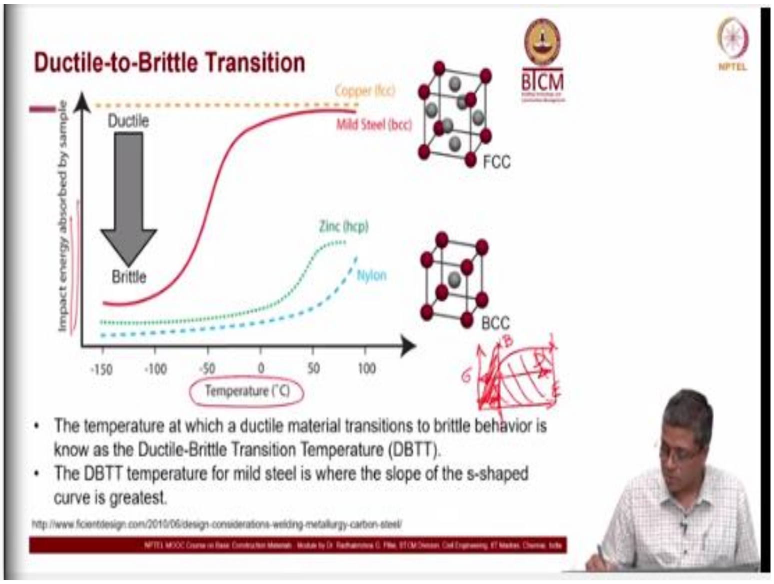

Now this is a graph which shows, you can see temperature here and then impact energy absorbed. So, when I say why we are looking at energy is, when we talk something is behaving in a brittle manner, that means it takes less energy. If something is ductile then it takes more energy, that's the concept.

So, I am going to show you a small graph here which I will delete later, so if this is strain and this is stress a material which has a graph something like this. And there is a breaking point, we can call it as a brittle material. Whereas another graph if it goes something like this and then it breaks here, then we can call it ductile behavior. That is ductile and this is brittle. The longer the area under this curve, the larger the area under this curve and if the width is more, then we can generally conclude that as a ductile material. Whereas if the width is less like in case of B, brittle material here, this width is very little, this much only. So, that is a brittle behavior. Whereas in case of ductile material it is much wider, the graph is much wider, so it is a ductile behavior.

So, looking at the area under this curve, that is what we really look at, that is the energy. In this case this whole thing is the area. So, for the ductile material you have more energy. So I am going to delete this.

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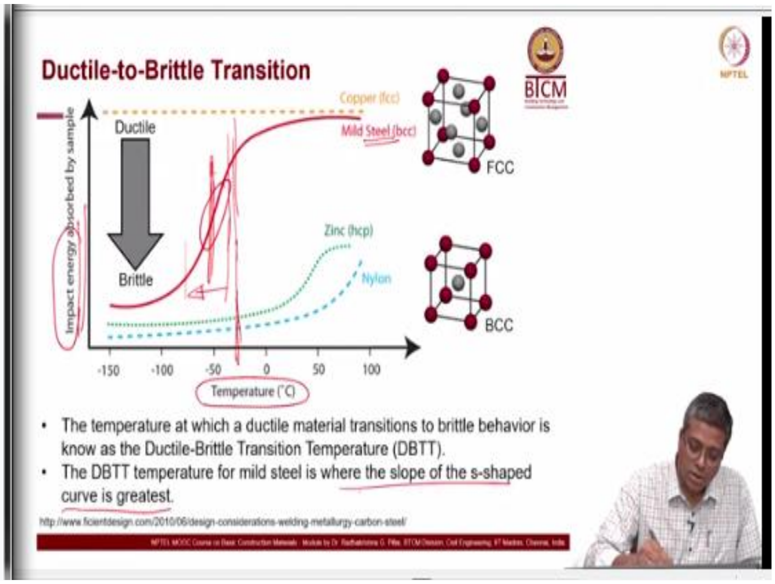

Now here, so that's what we are talking; energy required to break. If it is more energy required then I can call it as a ductile material, if energy required is less then I can call it as a brittle material. Now looking here let us say, you are talking about the mild steel BCC or the red curve here, the mild steel which is showing the red curve. So, I can say that that DTBT is somewhere in this region.

So, I can say or in what I am looking at is where is the maximum slope of that curve, where the slope of the s-shaped curve is greatest. So, in this region, I can say that mild steel will undergo ductile to brittle transition. That means, when the temperature is about, lets say we can even call this whole region, I mean from here onwards, let us say about - 25 degrees, if that is from here the slope is very, very high.

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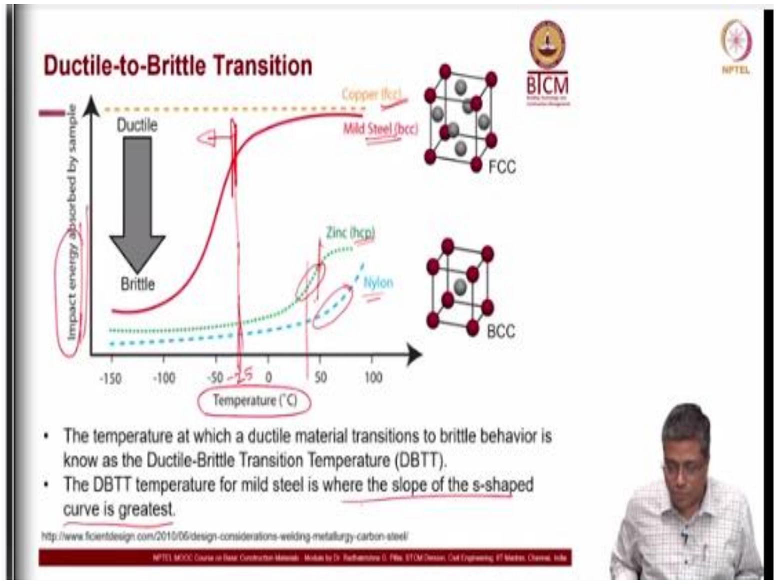

That means, from here if I take, the slope is very, very high from here onwards. So, the material start behaving like a brittle material from about -25 degrees. From there onwards as you reduce the temperature, the mild steel behaves like a cast iron. Cast iron is very brittle. Now, but copper which has face centered cubic structure, it does not change even for up to -150 degrees. This is probably one reason why copper pipes are even used for water supply systems in very, very cold countries.

Now for zinc, hexagonal and for nylon also you can see there is a significant change even at very high temperature. So, that is why some of these plastics they do not behave in a very ductile manner even at 0 degree Celsius.

So, for example zinc, here you can see it is changing somewhere here or maybe here. So, you have to look at the slope where it is changing significantly. And then beyond that point, beyond when I say more negative to that point, maybe it is not recommended to use that material if you are expecting a ductile behavior. Because for all safety purposes we want our systems to be ductile in nature and this is why we are moving away from using cast iron.

So, old times people used to use cast iron for building for structural steel. And then they started introducing steel because in cast iron, the carbon content is very high and that leads to brittle behavior. So, you do not want catastrophic failures, you want the structure to deform before it collapses. So, we want ductile structures, so started using steel. That is how the change came. But this steel will become brittle when the temperature is less than – 25 or less than that.

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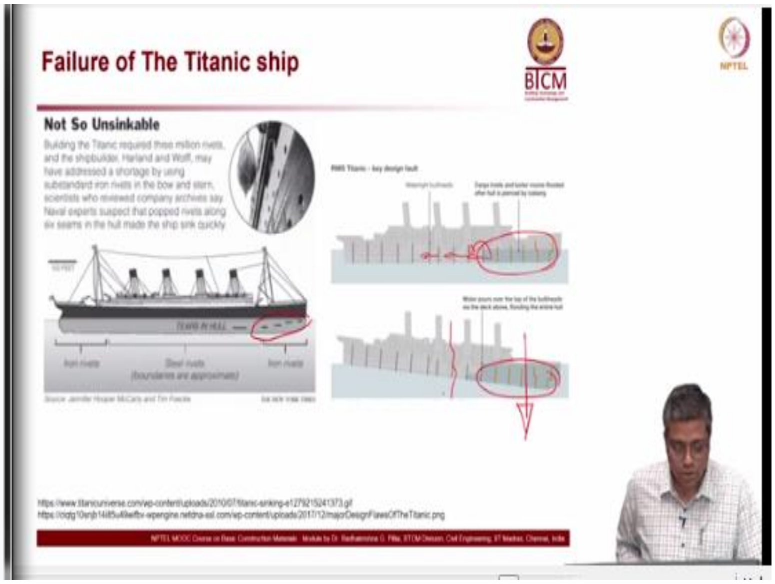

Two examples of a large scale failure because of this ductile to brittle transition. One is about the titanic ship. What happened, you know the story. These are the locations where the iron rivets were used. You can read the story in the paragraph on the top left, you can pause a bit and then read the story. But main concept here which I am trying to say is that iron rivets of poor quality were used.

And when they hit the iceberg, there are different theories on this but one theory is that, this material which was used behaved in a brittle manner and led to the failure, complete failure of the rivets which further led to the collapse or the sinking of the ship. As you can see that is also associated with the hull design, you can see these different compartments but water was not moving from this compartment to this compartment, it was not allowed in that design.

So, later on, this failure also changed the way the ship hulls are designed. If water was going like this, to all the hulls, then it would not have failed like this. So because of this heavy water on the right end then the weight acted like this and then the ship broke over here. This is what happened in titanic ship.

Anyway, point for this class is that the material which was used for rivets became more brittle when it went through the Atlantic ocean and near the iceberg temperature was very low. So, the material which was ductile in Belfast, where it was made or during the construction time, became brittle during the service which is as you sail through the ocean cold water, that is what led to the failure.

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This is the story, you can read the story in more detail.

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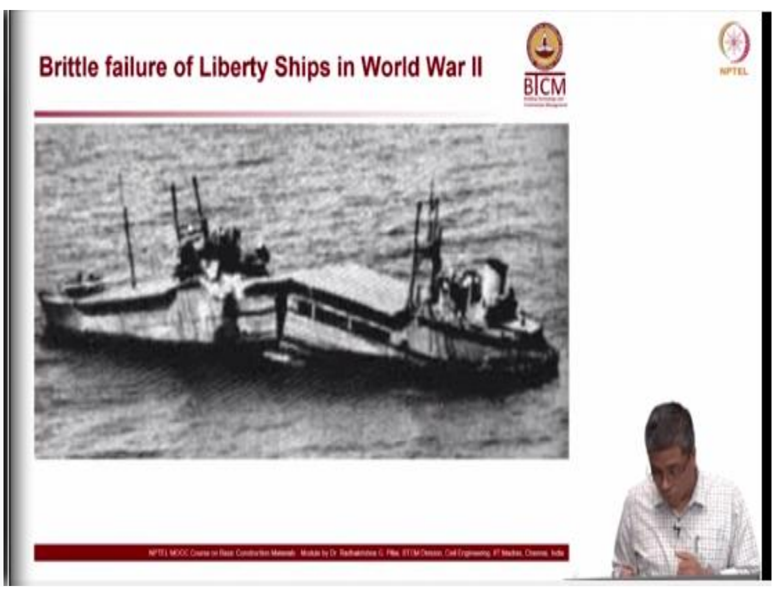

Now, another example of such failure is the failure of liberty ships in World War II. Here also you can say, this is failing like broken into two at the center.

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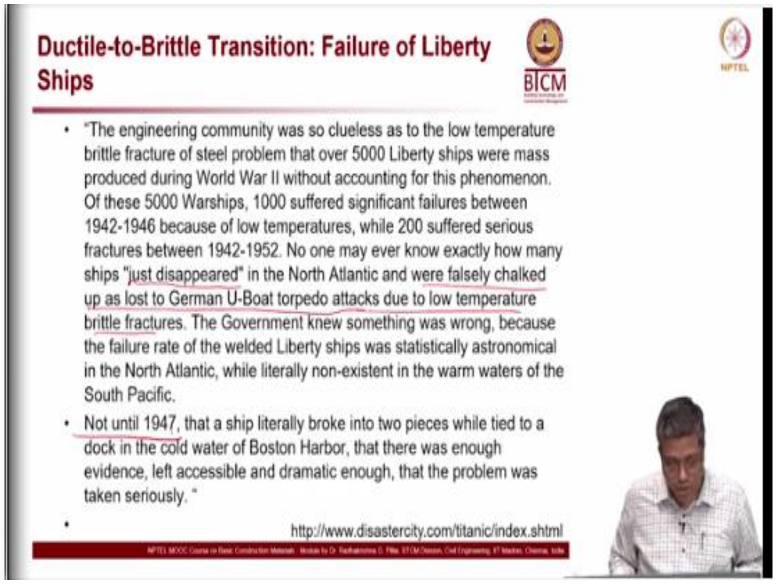

And this is also associated with the ductile to brittle transition of the material which is used and it led to the breaking of the ship into two and then sinking. And people were thinking that actually it is lost or the just disappeared in the north Atlantic and were falsely chalked up as lost to German U-boat torpedo attacks due to low temperature brittle fractures, but it took several years for scientists to confirm this behavior and so, this was written not until 1947. So several years it took before real reason for the missing ships were identified.

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So, to summarize we looked at viscoelastic behavior, we looked at creep and relaxation, very important for pre-stressing strands the relaxation behavior. And then we also look very briefly on how to model these viscoelastic materials. And then looked at temperature effects and looked at the viscosity. How viscosity of materials changes as temperature increases And how the ductile to brittle transition happen as temperature decreases.

We also talked briefly about the load rate and it is duration. How that affects the flow of materials which are used for construction. Example we use was asphalt. I think with that we will conclude today's lecture, thank you.