Materials Science and Engineering
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Lecture – 25
Tensile Test

Hello friends. Today we will start our lecture with one of the very important test used in evaluating mechanical properties and that is tensile test ok. So, we have already introduced you to the stress and strain ok, and then we discussed about the elastic part of elastic behavior of the material ok. So, when we go to this tensile test and we will see that how what kind of information you get from this you will understand that whatever we discussed there is again coming back here and it is kind of getting integratedm and you will be start appreciating that how we get all these values from a tensile test.

So, if you consider the whole mechanical properties as a as a as a whole that what type of mechanical properties are usually of interest to us. There are two colors I have used here one is this dark brown and one is blue ok.

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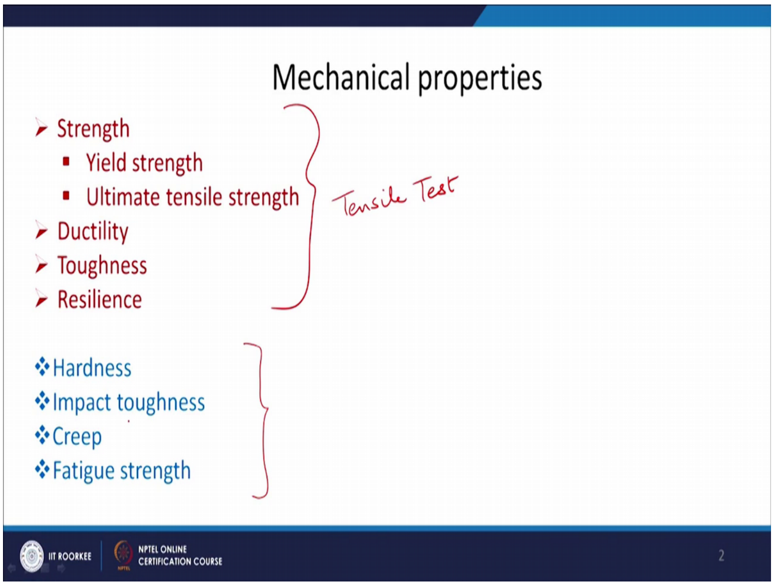

So, the first part properties mentioned in the first part basically. So, these ones, these are you are going to get from a typical tensile test or tension test this is what you will get from tension test. So, strength of the material in that you will have couple of strength yield strength and ultimate tensile strength, one two of the most important strength we which we have or which we need and that when you have ductility toughness and resilience ok.

Then there is another set of property which is mentioned here hardness, impact toughness creep and fatigue strength these are not part of the tensile test per say. But some of the properties actually you can get from a very similar kind of test hardness is of course, very different, but some of the other properties actually the kind of sample or the kind of machine which you use are very similar to what you will get in a tensile test ok.

So, let us start with the tensile test first and basically the idea is to understand all these properties how I can get this properties from a from the information which I get from the tensile test. So, this is the basically the samples which you use for doing tensile test.

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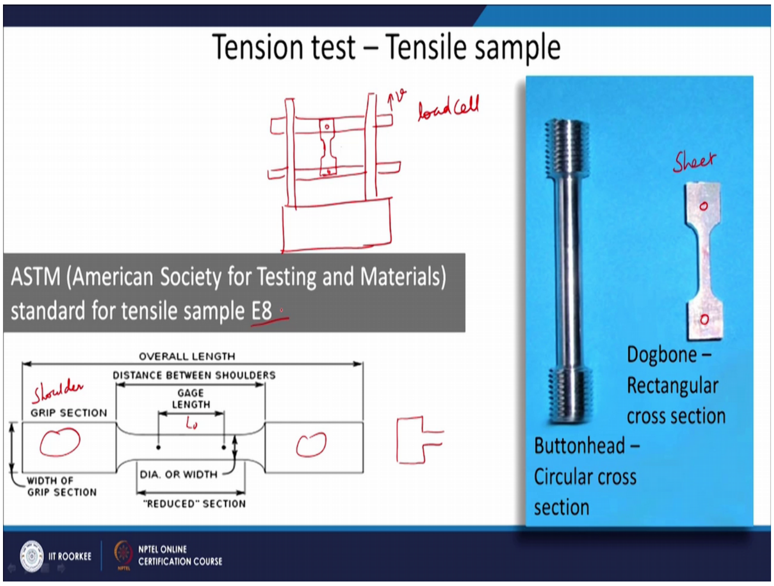

One is if you have sheet, if you I have sheet for which I want to know the mechanical properties. So, then we have this dogbone or rectangular cross section area material sample ok. So, basically the cross sectional area of this sample is rectangular and or if you have some kind of a bar may be a torque steel or something like that then we have this kind of button head with circular cross sectional area ok. And in this sample there are few things which you can notice that, one is what we call is the grips section which is mentioned here. So, this is you can say either sometime people refer to it as shoulder ok.

So, it is like shoulder kind of thing. So, it is either a shoulder or it is a grip section and this is the basically either diameter or width of the grips section this is where the machine holds the sample ok. So, if you look at a typical tensile test machine basically you will have some support system which is mounted on a base here and then there is a unit called cross head ok, you have a cross head here ok. And basically there will be some (Refer Time: 04:37) one is going to be stationary and another going to be moving. So, suppose if this is moving then there will be a stationary one in the bottom ok, and your sample comes here suppose some arrangements will be there I am not showing in to that details ok. Suppose the sample will be like this of course, it drawing is not very nice here ok, suppose we are able to load by some pin loading. So, sometime you will also see that there are there is a hole here in the sample. So, you can insert a pin and that is how you are going to load the sample.

Now, this cross head is going to move this is going to apply a strain on the material and the response of the material will be in form of stress and for measuring the stress there is a part of this machine which is called load cell ok. So, load cell will measure the stress of the material which is basically the response of the material to the strain which we are imposing on that ok. Now, you can understand that I can move this cross head with different velocity v ok. So, if I am doing with that of faster velocity then I am doing it the deformation at faster rate if I am moving it slower speed then I am doing the deformation at slower rate.

So there can be different rates also I can apply to that this is how a typical tensile testing machine will be. So, basically the machine is going to grip the sample in this region ok, there can be different methods to grip one as I told you that you can have hole in the sample and you can insert a pin and then it will be called as pin loading. In some cases you have some kind of griping section it is like a clutch kind of thing which you see in automobile that you have to have some friction which and you have to have a normal force with grips the sample.

Now, one of the most important part of this sample is what we call is the gauge length which is mentioned here ok, between two points and there we have also reduced the cross sectional area of the sample ok. So, the idea is to reduce the cross sectional area of the sample such that the this part of the sample will experience more stress because the cross sectional area is reduced. So, the deformation will be concentrated in this part and the shoulder part is what we are saying that it should not deform normally ok. So, by reducing the cross sectional area, so I am say, I am assuming that. Now, the deformation will be concentrated in the gauge section only and there will be a gauge length which you can call as something like l naught for argument sake. And then you will have some diameter or width diameter if it is a round cross section circular cross section and width if it is a rectangular cross section ok, and this is the distance between the shoulder ok.

One the more important thing you will see here is that when we are reducing the cross section we are not doing the reduction like this. For example one way to do that is I can reduce the cross section like this also ok, but this kind of very sharp corner is going to introduce stress concentration in the material this we will see later on when we discuss fracture ok, and your material will fail at this root itself ok. So, you are not going to get the representative property of the material, but just some kind of a fracture property of the material because you have a sharp corner here. So, you have to have some kind of curvature here and the whole standard that how you can prepare this sample is given in again ASTM standard, American Society for Testing and Materials and the standard name is E8 ok.

So, you can go through that and make your sample accordingly. So, this is what typical tensile curve will look like ok.

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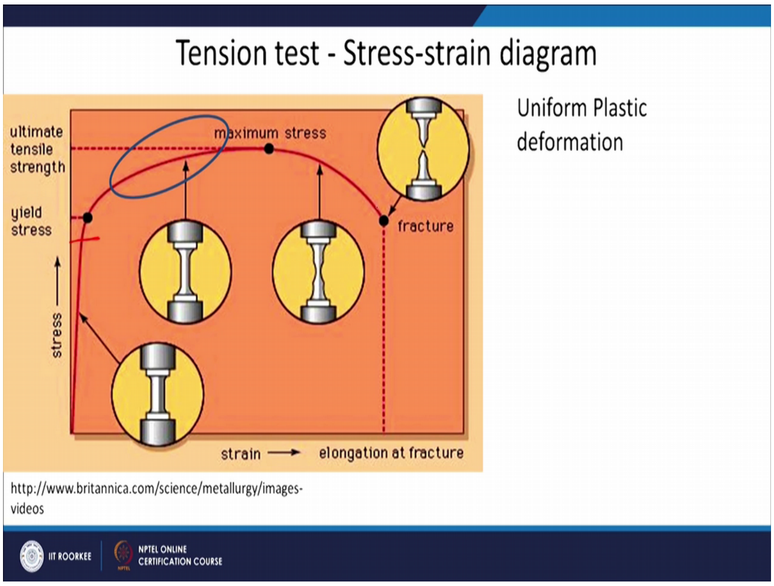

So, this on y axis stress on x axis have a strain ok. So, strain is what you are imposing on the material and stress is your response of the material. So, you will have some linear part ok, which is what we are going to call as where the elastic deformation is going to takes place and Hooke’s law will be a built this is already we have discussed. So, this is I think this circle has gone little bit too far actually it should have been some up to here only. So, this actually should be down.

So, your elastic part will be up to somewhere here and then your material will start going into a non-linear kind of dependence of stress in to with strain and that is where we call it as the material has now, started deforming irreversibly or there will be a plastic deformation ok. So, this is I will come back to this again that why we are plotting this line here ok. And this is where you will get uniform plastic deformation. So, after yield point, yield will be where your material started showing the plastic deformation ok.

So, after that you will have a plastic deformation in that also we are dividing this deformation into two parts, one is which is what we are calling as uniform plastic deformation. So, during this time if you see this two samples here this is where initially when the elastic deformation was there, then you can see that the cross sectional area has reduced from here to here and the length has increased, but the cross sectional reduction in the sample is uniform throughout the sample same cross sectional area throughput the sample. So, in this right now, in this case the plastic deformation is uniform throughout the gauge length ok, during from yield point to where we reach the maximum stress in this stress strain curve and that maximum stress is called ultimate tensile strength. And after that you see start seeing that there is a drop in the tensile curve or materially showing that there is it cannot take the load and there you get the non uniform plastic deformation.

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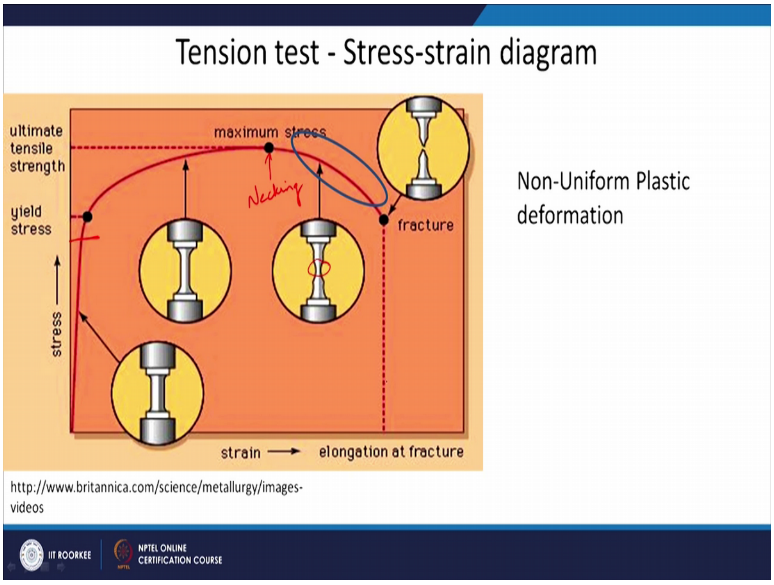

So, now, you can see in the gauge length ok. So, this was the initial this was the cross sectional area before the necking and now, there is a phenomena called necking which has started it look like a neck. So, they are called it necking. So, at this point in your sample necking starts and that is why we are calling this has now, there is a non uniform plastic deformation; that means, the deformation will be concentrated only in this region where the cross sectional area is reduced. And since now, the cross sectional area has reduced my material cannot take the response of the material will be reduced because I have less amount of material to give the resistance to deformation ok. So, now, my cross sectional area reduced, so my material what response it is going to get is also going to be reduced ok, and that is why you will see that the stress is coming down.

Now, when we say that this again we will come back to this discussion when we will discuss about two different type of calculation, one is what we call engineering stress and another what we call is true stress ok. So, there you will again start appreciating that we can have different type of calculation to get tensile stress strain curve and at this point my material will fracture into two part ok. So, now, there is no resistance to deformation because now, they there is no connection between the two material they are independent. So, at this point it is fractured and now, my stress strain curve will also stop here this is where the I will call it as the material is fractured and this is the total strain which material is taken ok.

So now, before going further I want to discuss two very important type of stress strain curve ok. So, one which you can see in a aluminium material, aluminium material or in one which you can see in steel plane carbon steel or mild steel ok.

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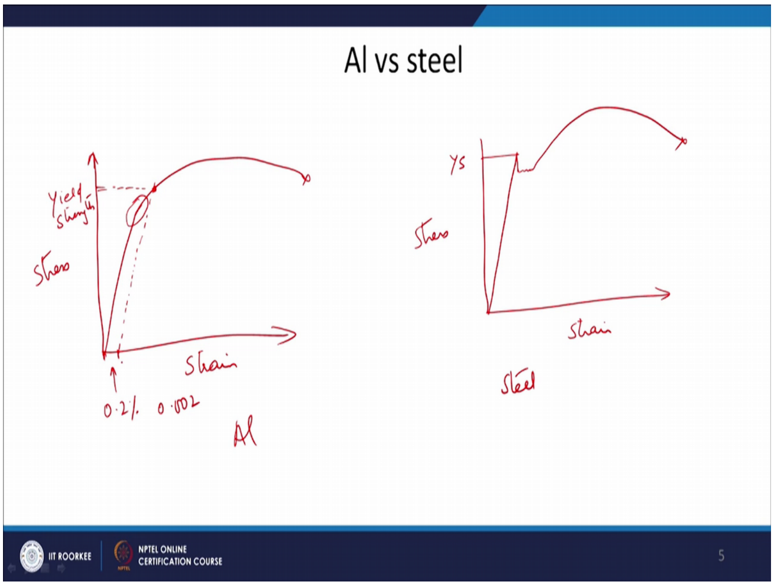

Because this two are very important distinctions ok. So, let me draw it. So, this is my strain, this is my stress. So, one we have already seen ok, so one which is like this. So, you have elastic part then somewhere the yielding will take place and the plastic part and you have fracture head somewhere here ok. So, this is one type of curve ok.

Now, the problem in this particular curve is that you have a linear elastic part and then non-linear plastic part, but where this transition takes place I am not sure about that point where the yielding in the material started ok. So, to find out the yield strength or yield point in this kind of stress strain curve what we do is we take a offset on this strain and this offset is equal to 0.2 percent or 0.002 strain total in fraction ok. So, you take an offset of 0.2 percent strain and then you have to plot a line which is parallel to the this linear curve this elastic part of the this plastic portion of this stress strain curve and where ever it is cutting the stress strain curve that I will call is my yield strength ok. Because I am not sure where this linearity and non-linearity is going, so I will call it as or you sometime call it as 0.2 percent or offset yield strength or 0.2 percent proof stress there are different names for this is how you get if you are not sure about it.

In steel or mild steel or plain carbon steel this is even simpler the stress strain curve for that is usually like this you have elastic part and at some point the yielding start and actually the stress strain curve drops and then there is some kind of serrations are there and then it start becoming like this then it flexures ok.

So, very different curve form what you will see in aluminium alloys ok, not all alloys in some alloys or in different materials you will see this type of currents some material you will see this type of curve where you will see a very sharp yield point. So, in this case defining a yield strength is very easy. So, wherever you get this maximum strength and then there is a very sharp drop ok. So, this is very easy to identify this is my yield stress. So, in case of steel we call this as the upper yield point and then that is a lower yield stress ok. So, it drops then there are some serrations and then it goes into plastic deformation ok.

So, these are the two different types of stress strain curve you will see generally in books or in some other places ok. So, this for steel and this is for aluminium in case of aluminium as I told you have to do this 0.2 percent offset and then plot a line to get the yield strength ok.

Now, these already we have discussed elastic there will be two parts of tensile stress strain curve elastic part that will be recoverable strain, you will have linear dependence of stress on strain and so on and plastic deformation which is non recoverable and it will be permanent ok.

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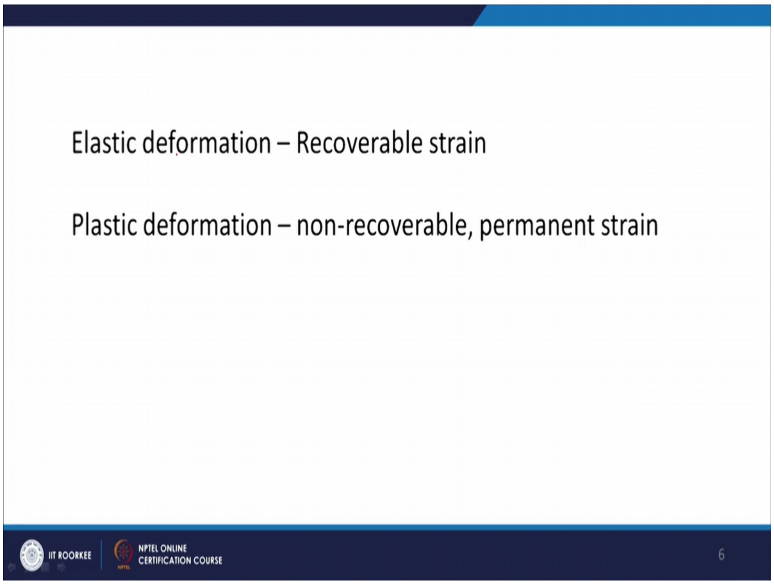

So now, next we will try to see different properties at different stages in stress strain curve ok.

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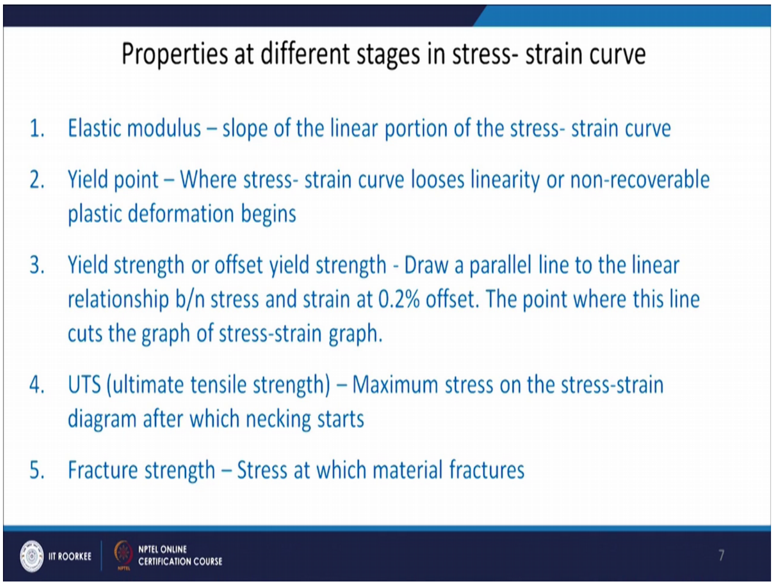

So, some we have already discussed earlier also that one property which you will get from stress strain curve will be elastic modulus ok, which is basically slope of the linear portion of the stress strain curve. Then you will get the yield point where stress and strain curve loses linearity or non recoverable plastic deformation begins that will be your yield point then you will have yield strength or offset yield strength ok. As I told you that in the some material where stress strain curve is a continuous curve you cannot find out the yield strength. So, what we do is we draw a parallel line to the linear relationship between stress and strain at 0.2 percent offset the point where this line cuts the graph of stress strain curve graph is your yield strength ok..

Then you will have ultimate tensile strength maximum stress on the stress strain diagram after which necking starts ok. So, up to this point you will have uniform deformation after this you will have non-uniform deformation in stress strain curve it is very easy to easy to find out that way which is your ultimate tensile strength then the stress strain curve where the slope is becoming 0 that is your that is the stress strain which you will have ultimate tensile strength.

Then you have fracture strength stress at which material fractures ok. So, very simple different location of the stress strain curve. I can get you can understand that I can get so many properties just by doing one tensile test you can get elastic modulus you can get yield point or yield strength or you can get UTS ultimate tensile strength or you can get fracture strength ok.

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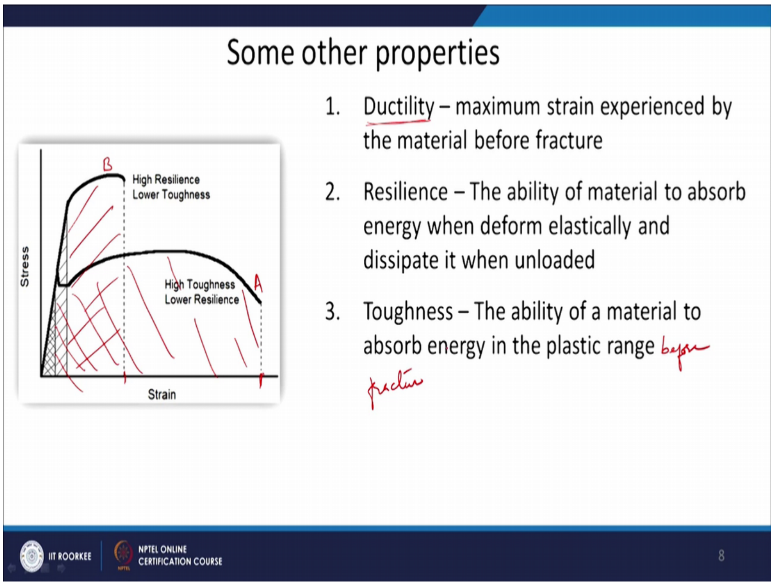

Some other properties which you can get from this tensile test one is called ductility ok, important for a metallurgical engineer that tells you that what is the maximum strength experience by the material before fracture ok. So, basically this is the total strain experienced by the material before fracture and this is another material in which case whatever is the maximum strength experienced by the material before fracture ok. So, I can easily tell you that the ductility of the this material let us call it as A here and let us call it B here. So, ductility of A is more than ductility of B material A is more ductile.

Then there are some two important properties again one is called resilience and that is the energy absorbed by material when you are deforming elastically and of course, because elastic deformation is reversible this material this energy will be dissipated during the unloading cycle ok. So, this is what is resilience as you can see in curve A the up to this elastic part whatever is the area under the curve that will be the resilience ok. So, it this much energy the material is going to take, but because this is elastic deformation it can be recovered of course, it will be recovered in form of heat afterwards. In case of material B the resilience is up to this point because the strength is more in this yield strength is more ok. So, you can see that the resilience is increased in this material. So, this material will be more resilience.

Then another property called toughness the ability of material to absorb energy in the plastic range ok. So, this is for elastic range. So, whatever is the remaining stress area under the stress strain curve ok. So, for example, for this material A ok, if I want to draw the sorry it will be like this area and so on ok. So, this much area is under the curve A. So, that will be the toughness similarly in case of material B, this much will be the area under the curve where the plastic deformation is there. So, this much will be the toughness of the material B ok.

So now, you can see it is area which we are comparing in this case strength is more, but ductility is less in this case strength is less ductility is more ok. So, it depends up on the area how much area it is covering, but in general I can say from this two curve that toughness of A is more than toughness of B. Reason is that ductility of also A is more than ductility of B and area in terms of area also you can just qualitatively say that area under this curve is more than area under this curve. So, in this particular case the ductility of A is more than ductility of B and toughness also of A is more than toughness of B.

So, it is not always true that ductility is more the toughness will be more it depends upon the area which is under the curve. So, in this case it looks like the area under the curve for material a will be more than the B. So, toughness of material A is more than the toughness of material B, ok. So, this is the basically the energy material can take before fracture in the plastic range. So, the ability of material to absorb energy in the plastic range and you can say before fracture ok. Very important in some materials ok. For example, if you are designing an automobile or want to select a material for automobile how much energy it is going to take suppose there is some kind of impact before it fails. Of course, in that case we call it as impact toughness not only toughness we will come to that later on.

Then there can be different behavior brittle or ductile of the material ok. So, what do we mean by brittle fracture brittle behavior or ductile behavior?

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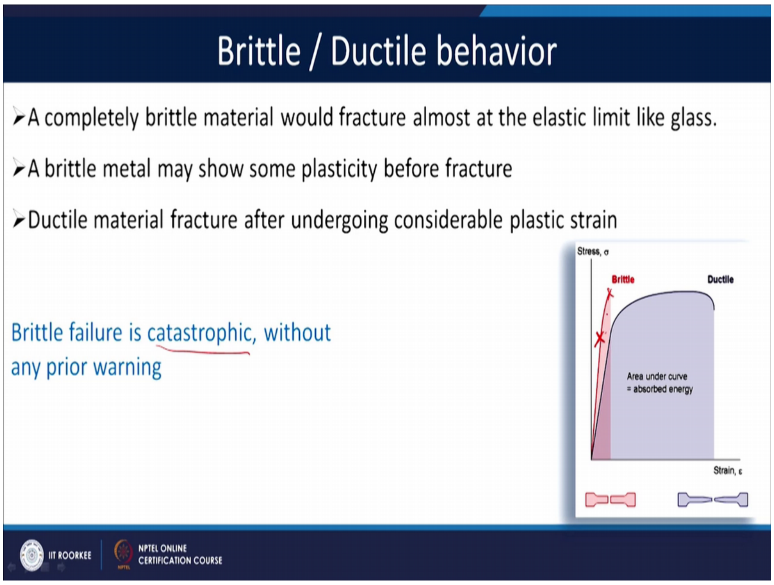

In case of brittle material which is showing brittle behavior ok. So, the fracture will occur almost at the elastic limit ok. So, it may not even see this plastic part the fracture will take place somewhere here ok.

If it is a completely brittle material for example, glass ok. Glass is a brittle material if you just apply some stress it will fracture into parts and this will happen without showing you any plastic deformation, it will be under elastic part itself ok. In metals again we call some metals are brittle metal ok, but in metals you slightly see some plasticity before fracture. So, it is not in metal it is not, it is not going to fail in the plastic limit itself some plastic deformation you will see and then it will fracture ok. So, it is in case of some brittle metals. Glass of course, is different class of material in that case you will see the fracture in elastic limit itself.

Ductile material fracture after undergoing considerable plastic strain and this is what is ductile material ok. So, considerable plastic strain will be there or deformation will be there. So, area under the curve will be obviously, more for the ductile material absorbed energy will be more. So, you can also say the toughness of the ductile material will be more.

Nowadays, in glass also lot of research is going on to make it tough sometime you must have seen on the windshield of the automobile toughened glass ok. So, they are trying to increase the toughness of the glass also. So, that it can take may be if something some small stone or something comes and hit the windshield it should not fracture in those situations and your mobiles smartphones, all those glasses are toughened glasses they are very hard and very they are toughened. So, that if you apply accidentally some stress also the idea is that it should not crack ok. So, these are toughened glass and then they are giving very specific names to them, then there are some specific glasses gorilla 2, gorilla 3 and so on. So lot of research is going on in the improving the property of glass and making it tough.

Problem with brittle failure is that fracture is that it is catastrophic. So, it does not give prior warning. So, what prior warning you can get if it is not brittle is? The prior warning is you can get a plastic deformation suppose you have designed a structure and a the material you have used is brittle for example. And suppose due to some unforeseen reason there is very high load on your structure and you did not design it for that kind of load what will happen if it is a brittle material it will just fracture ok. And suppose there are humans who are using that particular structure there will be lot of damage to human life, but if it is a brittle material sorry if it is a ductile material suppose now, if you put the this kind of load what will happen is it will first deform ok. And this deformation is very easily because this is the kind of very clearly you can notice this kind of deformation ok. So, before failure you will be able to see this particular structure is now, there is a sag in the beam or whatever ok. So, there is some plastic deformation in that and you can take some corrective measure before the if before any accident takes place ok.

So, that is why having some kind of plastic deformation in the material is required, though mechanical engineer who or design engineer is not going to use his material in that range he is going to use that material in elastic range itself. But it gives him confidence that if because of any reason in the service if the load increase beyond the design load the material is not going to fracture it will show some plastic deformation and that can be easily noticed and it can be corrected.

Just a comment on sometime we get confused between fracture and failure ok, two kind of have separate compartment for both these terms. So, failure can be defined differently depending upon application ok.

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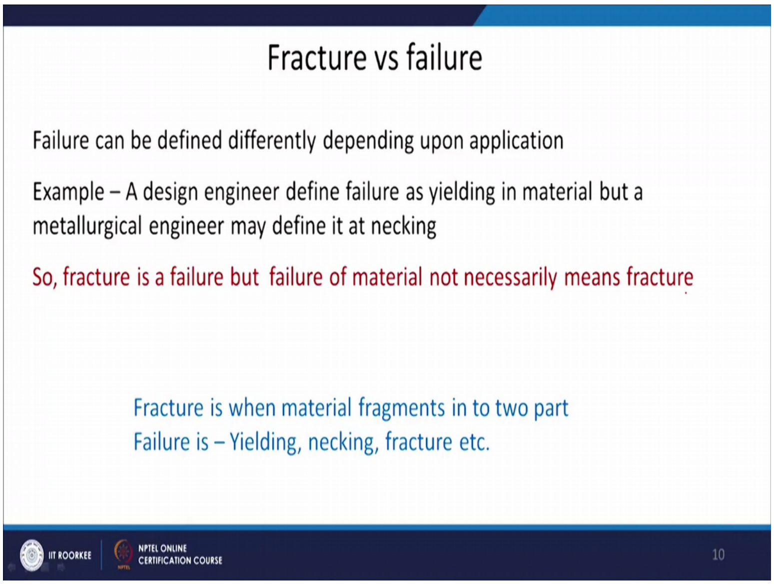

I can say failure can be defined in a very broad sense and people can use failure in different context. For example, a design engineer define failure as yielding ok, because design engineer always likes to design his structure within the elastic limit. In fact, there also he takes lot of factor of safety. So, much below the yield point he will design in such that the stress in the in the structure remains much below the yield point ok. So, if because of any reason the material deform plastically then for him the that is the failure of material it material should not have yielded ok.

For a metallurgical engineer on the other hand he can define the failure as necking ok. So, metallurgical engineer do lot of all the processes which we use in metallurgical engineering are in plastic deformation only through plastic deformation only. For example, if you want to do forging you will have to do plastic deformation change the shape if you want to do rolling you have to reduce the thickness of the sheet by rolling or you can do extrusion all these processes depend upon plastic deformation. So, for a metallurgical engineer the material is good if it is showing lot of plastic deformation lot of ductility because that is how he process the material. So, for him the failure is suppose a locale ate some location there is a non uniform deformation not exactly necking, but non uniform deformation ok. So, for him that is a failure, because the cross sectional area of the sheet or any bar or something like that will reduce in that particular section. So, it is a failure.

So, I can say fracture is a failure ok, but failure of material not necessarily means fracture is another type of failure and what happens in fracture that is what is shown here fracture is when material fragments into two part or multiple part also whereas, failure is can be yielding, can be necking, can be fracture etc. So, lot of different things can be failure, but fracture is very clear that my material has to fragment it has to be in two parts or it can be multi parts also, but there has to be some discontinuity in the material in the form of that they have to be two separate part. So, that is my fracture.

Now, on this type of tensile curves ok, I can do this tensile test at room temperature ok, I can do this tensile test at high temperature ok. So, when you do at high temperature of course, with some different type of test we do that ok, but in general what happen when you do at high temperature what is the effect of temperature is that strength decreases and ductility increases. So, this is the general behavior you will see when we increase the temperature.

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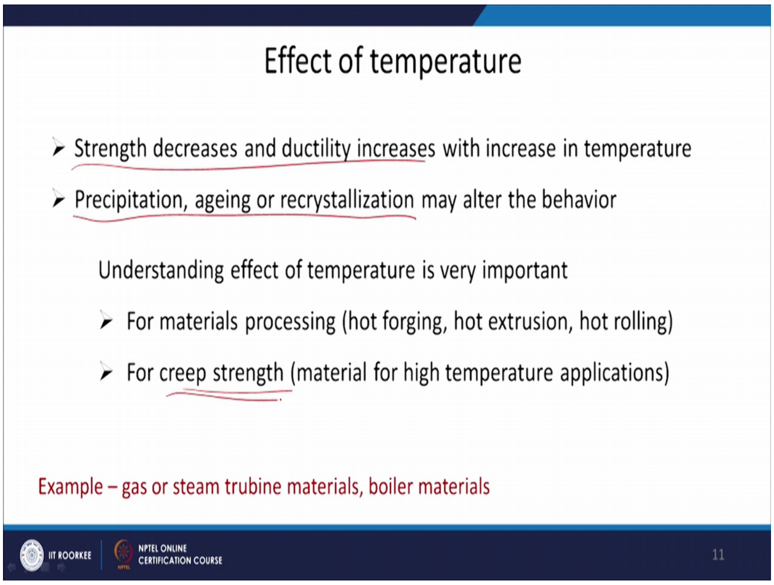

Of course, there will be some other metallurgical process taking place when you are doing at high temperature these are precipitation can be there ageing can be there all these things we have already seen, or recrystallization can be there which may alter this behavior that may be strength may not increase or decrease or whatever.

But in general strength decrease and ductility increases with increase in temperature and that is why all the metallurgical processes also we try to do at high temperature, hot due, hot forming, hot forging, hot rolling and so on. So, basically why understanding effect of temperature is important that is for material processing all the processes we do at under hot condition of course, not always, but at least in initial part when we want to impose large deformation all these processes are done under hot condition. So, I should understand that what is the effect of temperature on the stress strain curve of a material.

Another very important application of temperature on the on the stress strain curve of a material is creep strength ok. For a higher temperature application we need creep strength of the material ok. Of course, the way we do the test is slightly different than how we do in tensile test , but the important part here is that the temperature is the factor which is important to consider here.

The example where you will have this temperature effect is where we use material for gas or steam turbine for boiler material and so on, wherever temperature is involved I need to know what is the behavior of material as a function of temperature.

Then there can be change in the material behavior as a function of strength rate also ok. And what is strain rate? Strain rate is strain per unit time.

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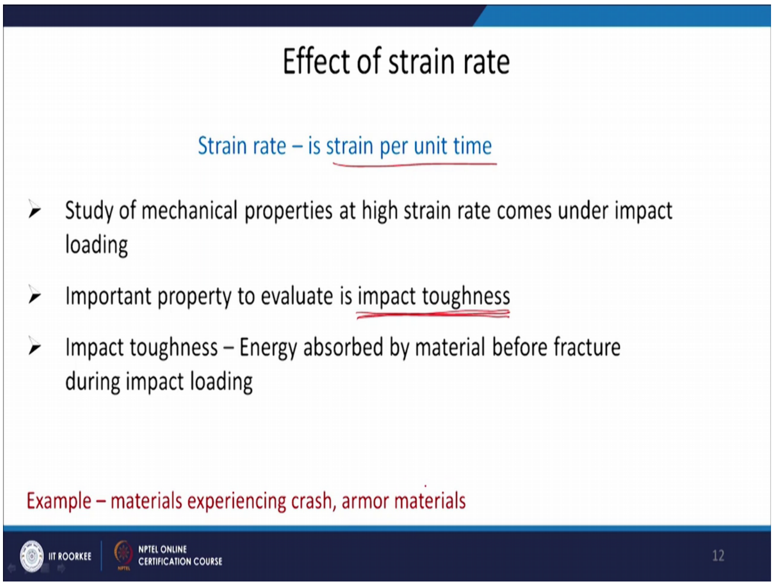

And that will be dependent on when I was discussing the tensile machine, I said I can move the cross head with different velocity. So, if I am doing it at high velocity; that means, I am having high strain per unit time; that means, I am doing at high strain rate. If I am having a low velocity then my strain per unit time will be small and my strain rate will be low.

So, study of mechanical properties at high strain comes under impact loading again the way we do the test can change we will have other type of equipment then tensile test. But when we have high strain rate type of deformation then it is a comes under impact kind of loading or impact kind of new formation behavior.

Important property to evaluate the impact toughness, so basically we want to know that how much energy is absorbed by the material during the impact. For example, in case I told you automobiles this is a very important property for a material to have that how much energy it is going to absorb during the impact because that is what is going to save the occupant of that particular car or automobile if it absorbs more energy then it will transmit less energy in to into the cabin or can you will be saved. Nowadays, if you see some automobile advertisement they actually tell you that they are using very high strength steels ok, so to improve the crashworthiness of the material. So, those material will be able to absorb more energy during deformation.

Impact toughness is basically energy absorbed by material before fracture during impact loading example material experiencing crash or armor material also have to have good impact toughness. Then there is a one another property which is not actually comes under the tensile test it is a very different property, but important one which we will see in detail later on. And that is basically to resistance to deformation by indentation or scratch ok. So, in this case we do not do the deformation of the whole material we do deformation of a very localized region by some indenter and there we look at the deformation locally.

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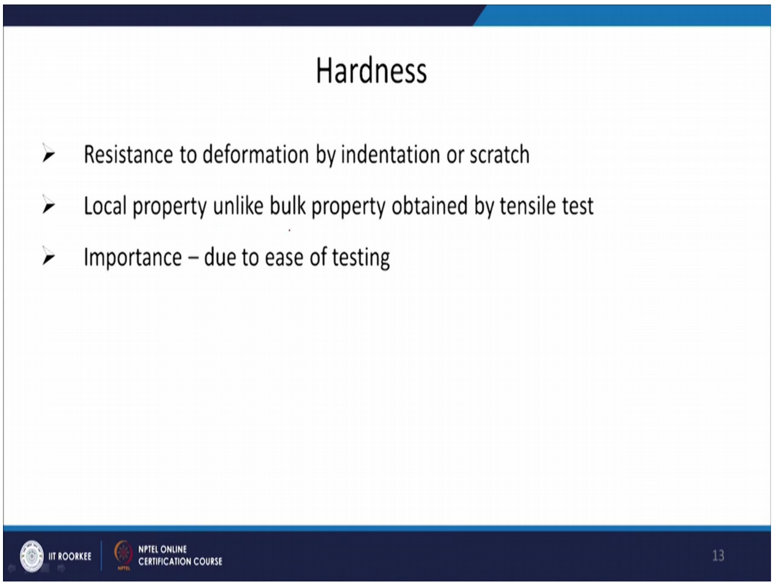

So, basically we actually measure local property here unlike bulk property obtained by tensile test, but it is a very important one to do a quick evaluation of properties of materials. So, you do two different treatment and you want to have a quick understanding of that how the strength is changing you can do hardness, then you can go for tensile test. And because ease of testing you can this is a very important property to evaluate ok. So, this is what we have to discuss today in the tensile test.

Thank you.