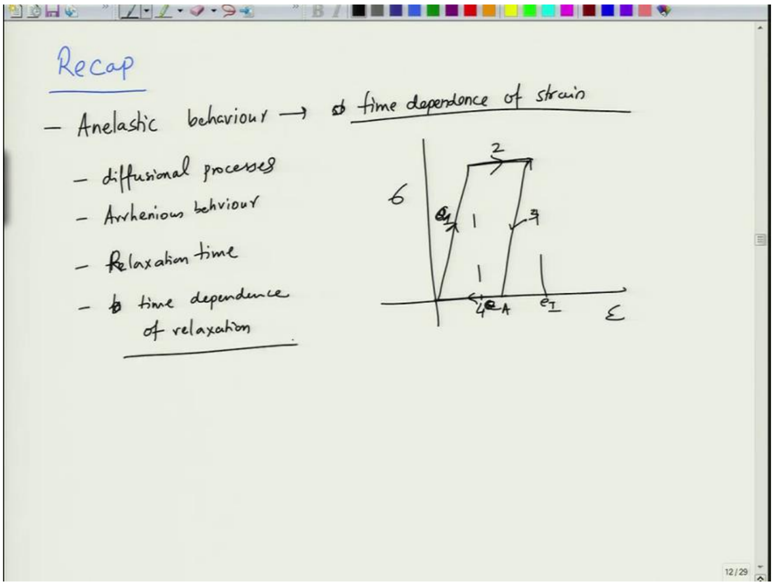
Properties of Materials (Nature and Properties of Materials: III)

Professor Ashish Garg
Department of Material Science and Engineering
Indian Institute of Technology, Kanpur

Lecture 16 - Plastic Deformation of Materials

(Refer Slide Time: 0:26)



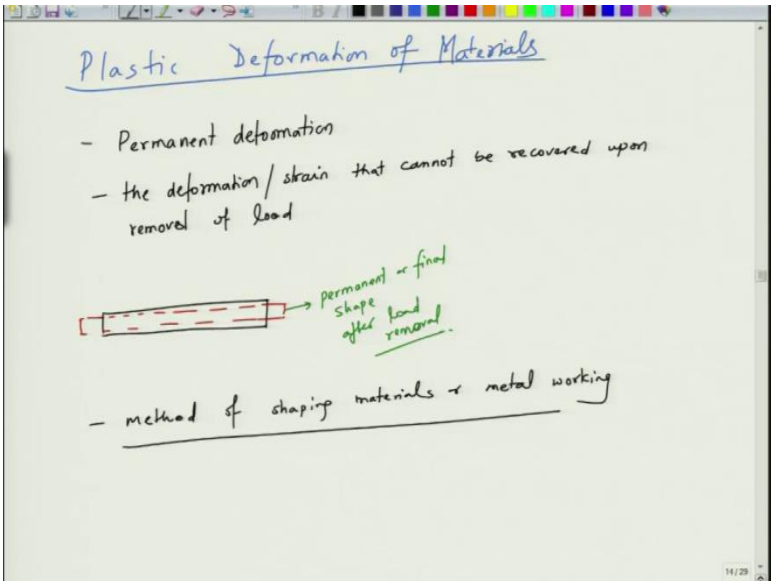
Welcome again to the new lecture of this course, Properties of Materials. So let us just briefly rewind what we did in the last lecture. So, in the last lecture, we looked at anelastic behavior. In fact, we were doing that in last few lectures. So, inelastic behavior is essentially the time dependence of strain you can say. So, strain basically does not follow the stress at the same time, as a result it takes time. So, what you end up getting is this kind of behavior.

So, this is how, so this is the path 1, path 2, path 3, path 4, so the first strain is developed until e A finally develops to e I, but it takes a little bit of, you have to hold that stress for some time and the constant stress. And then again, when you unload, you get back the same strain which was imparted earlier, then again, you have to expand it for some time, leave it for some time to get the strain back to 0.

And this is because of basically you can say diffusional processes, which are explained by Arrhenius behavior. And then, we looked at and these are characterized by a time, which is called as a relaxation time, which is a particular time for something to occur for a given phenomenon. So, average time taken by let us say atoms to move from one place to another, that is for a given phenomenon and then we looked at the dependence of strain on time.

So, we looked at the time dependence of relaxation. So, this is what we did in the last few lectures. Now, what we are going to do is that we are going to move to a new topic, which is called as Plastic Deformation of Materials. So, so far what we looked at was the elastic behavior where material, let me just finish writing it.

(Refer Slide Time: 2:42)

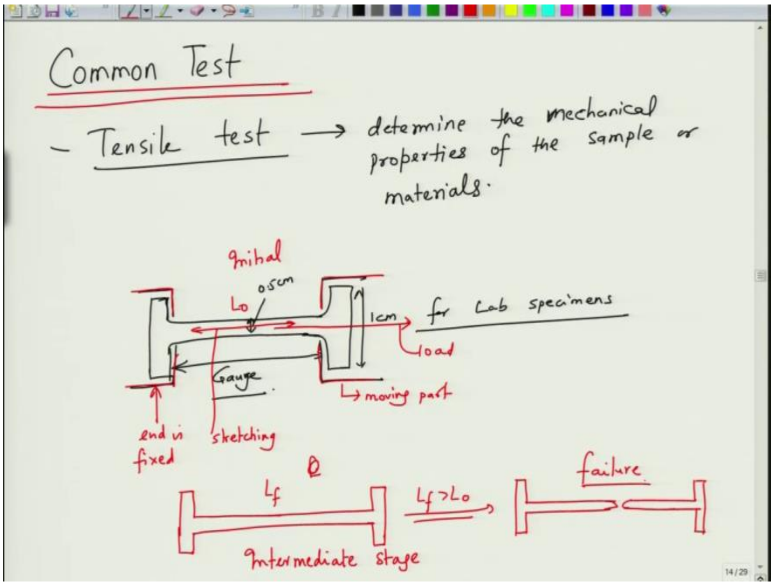


So far what we looked at was elastic deformation of materials where the deformation that is carried out is recovered, it is recoverable. So, if you deform a, let us say 1 meter long rod to let us say, 0.001 percent strain or 0.002 percent strain, it gets back to its normal position as soon as you remove the load. Whether through elastic behaviour or anelastic behaviour, that is a different thing, but it is elastic deformation which is recoverable.

Plastic deformation on the other hand is called as basically permanent deformation that is the deformation slash strain that cannot be recovered upon removal of load. So, you have a material, you expand it to certain size, okay, and when you remove the load back so this is the expansion, and when you remove the load back, let us say it comes back, it does not come back.

So, it might come back a little bit. So, what you might recover is, so, this is let us say the permanent or final shape after load removal. So, this is what is permanent deformation, which is the main method of deforming or shaping materials. So, this is basically the method of shaping materials or you can say metal working. And this is what we are going to focus now on in the next many lectures.

(Refer Slide Time: 05:06)

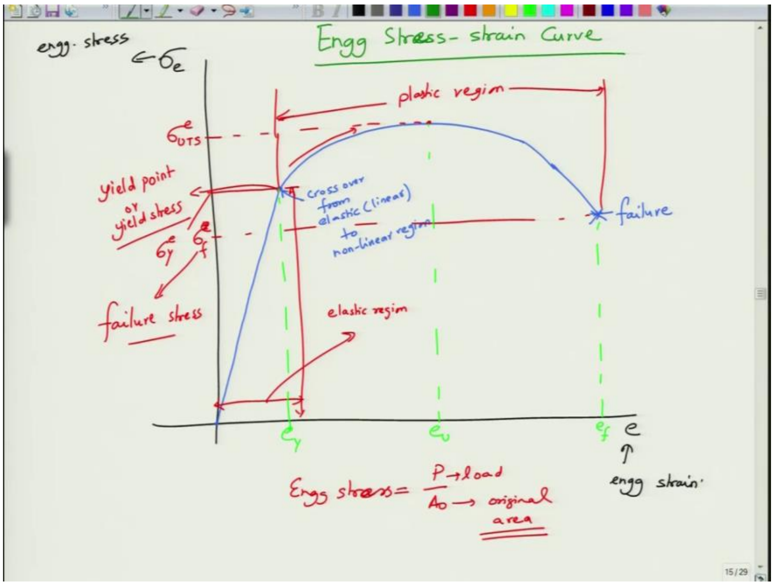


So, the most common deformation, most common test that we do on materials is called as tensile test in which this test is to basically determine the mechanical properties of the sample or material. So, basically it is a laboratory-based experiment where we prepare the sample in this fashion. So you have a sample like this which is this fashion, so it is this kind of sample or so, these are what we call is the gauge. So this portion is the gauge. And this sample generally, for laboratory it would be about a centimetre or so. And this could be roughly 0.5 centimetre for lab, lab specimens, alright.

So, generally, we measure the length and then we, these are basically you put enclosure around it so, these are the clamps let us say. So, you put clamps around it like this, so let us say these are the clamps which are so, this end is kept fixed and this end is then moved, so, this is load and this is moving part. So, as a result this will stretch, there will be stretching. So, after a while the material may become like this. So, it is not up to the scale, but it will become longer.

So, if this is L naught, this will be L f, so, this L f will be longer than L naught. And if you carry out completely, after a while this will fail into pieces. If you keep extending it, it will break into two pieces. So, this is initial, this is some intermediate stage, and this is failure. So, how do you depict this graphically?

(Refer Slide Time: 8:17)



So, we depict this graphically using this plot. So, here we change the quantities a little bit. So, let us say this is sigma e. So, this is engineering stress and this is engineering strain. So in this plot, when you start loading it, follows elastic behavior up to certain point and at this point, the material converts to from, so, this is the let us say the crossover from elastic linear to nonlinear region before the material comes down sometimes, so the failure stress can sometimes be, so, this is what is failure.

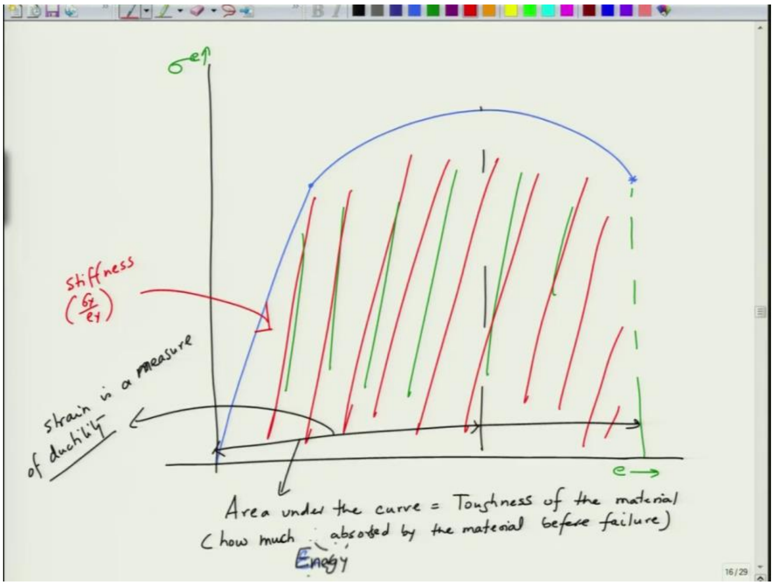
So, this is the typical stress strain plot for a given material. So, what we are discussing is this stress-strain curve between the materials. So, this is what most materials will show, most ductile materials will show a behavior like so, there is a crossover from elastic or linear region to the nonlinear region which is plastic region. So, this region we can say, up to this point is the, you can say is the elastic region or rather here we can say up to this point this is the elastic region.

And between this point and this point, we have what we call as the plastic region. For the place where major crossover, this stress is called as yield point or yield stress. Basically, this is the place where material has started deforming permanently or material has yielded and then it follows a behaviour, which is nonlinear in nature. It follows a maximum stress point which is called as….So, this is let us say, we define this as sigma y. And this maximum stress point is defined as sigma UTS, okay.

So, this is Sigma e, let us say here because it is an engineering stress, so by the way engineering stress is defined as load divided by original area. So, this is load divided by original area and then the material fails at certain point and this is called as corresponding stress is called as sigma f, which is sigma f e, which is the failure stress. Corresponding strains are called as, the corresponding strain will be called as this is the e y, which is the yield strain, this is the e u, which is at ultimate tensile stress and this is e f which is the failure strain.

So, these are the corresponding parameters that we measure from this stress-strain. This is called as engineering stress-strain curve. So, this kind of plot is called as engineering stress-strain curve, right. So, we can determine various things from this plot, this has become a little crowded so we can make another one.

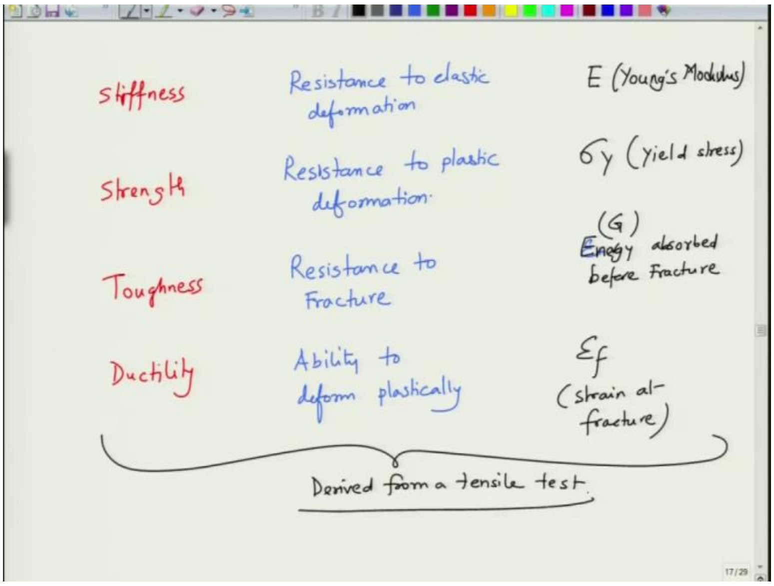
(Refer Slide Time: 12:22)



Okay. So let us say this is sigma e, this is e. So the area under this curve you can say that it is nothing but toughness of the material. Basically, it suggests that how much energy is absorbed by the material before failure. So, for a ductile material this is generally a large amount of energy. And here, this the extent of deformation that you can carry out before failing or before ultimate tensile is stress, these two strains are nothing but so strain is a measure of what we call as ductility, how much ductile or softer material is, how much can you deform.

And the slope of this linear region is a measure of what we call as stiffness, which is sigma divided by sigma y divided by e y. So, these are few things that you can determine from this plot.

(Refer Slide Time: 14:31)

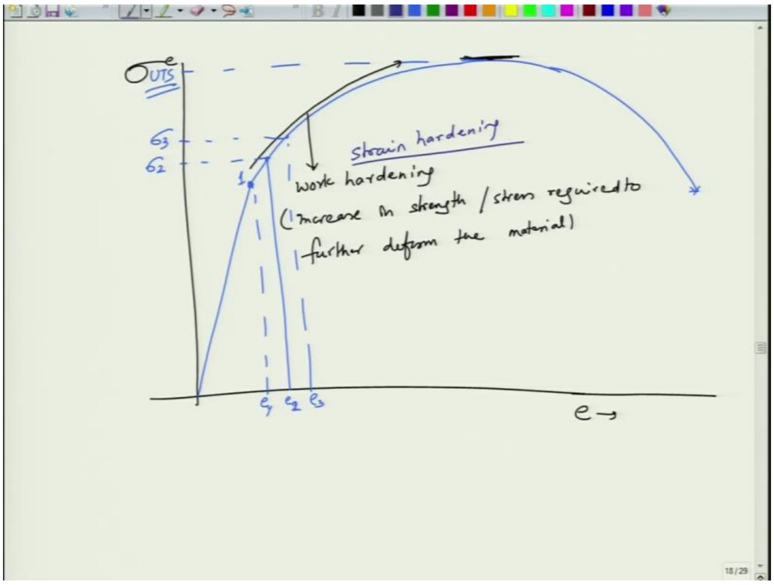


So, stiffness is basically we can say stiffness, so, there are four quantities that we define; stiffness, strength, toughness and ductility, which can be determined from this plot. So, what is stiffness? Stiffness is resistance to elastic deformation. So, higher the modulus is, more stiff it is, so, you cannot deform it very easily. And this is characterized by a quantity called as Young's Modulus E.

Then we define strength, strength is defined by defined as resistance to plastic deformation or indentation you can say. So, plastic deformation means, stronger the material is, more it is to deform the material. So, this is defined by a quantity called as sigma Y, which is yield stress. So, this could be engineering or true stress depending upon, we will define both of them again, already we have defined what engineering and true are but basically the yield stress.

And then we have another quantity, which is toughness, which is nothing but resistance to fracture and this is defined by quantity which is energy absorbed before fracture. So let us say this is G. And you can call it any quantity though, I mean, so you do not have to worry about the symbol as yet. Then we have ductility which is ability to deform plastically and this is basically by defined by what we call as epsilon F, which is strain to strain at fracture. These are the four main primary properties that you derive from the, from a tensile test.

(Refer Slide Time: 17:28)

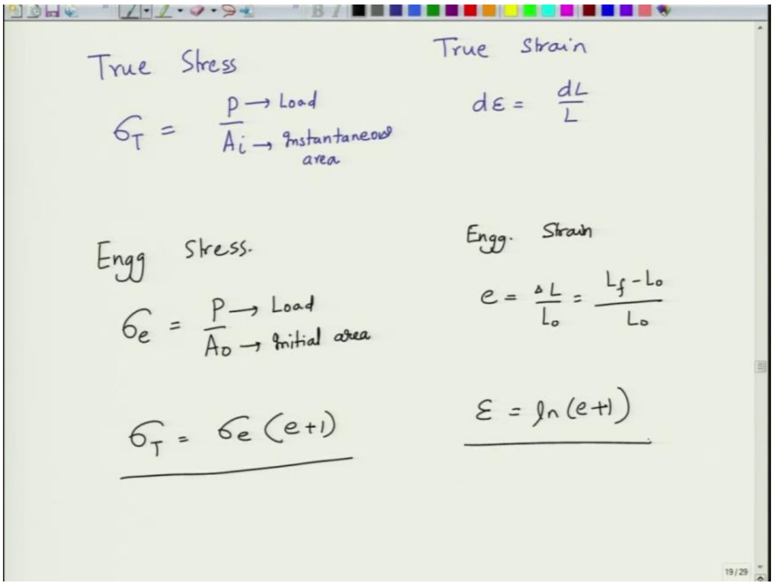


So, one thing that we notice here is in this curve, so, we will again plot it let us say. So, in this curve, what we notice is you have elastic region, then you have a plastic region followed by fracture. You see that the stress, the stress keeps increasing as you keep deforming the material up to this particular point, this is engineering stress. So, this is basically the increase in the stress upon deformation is called as work hardening.

Basically, increase in strength or stress required to further deform the material. So essentially, what I mean is that you start at this point, the yielding will start at this point, the plastic deformation starts at this point, let us say there is a point, one point. When you reach point two, so this is epsilon Y, let us say this is epsilon 1 or epsilon 2, okay, you have a stress level of sigma 2.

When you want to reach to this strain of E3, you will need to go to higher value of stress which is sigma 3, which means material is getting more and more stronger to deform. So, up to the point of UTS, which is UTS, the material will work hard and this is called a strain hardening or work hardening. So, some people also call it as strain hardening. That as you work the material or as you strain the material, the materials become stronger and stronger.

(Refer Slide Time: 19:32)

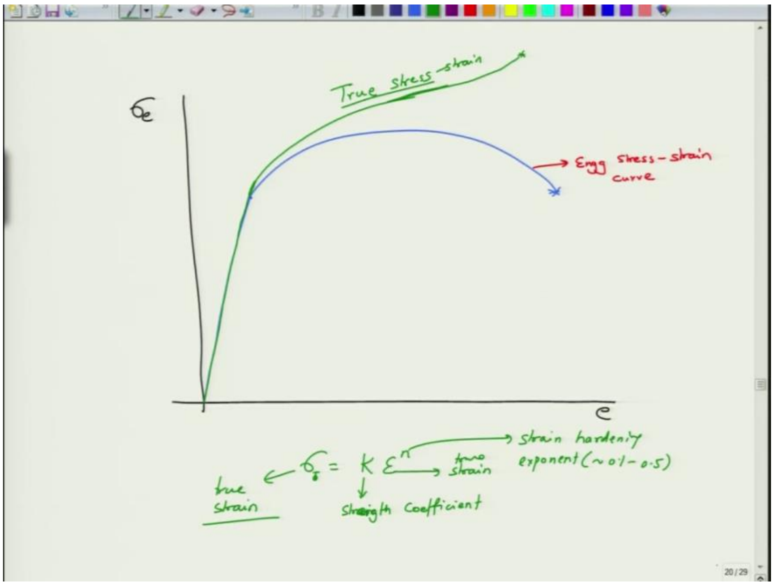


So, now let us look at a quantity here. There are two quantities that we have here in stress-strain curve and tensile test, one is called as true stress. We have seen these things earlier, but let me just define them for you again. True stress is given as sigma T is given as P divided by A i, this is load, this is instantaneous area. And this is defined by a quantity, true strain is d epsilon is equal to d L divided by L.0

On the other hand, engineering stress is given as sigma e, which is given as P divided by A naught. So, this is load, this is initial area and then we have engineering strain, which is defined as e, which is delta L divided by L naught or you can say L f minus L naught divided by, and we have seen what the difference between true strain and engineering strain is.

And there is also a difference between true stress and engineering stress. And if you relate these quantities, you find that sigma T is equal to sigma e into e plus 1 and you can relate epsilon as l n of e plus 1. So these are simple straightforward relations that you can obtain by doing simple manipulation of parameters. So, this is what we will…..

(Please Refer Slide: 21:23)

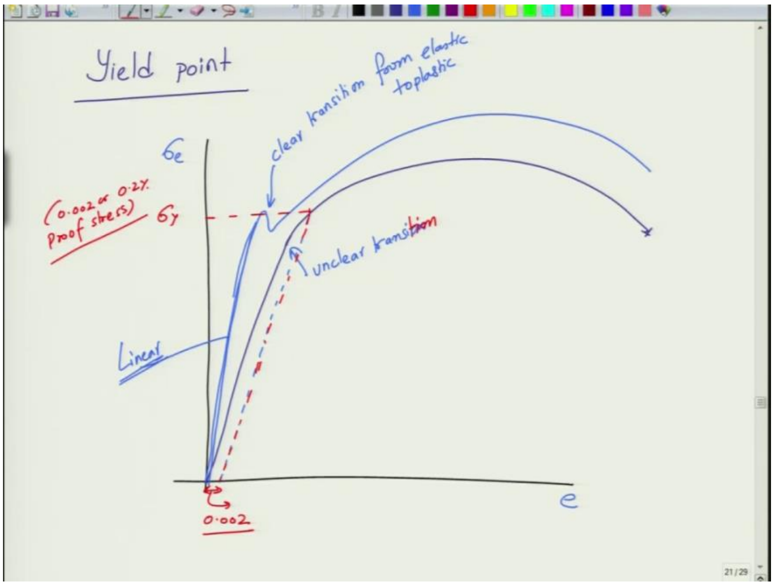


Now, when you compare these two plots, when you compare these two plots, so, you can also plot not only the….So, let us say we plot first the sigma e versus e, we know that sigma e versus e looks something like this, okay, this is what sigma e versus e looks like. But when you plot the true stress, so this is engineering stress-strain curve.

When you want to get the similar plot for let us say the true stress-strain, true stress-0strain follows the similar behavior up to nearly up to yield point and because they are very small strains and then, it basically keeps increasing before it sort of fractures the material.

So this is the true stress-strain curve. In the true stress-strain curve, the stress always keeps increasing, okay, and the true stress behaviour is given as sigma T or sigma is given as K into epsilon to the power n, where K is the strain, strength coefficient sorry, strength coefficient, epsilon is the strain or true strain and is called as strain hardening exponent, which is generally equal to 0.1 to 0.5 and sigma is true strain. So, you can see that generally a true stress is always higher than the engineering stress, engineering strain. So this is true stress-strain, this is engineering stress-strain.

(Please Refer Slide: 23:30)



Now, finally, we will come to one more point that we have not discussed yet is the yield point criteria. So, how do you determine the yield point in these materials? So if there is, generally what you see is that in certain materials, the transition from elastic to plastic region is very fuzzy. In certain materials, you may obtain a behaviour like this let us say, so this is a clear transition.

But here we do not have unclear transition. This is sigma e versus e. In such cases, what we do is that we, so, in these cases the stress-strain measurement is easy, because we have a clear linear region. So, this is the clear linear region. So, this is the linear region and we can easily calculate from the from this what is yield stress and what is the yield strain, but if there is no clear transition then 0.2 percent proof stress is used.

What we do is that we draw a parallel line here. So, I use the red. So, this parallel line with respect to elastic stress, plastic region, is at a strain of 0.002 and the corresponding strain is the sigma y, which is 0.002 or 0.2 percent proof stress. So, this is another method of determining the yield stress from the stress-strain curve if the transition from, transition if the transition from elastic to plastic region is not very clear.

So, what we will do in the next class now is, we will look at the more, look at more characteristics of this plastic deformation and microscopic mechanisms. How, what are the things that you can do with different materials to change the plastic deformation behavior of materials, that will come in the subsequent lectures. Thank you very much.