Properties of Materials (Nature and Properties of Materials: III)
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Lecture 18 – Necking Phenomenon during Tension Test

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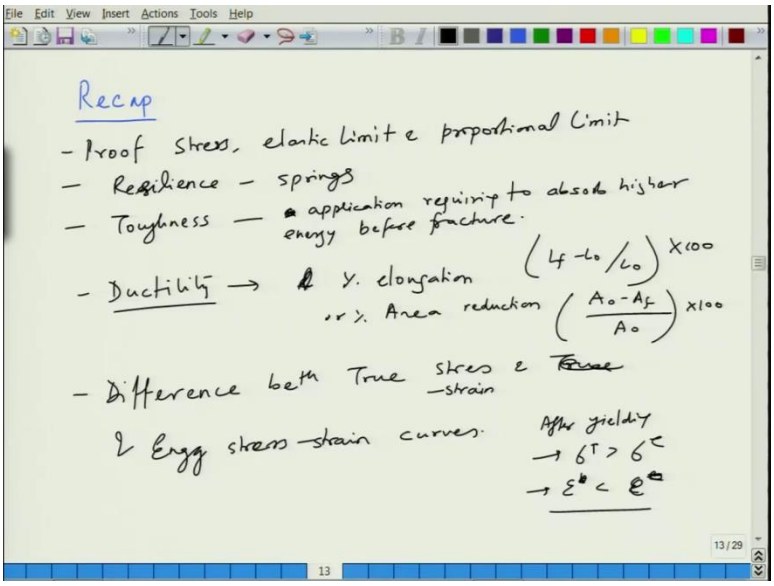

Welcome again to the new lecture, Properties of Materials. Let us just briefly see what we did in the last class. So in the last class, what we did was we looked at various characteristics of stress-strain curves again, and we looked at properties such as you know, what is proof stress, what is elastic limit and what is proportional limit and distinction between these.

Then we also looked at what is resilience, which is basically the ability of material to absorb the energy in the elastic region when deformed up to within the elastic region and then come back. So, it is important for things like springs, okay. Then we looked at what is toughness also and the difference between toughness and so, toughness is good for basically applications requiring to absorb high energy before fracture.

So, basically, here fracture strain generally is very large. So, as a result the area under the stress strain curve is very large. Then we also looked at what is ductility. Ductility is essentially a quantitative measure of how much the material can be deformed. So, it can be defined in terms of elongation, percentage elongation or percentage area reduction.

So, percentage elongation will be L f minus L naught divided by L naught into 100 and percentage reduction will be A naught minus A f divided by A naught into 100. So, this is what ductility is quantified as. Then we also looked at the difference between true stress and true stress-strain and engineering stress-strain curves. And we found that one after yielding sigma T is always higher than sigma e and then the corresponding strain for epsilon true stress is always lower than epsilon e.

So, epsilon is lower than e. So, as a result, the points on the engineering stress-strain curve are on the slight left of themselves on true stress-strain curve and that we saw by looking at the values.

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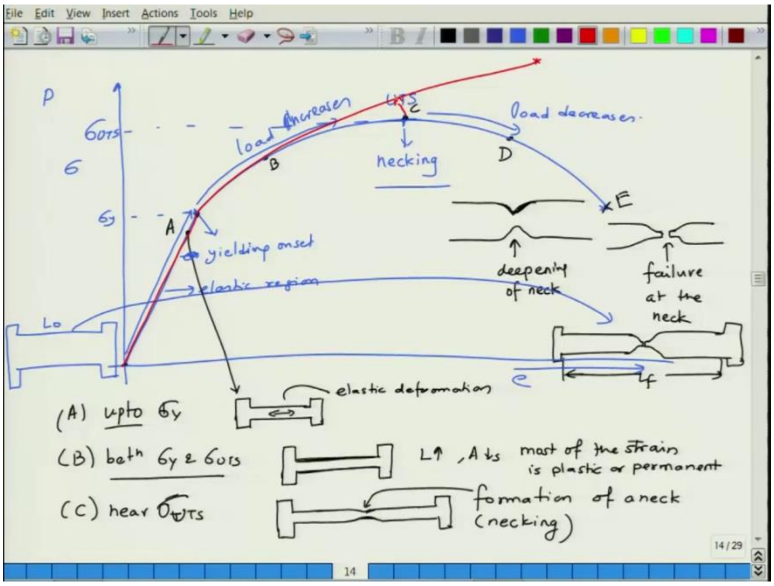

Now, let us see what is the difference, first of all, what is the true stress? What is this stress-strain curve all about? So, we see the stress-strain curve that you have a behaviour like this. So, we saw that up to this point you have yielding so, this is yielding, this is sorry, this is the yielding, yield point, yielding onset and this is the elastic region. And then you have stress, you have a maximum stress at UTS after which the stress drops.

So, the question is, first observations are first thing is, as you want to expand more and more up to yield point, you have to spend more energy, but this is elastic region. So, all the energy that you spent can be recovered. Then you come into a nonlinear region where for every step of deformation you have to spend more energy, so basically the stress is increasing or the load required to cause deformation keeps increasing, because this can be also plotted as load versus strain. That is why it is yielding stress-strain curve, because the area remains constant.

So, up to a certain point the load increases and then the load drops. So, the question is, what happens at this point? So, load first increases and then load decreases. So, what is that? What happens? So, this point which is called as ultimate tensile strength is corresponds to a point which is called as phenomena necking. So, what happens is that when you have a tensile specimen, so, up to sigma Y, you have a specimen like this which is stretched.

So, you have elastic deformation, okay, between sigma Y and sigma UTS sample is deformed, this become thinner and it has become longer. We can say, L increases, A decreases, and you have some strain, so most of the strain here is plastic or permanent. And the area reduction happens fairly uniformly across the whole length. Near UTS or just, just add the UTS, what we have is the phenomena called as necking.

So at about, so let us say if this is, this is let us say point A, A, this is let us say point B, so this is B. And at point C, what happens is that as an example so let us at point C what happens is that you have a formation of what we call as a small neck and this happens somewhere in the middle of the sample. So, this is basically what we call as a formation of a neck, and this phenomena is known as necking.

So, this is where the necking occurs. And as we go to point D, so, this is point C. At C you have formation of a neck and at D let us say when you go a little further, the neck gets deeper. So, at this point the neck will be more like this, so we can say it is sharpening of neck, it is like this, and then at this point, finally, e point essentially material fails like this, failure at the neck.

And this when you put them together, so this basically let us say this was a sample and this was a failed region. When you put them together, so this would be L f. So at here you had certain length, this is L naught, L naught has gone to L f. So of course, the diameter would be larger. So, let me just, so diameter would be larger so this would be L naught. So, this L naught has gone to L f up to this point.

So, basically, what has happened is you have first elastically deformed, increased a length a little bit, area has reduced, then you come cross yielding, but it has deformed plastically, length has increased further deformation is pretty uniform. Near UTS a sort of neck starts forming right in the middle of the sample, which is called a phenomenon of necking, and at that necking point the neck gets deep and deep as you keep continuing the deformation but the load decreases. We will see how the load decreases a little while.

And as you keep continuing the deformation as you keep pulling it apart, the failure happens at the neck. So this is what basically the phenomenon of plastic deformation is. So the question is, what happens at the neck? And why is that? So let us first look at why is that, why is there a change in load at necking? Because you observe only this in engineering stress-strain curve, you do not observe the same in true stress-strain curve.

So basically, the true stress behaviour is something like this so true stress it is going on. So, the necking point would be somewhere here in but it is not visible very clearly. So, but in the in the true stress in the engineering stress-strain curve, the necking behaviour is very, very visible. And that is why engineering stress-strain curve is preferred because you want to go only up to the necking. So we will see what happens with the necking a little while.

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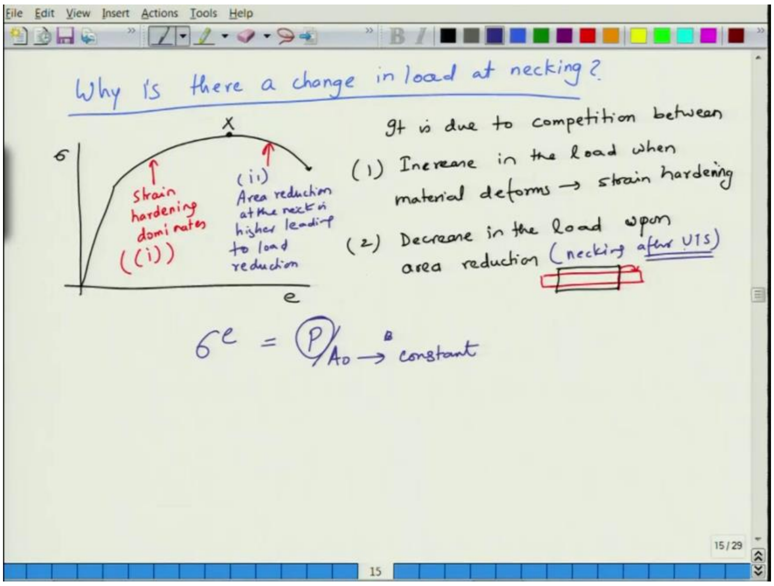

But first the question is, why is there a change in the load at necking? At necking we see that the load changes like this. So, this is the point let us say x sigma e. So, there are two things which happen, it is due to competition between first, you have strain hardening that is happening, so increase in load. There are two things which are happening when material deforms, increase in the load when material deforms due to strain hardening.

And we do not know what strain hardening is microscopically, we will see that in a little while after a few lectures maybe. And then we have another thing that is happening, but we know that the materials area is decreasing. So, area decreased leads to a decrease in the load because first, the sample was like this, and now it has become like this. So obviously, when area reduces, so, this was the area to begin with and this is the area to end with.

So area has reduced, which means the load should also reduce to deforming, but at the same time, the load is increasing because the material is getting stronger and stronger. So these two things compete. So what happens in this region, in the first region, the increase in load by strain hardening dominates and that is why, so, number one, that is 1 is dominating and the 2 because of necking you can say.

So, after point P, although the load increases because of strain hardening that still happens, but the necking leads to a faster reduction in area. So, basically number 2 that is decrease in the load upon area reduction is higher leading to load reduction. So, after point x, it is the decrease in the load upon area reduction especially at neck that dominates and before point x it is the strain hardening, which is which leads to increase in the stress required to reform the material that dominates.

So, basically, we know that engineering stress is proportional to load because, as engineering stress is nothing but equal to we can say that it is equal to P divided by A naught, A naught is nothing but constant. So, since we are looking at only the load, these are two things which happened, but what happens to stress so, we have seen in engineering stress that first the load increases, because it because of dominant strain hardening and then the load decreases because of the dominant reduction in the area because of necking after UTS. So, this dominates because of necking after UTS.

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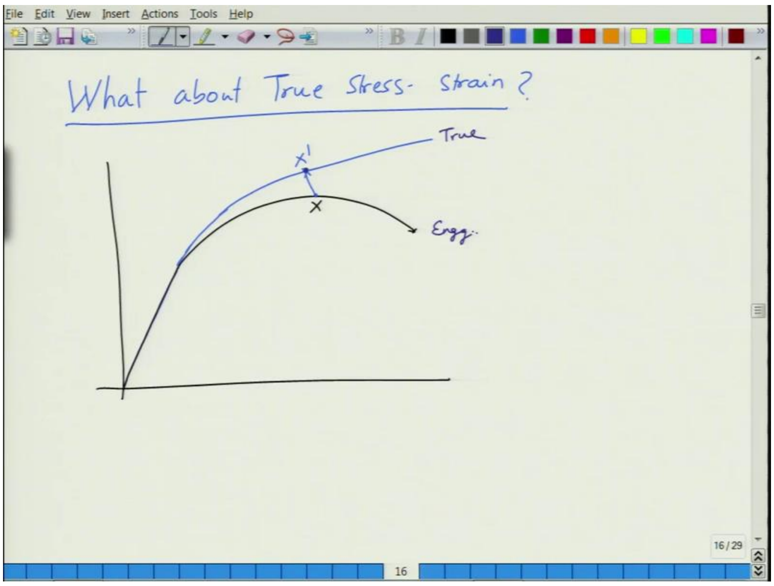

So, what happens in terms of true stress-strain curve? If you look at true stress, what will happen is, so, this will be our engineering stress-strain curve. The true stress-strain curve will be something like this and it will be, so, this point will correspond somewhere on the true stress-strain curve. So, if this is an x point the necking so, if this is x here, it will be represented as x prime somewhere here. So, basically, we can say a few things about this deformation. So it is here also, but it is just that it is not very clearly visible. So, this is true, and this is engineering.

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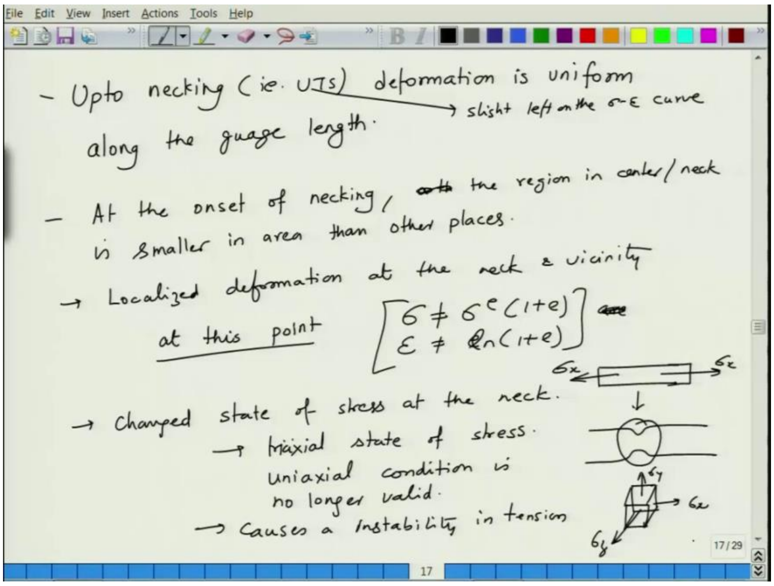

So, there are a few things that we want to note. First thing is up to necking that is UTS point deformation is uniform along the gauge length, that is first thing. At the onset of necking, so basically this point will be slightly left on the true stress-strain curve. So at the onset of necking which means, the region in the center or at the neck, may not be at the center, is smaller in area than other places.

So, as a result we have localized deformation at the neck and vicinity. So neck and around it the deformation is localized. And at this point sigma is not equal to sigma e into 1 plus e the epsilon is not equal to l n of 1 plus e. So, these things they do not. So, these things are not valid. So, these equalities which were there earlier they are not valid around necking because of non-uniform deformation.

So, the neck deforms at a different rate than the rest of the sample and the deformation is more localized and more at the neck than in the vicinity because of the area reduction. And what it leads to, it leads to changed state of stress at the neck. The neck shows triaxial state of stress. So, in the earlier initial stages, sample was actually being deformed so, you had sigma x sigma x, but at the neck then this region has a stress state which is like this.

So, this has this as well as this, so sigma x, sigma y, sigma z. So triaxial state of stress as a result, the uniaxial condition breaks down and hence neck deforms far more rapidly than the, and this causes a instability intention, instability in the tensile test, so that is where this necking is basically a very important phenomena in deformation.

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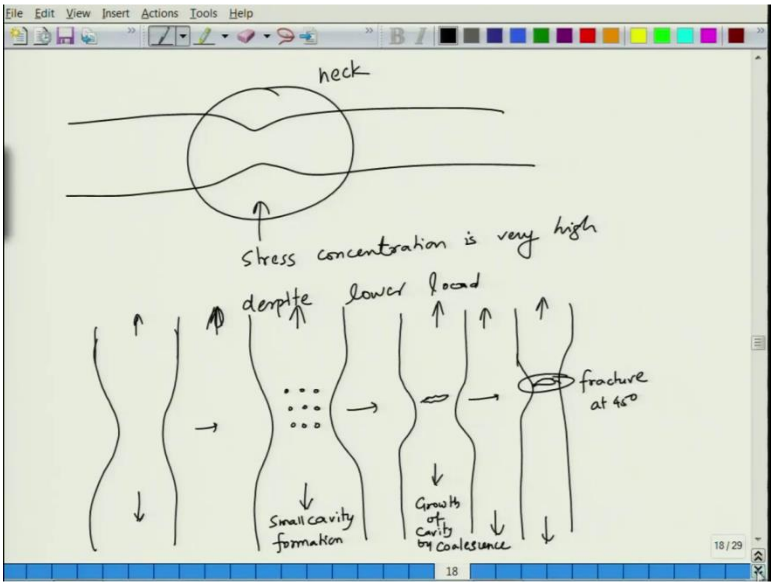

And basically, we can say at the neck the stress concentration is very high despite lower load. And basically, what happens microscopically at this point is that you have formation of little voids at the neck. So, what happens is that when you have this neck, so your neck starts forming something like this as you keep up. So, this is like as you keep deforming it, and then you deform it further and you nucleate these small voids, let us say, so we can say small cavity formation.

And these cavities grow to bigger size, growth of cavity by coalescence of smaller cavities. And when you increase the further deformation then situation may be something like this, this sort of they join a particular plane. So basically, there is a shear fracture that happens. So, basically, you have fracture here, which is at about 45 degree to the tensile direction so fracture at 45 degree to tensile axis, this is the tensile axis. Sorry, this, this. And this is what happens at the necking. So, this is a microscopic picture of what happens that I think.

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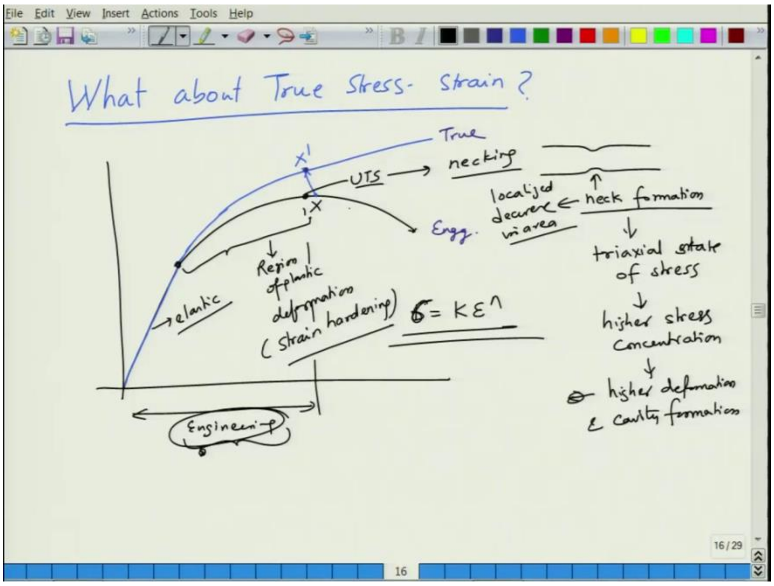

So essentially to summarize what happens here is just in the beginning, you carry out elastic deformation then the load keeps increasing, then you go to a region of strain hardening. So, this is a region of plastic deformation where we have strain hardening. So, although area reduces which causes a decrease in the load, but strain hardening leads to increase in the area. And this we will see the microscopic regions of strain hardening later on and in this region the stress is given as K epsilon to the power n. So, the stress keeps increasing as the strain increases.

As we reach UTS, you have necking that happens. So, necking is sudden form of the neck, formation of a neck somewhere in the along the gauge length generally at the center, neck formation and neck formation has triaxial state of stress leading to higher stress concentration and this higher stress condition leads to higher deformation and cavity formation. This higher deformation basically, so, you have a localized decrease in the area, localized decrease in area.

So after the neck is formed, the load decreases because of localized decrease in the area. And then, once this area is decreased in the local region, the load keeps dropping before the sample fractures because of the. So, between UTS and fracture point the cavities form, the cavities grow bigger, they form a bigger cavity and this big cavity spreads across the cross-section leading to fracture.

So, generally from the generally, from the deformation perspective, we do not cross the UTS point because that is when instability arises, that is when the stress changes, that is when the material starts having defects like cavities and voids and so on and so forth. So, from the engineering perspective, the deformation is limited. So, this is why this engineering from the engineering point of view, we are interested in deforming the material up to sigma UTS.

This is and that is why we do not use the plots, you know although the true stress-strain curve is the real or more accurate representation of stress and strains in the material, the difficulty of measuring the area instantaneously does not allow you to measure the true strains accurately. And it is easy to measure the load and engineering strain, engineering stress in the true stress. And also the display of necking or the UTS point is more visible in the, it is very obvious in the engineering stress-strain curve than the true stress-strain curve. So, that is why we use for engineering purposes or practical purposes, engineering of stress-strain curve is more useful as compared to the true stress-strain curve.

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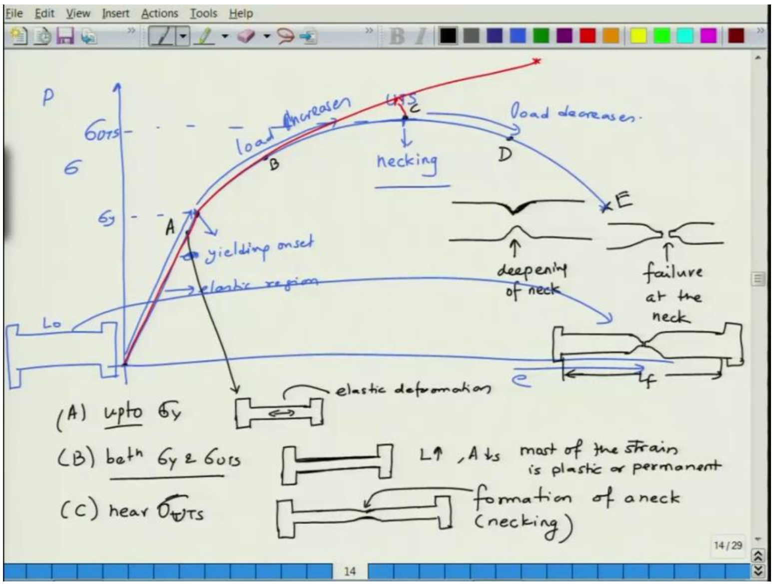

So, what we have done in this lecture is we have learned about basically, what is the difference between engineering and true stress-strain curve, what happens, what happens basically, what happens at various stages in terms of gauge length and formation of neck. So in the beginning we have elastic region followed by a strain hardening region, followed by necking and neck followed by failure. So, these are the four stages of deformation that happened.

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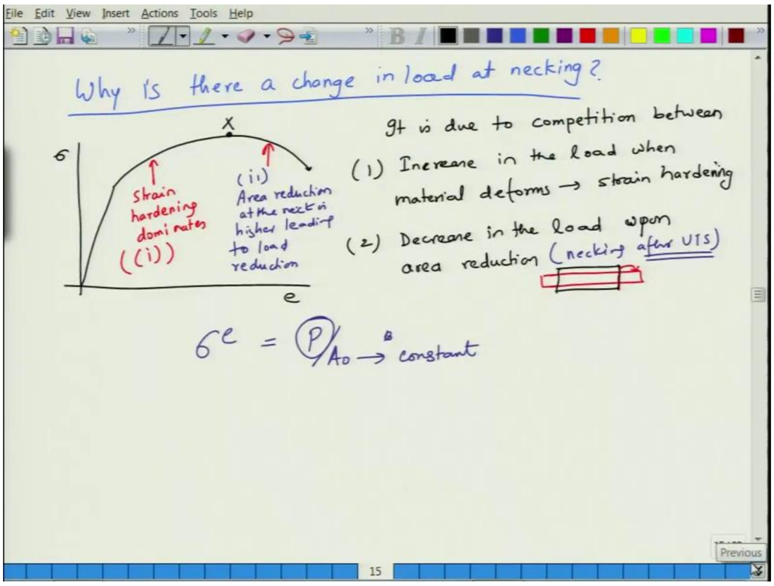

And it is the necking, which is important turning point in the deformation. And that is why generally from engineering perspective we do not deform the sample beyond ultimate tensile strength. And so, we will further look at the behaviour, this tensile behaviour and tensile properties and phenomena of strain hardening and other things in the, and the phenomena of plastic deformation at the microscopic scale in the next few lectures. Thank you very much.