Mechanical Behaviour of Materials - I
Prof. Shashank Shekar
Department of Material Science and Engineering
Indian Institute of Technology - Kanpur

Module No # 02
Lecture No # 08
Tensile Testing

Welcome back students so we start on the topic of plastic deformation today and we have already completed the elastic deformation of the elastic properties of the material. Now in between the elastic and plastic the transition that takes place from elastic to plastic. This transformation or transition can be best described by one of the mechanical characteristics of the material which is the tensile behaviour.

So we will start with tensile test of a material. Usually how does the tensile test; the test characteristic of a material look like the tensile response I should say.

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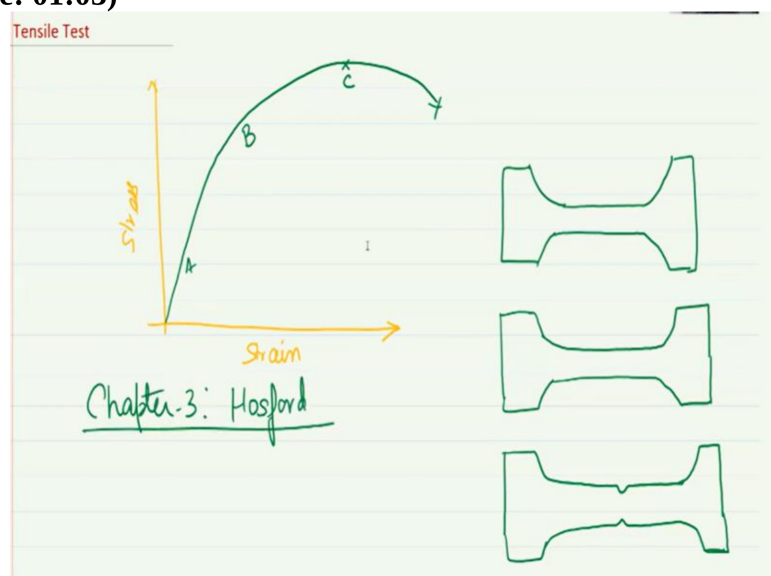

So it would look something like this so you will have a y axis and s axis x axis on the y axis you have usually stress and on the x axis you have strain and the plot is usually given something like this. So somewhere the material the will break and what you will have at point A you will have a sample which will look something like this. At point B over here you would see that sample as extended.

And we will talk more about it but what you will notice is that extension is throughout and drawing is not very clear let me redraw this part. It should remain have a, at somewhere at this point C what you would see is something like this happening. So now this particular region has unevenness or this region has become thinner than rest of the region this is called necking we will talk a lot about it later on. But for now that this called neck and what it means is that?

Now the stress would remain concentrated in this region why because now this is smallest cross section so the load will be here. So the stress will be higher would be here and therefore this is what will deform or fail first so the more, most of the not most all the deformation at beyond this point will take place in this neck region. So if you want to read more about these particular tensile characteristics you can read more about it from chapter 3 by Hosford mechanical behaviour of material by Hosford.

And you would see that usually there are 2 different in metals we have 2 different types of deformation or the stress and tensile test characteristics that you obtain.

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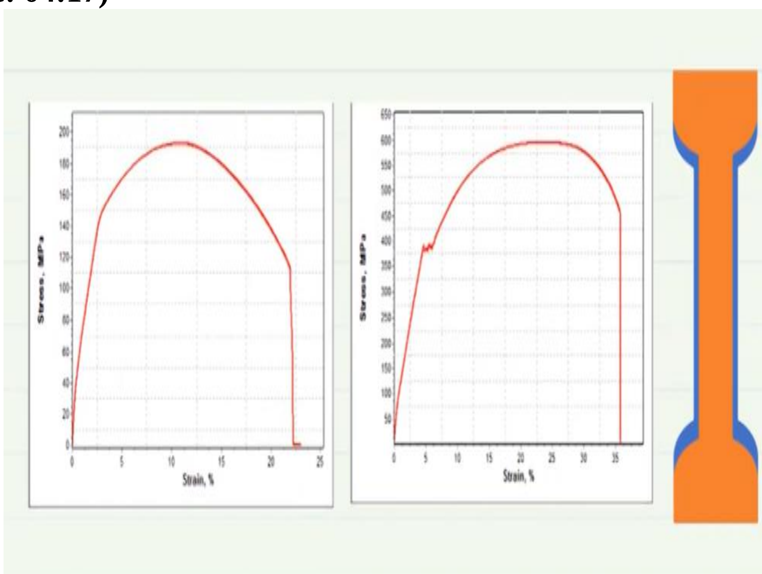

Usually one would be like this which will be very smooth so something like aluminum or copper or brass these kinds of alloys would give you the smooth curve that you see on the left. On the other hand medium carbon steel you would see a stress strain curve which looks more like this. So there is a point up to which stress increases and then it suddenly drops and then it fluctuates and after this particular point then it again starts to increase.

And the later on rest of the part is similar so it will go to a maxima then come down and then at some point it fails. So this is probably the point where it failed while for this one this is the point where it failed. Now there are so much information that is compressed in this one plot that you would be amazed. So this is, what we will look at but before that let us understand a few of the things. Now when we are talking about tensile test so one thing I want to ask you is.

Do you think that any kind of sample can be tested and then you can compare so for example let us say one of you are friend test a sample which is whose shape is like this. The one that you have shown in blue so you would imagine that it when it gets extended it will look like that sample in orange.

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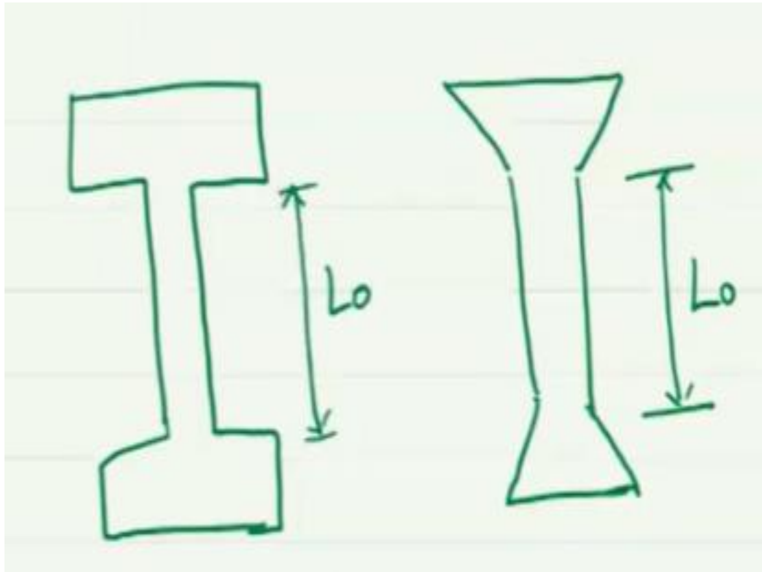

On the other hand one of you is other friend test a sample which tests like this sorry which looks like this. So very orthogonal in shape on the other hand still another friend test the sample which is trapezoidal heads. On the other hand you have tested a sample which looks like this so the question is would you get the same stress strain behaviour for all of these?

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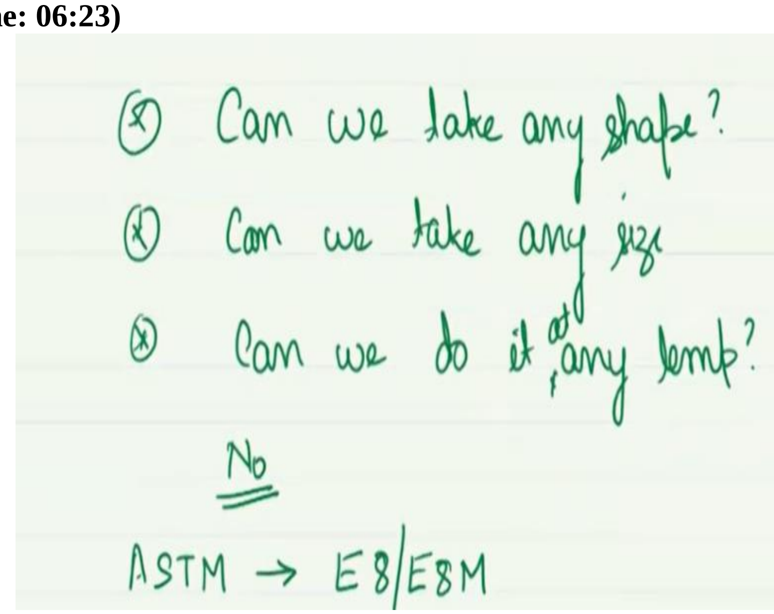

Next question is so one is the questions are can we take any shape? Second question can we take any size? Meaning no matter what is the level we can take whatever length we want. So we know that is called the gauge length for all these samples so can we take any size? Next is can we do it at any temperature? And when you take any shape any size and perform the tense at any temperature are we still going to see the same stress strain curve?

No matter where you are conducting whether, you are US or India or Europe and the answer is no. We cannot take any share we cannot take any size we cannot do it any temperature and there is a standard which has been defined. So for example for the tensile test there is a standard which is given by one of the standard making agencies which is American standard for testing of materials and the short form is ASTM and one of the standards that we have defined for metallic for tensile testing a metallic materials is E 8 slash E8M.

Why do we need to define that there has to be a certain shape certain size or range of shell size and range of temperature. The answer is that if you look at these you can clearly see that these regions will have stress concentration. And if you have stress concentration even in fact even in this one you would have stress concentration. And therefore these kind of shapes would feel very quickly.

On the other hand this is you are gauge length over here and the gauge length is gradually increasing. And therefore there is no stress concentration so the overall stress remain concentrated here and it does not it remains confined in this gauge length but and does not get concentrated at any point. And therefore it will not show any premature failure and therefore whatever values you would get would be the true value for the material.

And in fact you would probably if you do or test for all these different shapes you would see that you will get the highest stresses yield stresses or UTS for this particular shape. Now what about size you would one may ask shape maybe a problem what about size we can take very long size very small why does this matter? Because in the end we are talking about stress and not force so stress would be force per unit area.

And that is true but then there is also something called as size affect so very small samples show a; very different stress strain behaviour than a very large sample. And this is called size effect and there are host of reasons we do not want to get into that right now. But there exists what is called as size effect and hence if you want to compare Apple to Apple and oranges to oranges we need to have same range of sizes of the sample and this is what again this particular standard E 8, E 8 M defines.

In fact this is only for room temperature there is E 21 which defines for the tensile testing at higher temperature then again for specific materials for example cost materials there is a different type of testing define. So these are just definition of particular test so that proper comparison can be made. And for that standards have been developed and this is one of those standards that I have listed over here.

So that tells us about what are the different constraints for the sample now let us come back and look at the stress strain curve here. So you must have seen these kinds of stress strain curve even at you are high school level and you may have been told that there is a point which is called yield point. So you would have told or informed that this is somewhere the yield point lies. And this would be the point where elastic behaviour and the plastic behaviour starts.

But then how do we find that elastic what how do we find that in point and what would have been defined what you would have been told is that you find a offset 0.2% strain offset and that point would give you the yield point. Well for high school level that is knowledge is good but there is limitation in that. Actually there are 3 points which are very close to each other. What are these 3 points?

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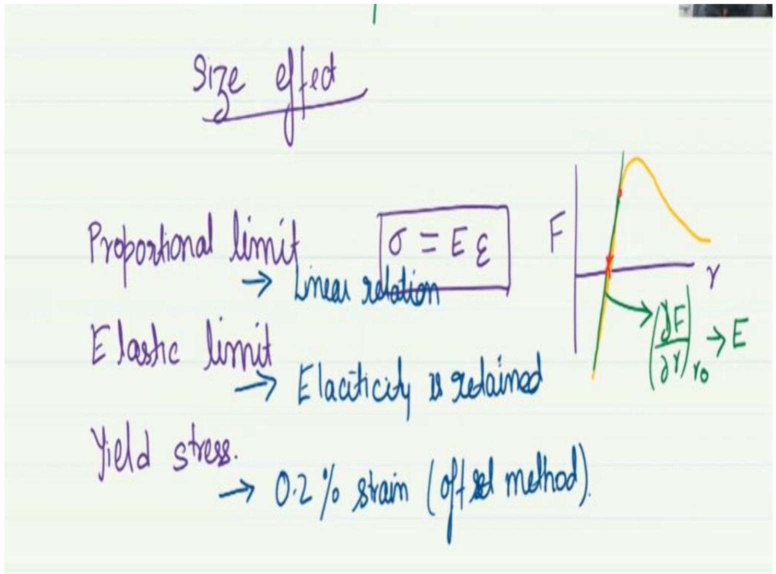

They are proposal limit, elastic limit and yield stress what is proportional limit? We know the relation $\sigma = E\varepsilon$. E is the elastic modulus times epsilon where epsilon is the true strain and sigma is the true stress. So this is a linear relation and what is the origin we remember from our first few lectures that if you look at the F versus r curve then this is how it looks like and in fact it is this slope.

If you remember from there it is this slope $\partial F/\partial r_{\circ}$ which defines the value E. So this is a region up to which this remains linear this is what is called the proportional limit. As you would keep increasing the distance separation between the 2 atoms or basically you is applying stresses so that the extension becomes longer and longer. Then at some point this no longer remains the linear relation and it becomes non-linear.

But still it retains its elastic behaviour meaning even if you come to probably somewhere over this point. So this is not really following this E or slope is not E over here but if you where to reduce the force or take away the force then the material will come meaning it has not yet transitioned into the plastic behaviour. And it retains its elastic behaviour the only thing that is not happening here comparing to earlier point which was somewhere over here is that this particular point does not follow the linear relation between sigma and epsilon.

So a point up to which this stress and strain let me be more precise up the point up to which it remains elastic and although it may not remain linear it may not follow the linear relation. That point is called a elastic limit so proportional limit where you have linear relation up to the point where up to which you follow linear relation between stress and strain. Elastic limit the point up to which actually the elastic properties of the elasticity is retained.

If you go beyond this point then the local stresses become so high that dislocation starts getting generated we will talk more about this locations later on which is the core of plastic deformation. So up to this point it is this point which up to which that dislocations are not generated. Now yield stress so ideally elastic limit is the point where yielding beings and therefore that should be yield stress.

But then when you are doing the measurement physically you cannot differentiate you cannot go inside the material and say now the dislocations are getting generated and therefore we have a way of defining or obtaining elastic stress and it has been defined as the point where you have 0.2% strain. So this is called offset method will come back to it later on but for now the point we are trying to make here is that here are basically 3 points.

Proportional limit elastic limit and yield limit and if you where to look at the stress strain curve basically you will have so the elastic limit so in this one it probably looks like the elastic limit sorry the proportional limit is somewhere over here and probably the elastic limit would be up to somewhere over here. And if you could draw a line for 0.2% strain so this is probably you are yield stress at 02% strain.

So clearly just by looking at this figure we cannot find where is the elastic limit even proportional limit is something that we cannot identify just from the figure. One because this figure the accuracy of the data that we obtained from this is not so high that we can say that it is linear up to this point or not. And second that even if it were then the variation would be so small that again you would not be able to identify from this plot.

So because of these reasons what we have is only one point which is the yield stress so that something you can physically obtain just from the data given to you. Next what we want to look at is when we talk about tensile characteristics. Then there are 2 different types of stresses that are calculated one is the true stress and the other is the engineering stress. Similarly for strain we have true strain and engineering strain.

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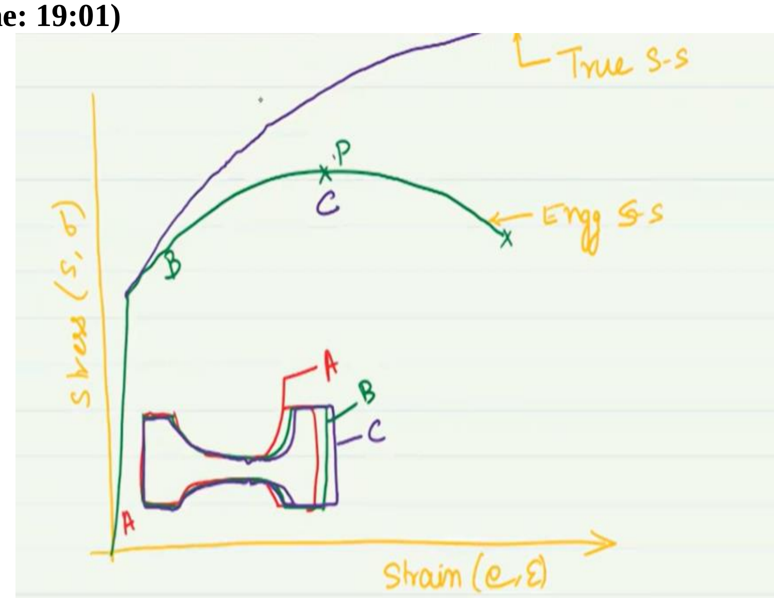

And therefore we need to understand what is the difference between these 2 and let me just correct this part. So now it is true stress strain versus engineering stress strain so we need to understand what is true stress strain and engineering stress strain. To being with again you may have seen the plot for true stress strain versus the engineering stress strain and this is how it will look like the schematic I am drawing a schematic.

Now on the x-axis we have strain it can be engineering which is usually given by e and the true strain which is given by epsilon. On the y axis we have stress the engineering is given usually by S and the true is given by σ. Now here which one is engineering stress strain and which one is true stress strain. So most of you will identify that this one is the engineering stress strain because; engineering stress eventually comes down. So this is true stress strain its characteristics is that it will never come down it is always increasing.

Now this is the curve that is usually obtained or plotted when we are doing any tensile test and that is because it is very easy to obtain or we have all the data to translate from load versus elongation to engineering versus engineering strain. On the other hand for true stress true strain we can only draw up to the UTS point and beyond that we need to get data from the sample like the neck radius etc to be able to draw the rest of the region. We will talk about each of these 1 by 1 but for let us look at the engineering stress strain curve.

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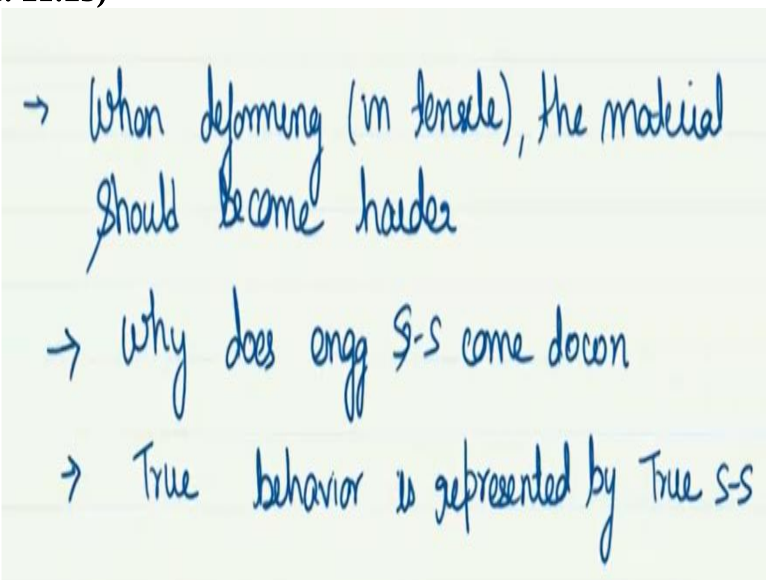

Now we know that when you are deforming a material or basically stress strain is also deformation so when you are deforming the material in tensile the material should become harder right. So this much is clear then the question is if the material is becoming harder meaning you need to apply higher stress then why does the engineering stress strain come down.

On the other hand you can clearly see that true stress strain is continuously increasing and it does represent the true behaviour in the sense that when the stress when you are deforming and the materials would becoming harder and the stress keeps on increasing. So this true behaviour is represented by now let us look at the 2 engineering stress strain and the true stress strain curve individually.

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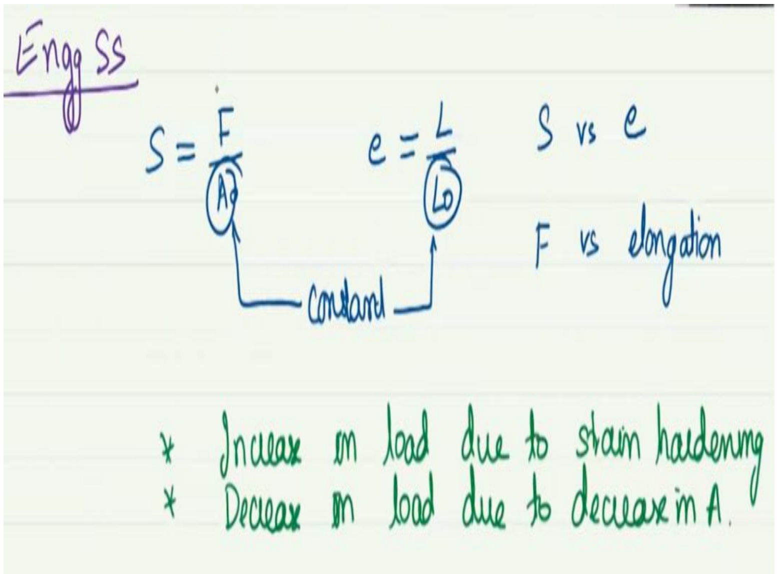

So here stress is given by $S = F/A_{\circ}$ and strain is given by $e = l/l_{\circ}$. Now you see that what is $A_{\circ}$ it is the initial area at the beginning of the test similarly $l_{\circ}$ is what it is the initial length at the very beginning of the test. Now when you keep doing the deformation this quantity and this quantity is not changing. They are constant so in affect S versus e depicts nothing but force versus elongation.

So in this particular curve there is competition taking place between 2 different things one is here also the basically stress work Harding is taking place. And at the same time the cross sectional area is decreasing but that is not been taken into account over here and therefore the load itself starts to drop. So the load itself starts to drop and ideally the $A_{\circ}$ would have also dropped if sorry not the $A_{\circ}$ but the instantaneously area would also draw.

And that would have reflected the true stress of increasing value but since we have kept the initial area which is constant and larger value therefore the stress the engineering the depicted by engineering stress that also falls down. So there is competition between 2 different things one is the increase in load due to strain hardening.

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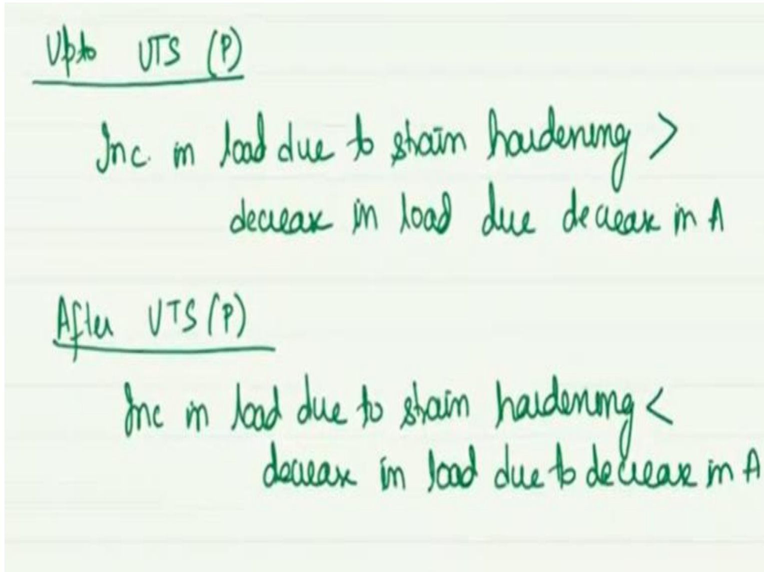

And decrease due to decrease in area now until the point so let us call this our UTS point as P up to this UTS point p this increase in the load due to strain hardening is greater than decrease. So there is slight decrease in the area if you remember from our so let me again draw the dog been here just for representation. So this is point C somewhere over here this is point B somewhere over here and this is point A somewhere over here.

Actually C should be close to point P so clearly what you see is that A to B there is a slight decrease in the area cross sectional area, as you keep increasing the length because of that change in the length there will be decrease in the diameter and therefore there will decrease in the cross sectional area. But what happens at C is that the cross sectional area as now suddenly changed drastically because of the formation of the neck.

It is no more gradual change there is a sudden change or unevenness that is taking place in the gauge length which had led to a drop in the cross sectional area at one particular region. And now this becomes the region where all the deformation will take place. So up to this point before that making takes place increase in the load due to strain hardening is greater than decrease in load due to decrease in area.

But things change drastically after UTS which is point P as you can see that cross sectional area has decreased drastically therefore strain hardening taking place but in a very small diameter that neck region is less than decreasing load. Or basically decreasing load is greater that due to decrease in area. So in the engineering stress strain this decrease has is now dominating after the UTS and therefore the load comes to starts coming down and this is why you see a curve like this.

And eventually this is very small cross sectional area over where you are applying the load and which gets saturated with the strain and eventually fails.
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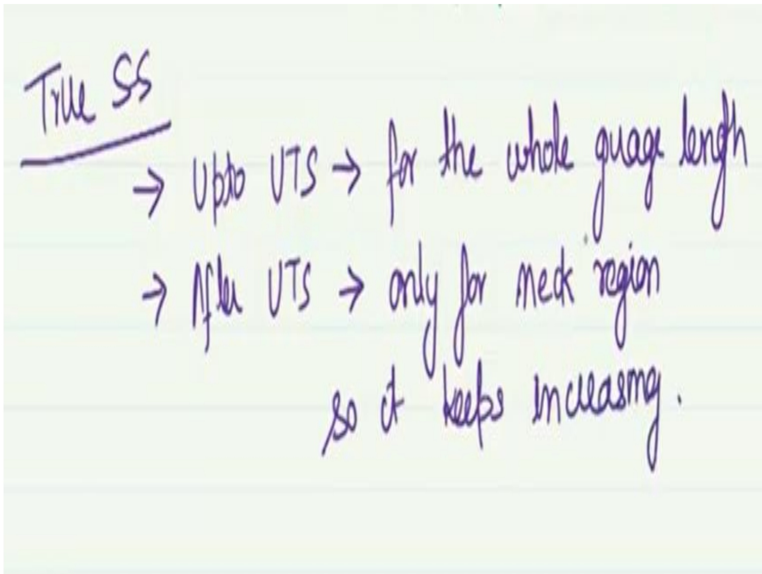

On the other hand when we are talking about true stress strain curve depicts up to the UTS it is depicting for the whole gage length because the deformation is taking place in that whole volume. So coming back to this diagram so up to if you look at A and B under C up to A B and just before C. C is actually some uh to be more accurate it is somewhere which is beyond P just beyond point P.

So up to A and B all the deformation is taking place in all of the gauge length so this whole volume is getting deformed. But point P onwards or if that what is happening in sample C the deformation is taking place in only this much region. So for true stress strain up to UTS it is depicting for the whole gauge length and after UTS it is depicting only for the gauge length unlike the engine in stress strain.

So here the area has also changed the area it is taking into consideration is that a small area. And therefore the stress value comes out to be higher which is actually depicting the stress of only the neck region and there and which we expect that it is strain hardening and effort should be higher and that is what you see so it keeps increasing. So now that clearly explains that why the engineering stress; strain will drop while the true stress strain will keep on increasing.

Now another point that we need to understand here is that we have a relation between or we can establish a relation between engineering, strain to true strain. And similarly we can establish a relation between; true stress to engineering stress. So we will not get into the details of it is very simple and you can refer to the book for that we will just show you the equation.

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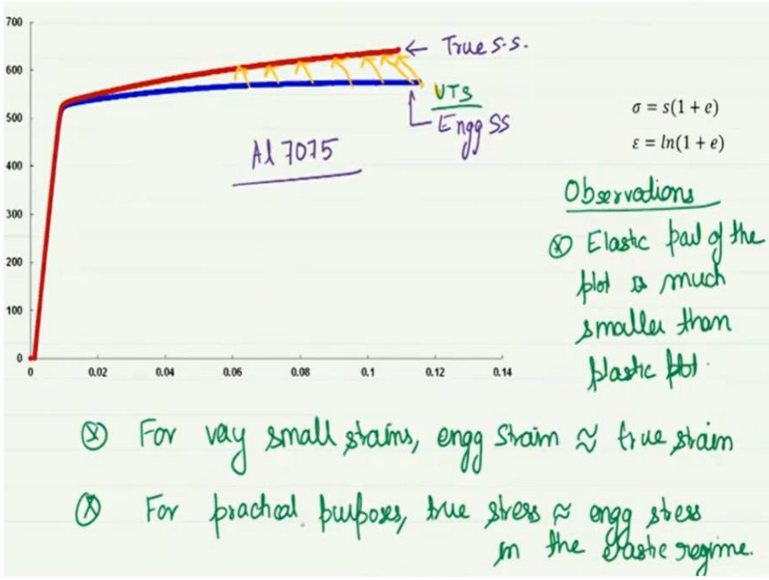

So the equation is given over here so sigma is the true stress and s is the engineering stress so it is given by related to each other by (1 + e) where e is the engineering strain. And epsilon is equal to epsilon which is the true strain is related to the engineering strain by epsilon = ln(1 + e). Now let us look at this data this has been obtained by a professor in his lab for aluminum 7075

So what are some of the observations over here? So they obtained obviously they obtained only the load versus elongation data and then they translated it into engineering stress strain curve which would be this one. And then also translated it; into true stress strain curve which is this one. So looking at this data what are some of the observations that we can make the first observation that we can make is that the overall elastic part is, so much smaller and this is not even failure this is actually the UTS point.

We will tell you why we are not including data beyond this which will come in next few slides. Now here what we see is that the elastic region is much smaller than the plastic region. I should not call region because it is not a not a physical space so I will say the elastic part of the plot. Another aspect that you would note is that for very small strains particularly this elastic regime you can see red and blue curves are almost overlapping.

Which; means for very small strains the true strain and engineering strain are same is approximately equal to true. And similarly if you look at the stress values so for all practical purposes the stresses are also same in the elastic region.

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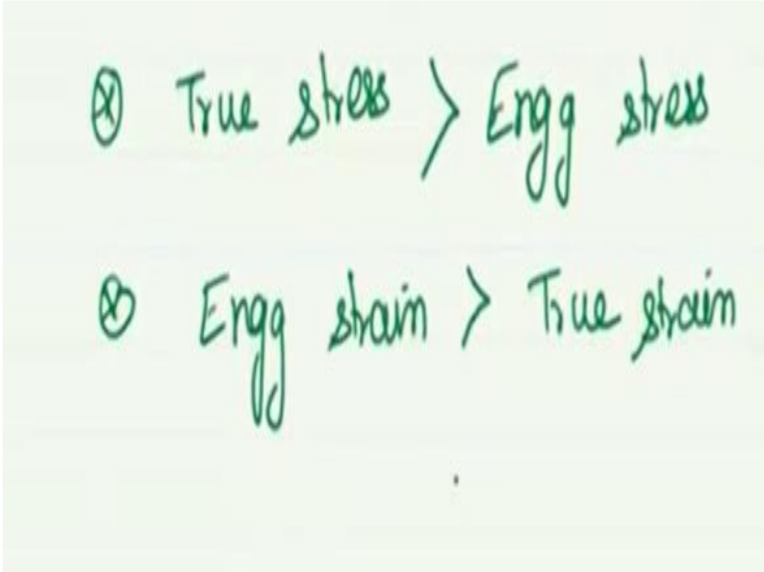

Another point to note is that if you go by this equation then you would note that the true stress is always higher than engineering stress. And the other aspect is that engineering strain is always greater than true strain. The implication of this is that you would always see the curve that equivalent points would always be like this. So it will always be the in true stress strain curve would always lie to the top left top hand left of the engineering stress strain curve.

So that is outcome of the relation that; we have given over here and like we said that it is very easy to obtain and not very difficult to derive this equation. Now that we have a good understanding of the engineering stress strain and true stress strain we are in a position to solve a problem. But again before we go there we I mentioned one thing which let me explain that.

So we said that this true stress strain curve is shown only up to the point of UTS. So this is the point which is our UTS over here and the equivalent of UTS is this point. Now beyond this point what; is so up to this point what happens is that the overall length is increasing in a very structured way. So we were able to get true strain directly from the engineering strain. But now beyond this point as you would remember from our figure over here there is a neck that has formed.

Now what happens because of this neck; we do not know the dimension just by the engineering strain values. You would actually have to measure the size of the neck to be able to detect or predict what is the actual diameter at this region to say? This is what the strain is that is one complication. Second is if you look closely what you will realize is that this is no more at this particular neck region it is no more a uniaxial stress condition it is actually a triaxial condition.

And therefore you need to make corrections for that too and therefore beyond this point it becomes a lot more difficult to obtain the data for true stress strain curve. And that is why most of the time what we draw is the engineering stress strain curve.

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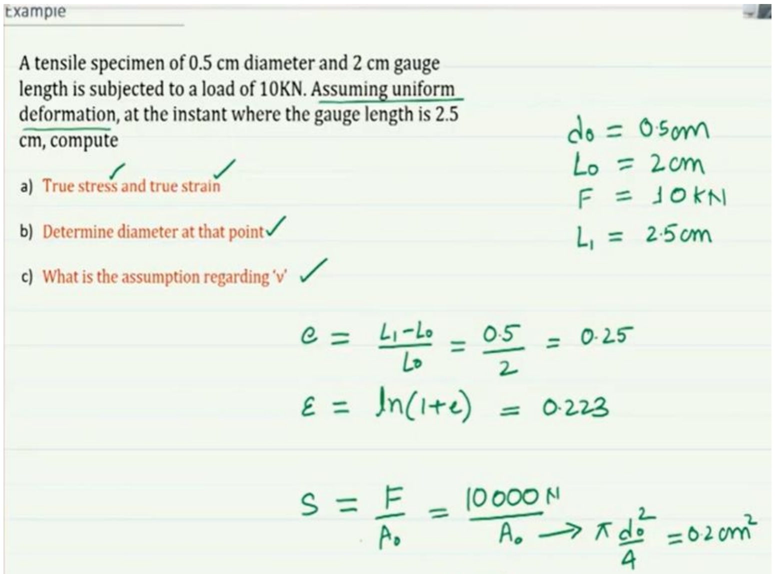

So with that now let us move on to solve one example it is given that a tensile sample of 0.5 centimeter diameter and 2 centimeter gauge length is subjected to a load of 10 kilo Newton. So the $d_{\circ}$ = 0.5 centimeter and $L_{\circ}$ = 2 centimeter and F = 10 kilo Newton now it is also given that at this particular instant L let us call it L_1 = 2.5 centimeter. So from here we have L naught and L 1 so we can clearly calculate first the engineering strain which is $(L_1 - L_{\circ})/ L_{\circ}$ = 0.5 /2 = 0.25.

And since we have the engineering strain so we can also calculate the true strain which is equal to Ln(1 + e) = 0.223. And for the engineering stress we know it is equal to F/A we know F which is equal to 10000 Newton and area is something which is $A_{\circ}$ actually. So area is something we can calculate given that $d_{\circ}$ so area is equal to (pi $d_{\circ}$) square by 4 and this comes out to 0.2 centimeter square.

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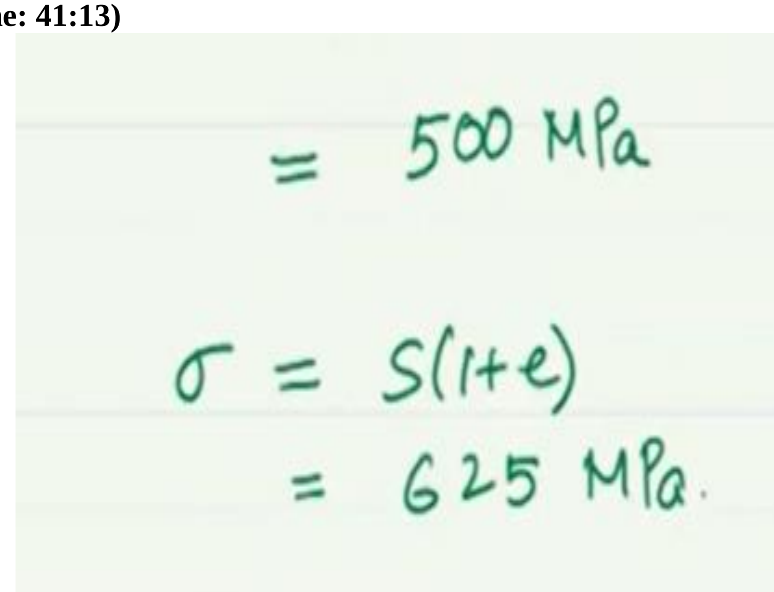

Therefore stress comes out to 500 MegaPascal and if we know S then again we can calculate the true stress which is equal to S(1 + e) which will be equal to 625 MegaPascal. So we have calculated true stress we have calculated true strain now we need to calculate determine diameter at that point.

So we know the initial diameter now what we have to find is the diameter at the other point. So for this we can assume that the volume remains constant so we will start with that assumption.

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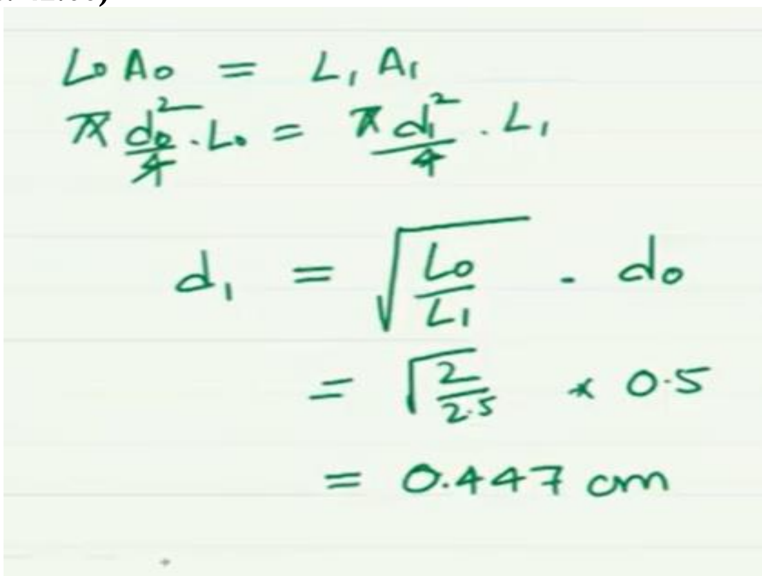

And therefore $L_\circ A_\circ = L_1 A_1$ and on solving it leads to

$$d_1 = \sqrt{\frac{L_0}{L_1}}\, d_0 = \sqrt{\frac{2}{2.5}}0.5 = 0.447 \text{ cm}$$

So we now we also know the diameter at this instant but then this is assuming uniform deformation which is already given to you.

If it were not uniform deformation meaning if it were beyond the UTS then we cannot apply this equation then we cannot apply any of this equation so we have determined this. Now since we have started with the assumption that the volume remains constant.

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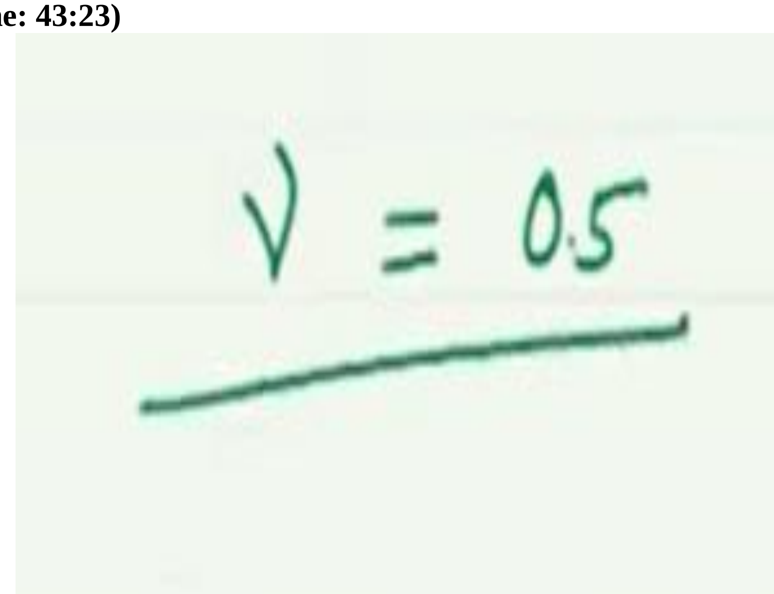

So we can clearly say that nu = 0.5 and therefore this is also done so we have calculated assume an example and here it was given the diameter and the initial length and the load. So from there we use the equation to calculate the true stress or translate it into two stress and true strain values. So now we will uh move on to some more tensile test parameters that can be obtained for the tensile test.

So first thing is uh we talked about the fact that tensile test that we conduct cannot give you the true stress value beyond the UTS. So there are some corrections which is called one of them is called bridgemen correction

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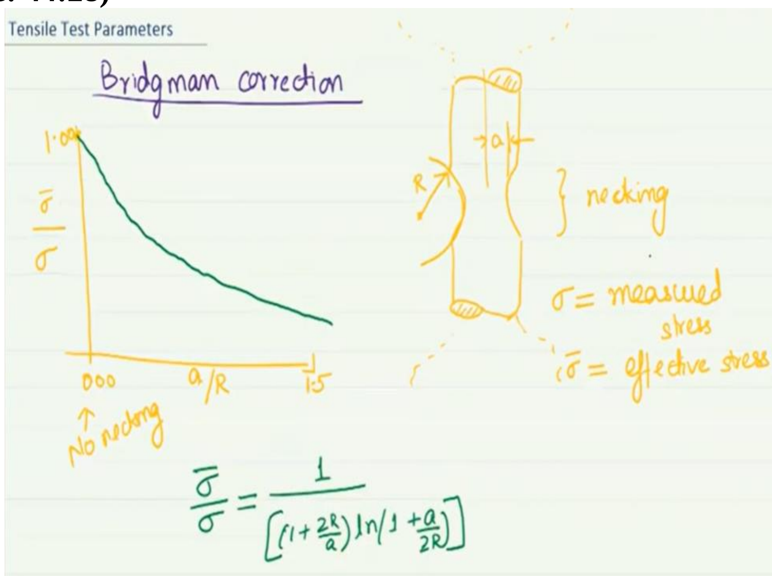

So we will look at that and see how it can be applied when we uh beyond this UTS point so what is Bridgman correction? So let us say we are using a circular dog bone so let us say we are looking at within the gauge length so this is part of the dog bone and over here it will go somewhere like this. And this is the neck that has formed or necking has taken place and this is a. And let us say that we can fit a radius R in the neck region so R is defined as that.

Now the Bridgman correction is given by an plot which is like this a/R and on the y axis we have sigma bar by sigma and over here a by r is 0.0 and onwards. So let us draw it up to 1.5 0 means a, is 0 which means that sorry not that a, is 0 but a by R is 0 which means R is infinite meaning no necking has taken place so this is the point of no necking. So at this point this and here sigma is the measured stress meaning the stress that or the resistance being applied by the material

And sigma bar is the effective stress that is being applied in this region. So if you had no necking actually taking place then sigma bar will be equal to sigma and therefore the curve starts from over here. And as the necking starts then actually this value drops and it asymptotically keeps reducing and this is how it looks like. So the overall equation that we obtained looks something like this.

So this is the form of the equation that from which this has been plotted and as you can see that as the necking keeps increasing the sigma well sigma bar the effective stress that is acting on this region is going lower and lower. So this way you would be able to calculate the true stress that is acting over there and based on this area you would also calculate the true stress.

So you will have that true stress plus this correction which would give you a lower value than what would have been obtained earlier. So if you look back at our previous example so in here if you apply the Bridgman correction then you would the data you would get would be a little lower than this. Meaning it would be somewhere like this so this is the Bridgman correction. So the next parameter that we will look at is the about yielding and strength.

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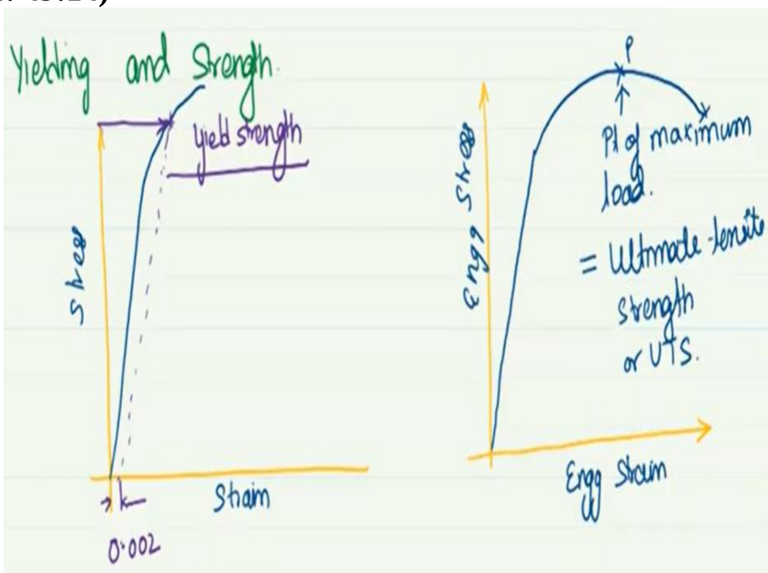

We have already given you a preview that yielding is a theoretical value and it is not possible to get the exact value and therefore what we have is a proof stress. So we define 0.2% strain and at that particular 0.2% strain we calculate the yield strength. So let us look at it how it is practically done? So this is how you are plot would look like on the x-axis you have stress and on the y-axis you are strain.

And as you remember that for the very small values of strain the true stress and true engineering stress would not very much. In fact even the engineering stress and true strain would not very much so we need not worry about whether it is true or engineering. Now over here we can if you let us say that at any particular point you reverse the load or remove the load, but happens is that the material will show some plastic strain and the elastic part of the strain would recover.

So it will follow a path something like this now the path for which you get a remnant strain of 0.002 which is equal to 0.2% that particular stress is what is termed as yield strength. So this is a value which uh tells you where the yielding begins and for a structural application you want to stay away from the yield strength. You would want to design a material or a component so that you are material never reaches anywhere close to yield strength.

And you will put a safety factor probably 2 or 3 so that the overall load is such that the stresses are so much below the yield strength. There is the still another way or another parameter which is used for defining the strength of a material. So yield strength is one way to define the strength of a material another one is the UTS. So we have looked at the UTS several times so far now let us look at it from application point of view.

So this is how a stress string curve would look like the engineering stress strain and somewhere over here is your yield strength sorry the UTS the point where you have the maximum load. So remember the shape of the curve would be same for force versus elongation as it would be for engineering stress versus engineering strain. Because in both the when you translate from force versus elongation you are only dividing it by a constant factor $a_{\circ}$ on for the y axis and $L_{\circ}$ for the x axis.

So the shape is same and therefore this point also reflects the point of maximum load which is called as ultimate tensile strength or UTS. So yield strength we said is more useful from the point of view of application in structural application. On the other hand UTS is more important from the point of view of forming of materials. When you are trying to deform a material for making some particular shape of out of the component so; you are basically performing a forming operation.

Now in that forming operation you want to know what is the maximum amount of stress that would be required for deforming the material? And this would come from these UTS so this is why it is also called the ultimate tensile strength. Meaning that is the maximum tension that you can or the stress tensile stress that can be bone by this material. And it has like I said it has a particular significance from the point of view of forming operations.

So you would want to design you are devices or equipment for forming so that it is able to apply at least this much of stress or probably you will apply also apply a shift safety factor. So that there is 40 20 to 30% higher stresses to ensure that there is proper deformation of the material. In fact we use a different term as we well see in one of the later lectures flow stress. So the material actually starts to flow you can keep deforming the material and it will keep flowing.

So we will define that term which is not really the UTS but and not even the yield strength but something which keeps on changing from UTS to keeps changing from yield strength to UTS. So that is the parameter about yielding and strength and we have already seen how to measure yield strength for measuring the UTS? All you need to find out is the strain at which you get the maximum load and then corresponding to that strain you will calculate the stress.

So that would be you are UTS in engineering or you can equivalently calculate the true stress at that point. So that the so UTS can be calculated either as true stress or as a engineering stress depending upon the application. Next parameter that we are going to discuss is the elastic modulus.
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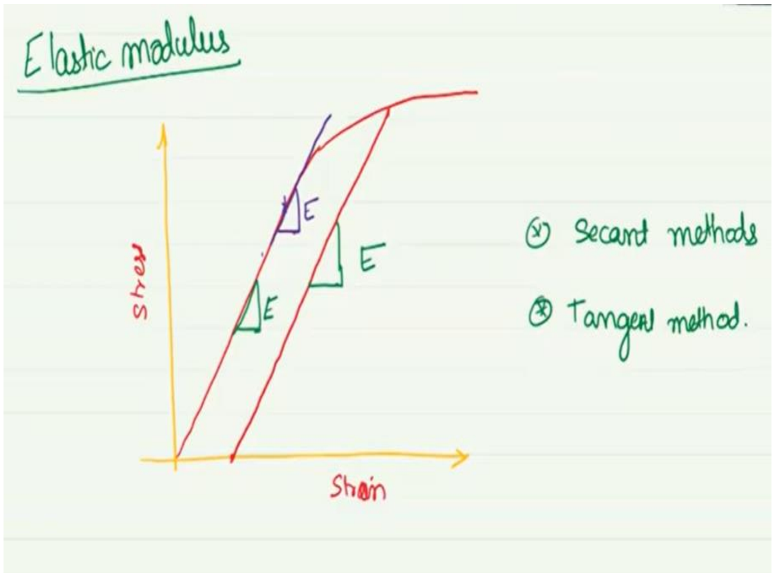

So we have already seen the origin of the elastic modulus and in today in this part we will look at how to calculate the elastic modulus from the stress strain data? But to warn you that the data that you obtain from stress strain is not very accurate for measuring elastic modulus, and it is rarely done and really you use the stress strain data to calculate the elastic modulus of a material. But nevertheless since you have data you can use it to obtain elastic modulus.

So again let us see so let us say you have the so I am intentionally drawing it a little larger slope why? Because I am assuming that the x axis is a little bit expanded and therefore we can see clearly the slope that we want to measure over here. So here we have on the x axis we have, stress and on the x , y axis we have strain. So ideally this is what you are the slope of this line is what should be termed as the elastic modulus.

But then we know that this can hardly be the case that you will get such a straight line. So there are 2 methods that are available either you can drop the load and then calculate the slope for this line. So this will be your elastic modulus or you can take a tangent at a particular point. So since it is continuously changing so; you can take a tangent at any particular point.

So let us say somewhere close to the value close to the 0 value but where you have depend reliability of the data you can take a tangent of the data and this tangent would give you the elastic modulus. So overall you have 2 different techniques one is the second method so you are connecting 2 different points and the other is the tangent method so this will give you the elastic modulus. Next let us look at another parameter which is strain and ductility.

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So we have already looked at strain at great length but now we will also look at some more parameters related to strain. For example there is uniform along uniform strain there is strain up to fracture these are 2 other parameters then there is plastic strain there is elastic strain. So again let me so let us say we are at the point UTS so if we drop the load then it will come down and it will follow the slope almost that you have in the beginning.

So it will be like this and if you drop a straight line from over here so it went all the way out straight up of a strain up to this point but this part was recovered. And therefore this can be called as elastic strain this part of the strain is not recovered and this remains permanent and therefore this can be called as plastic strain. So that is some of the other parameters related to strain.

Another few parameters related to strain are we already know that we get so the strain that we get up to this point this is called uniform elongation strain at uniform elongation. This will be the maximum uniform elongation that you can get. So it is or you can call it simply strain at UTS or strain at maximum uniform elongation. And likewise you will also have a strain fact fracture.

And this total strain which is the strain at fact fracture determines the ductility of the material. But in practical application if you look at it is the strain at the maximum uniform elongation that you get is what; is this that is the strain that is actually of any meaning to us. Because beyond that the all the deformation is taking place is only localized and it cannot be utilized or it cannot be made any use of.

And therefore the strain which if you want, if you are working on improving the strength and durability of a material what we want to increase is the total uniform elongation. So yes so that was the term I was looking for this is the total uniform elongation. So from the point of view of ductility this is an important parameter.

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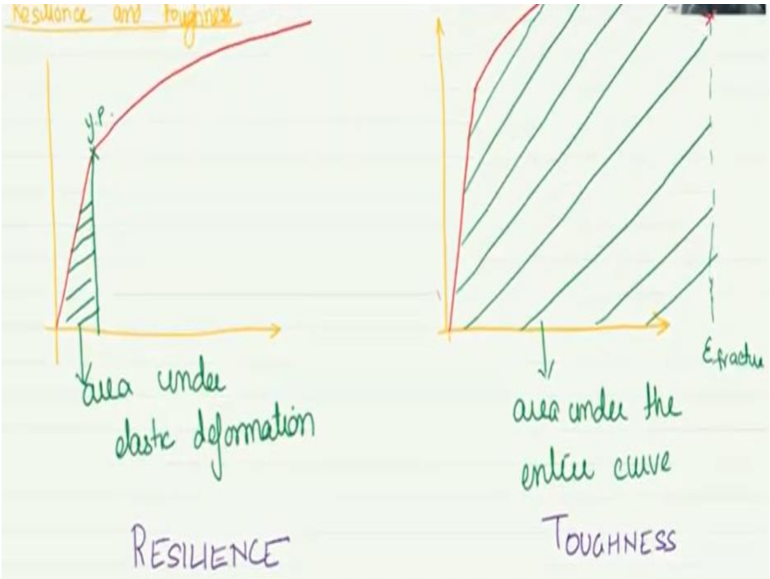

So moving on to one more important parameter related to stress strain this is resilience and toughness. Again to describe it let me first draw the stress strain curve. So again I have drawn a much gentler slope than you what you would observe because again we want to be able to describe what is resilience? So and this is smooth here it may look like so this is somewhere over here you have the yield point.

So if you take the total energy that the material can absorb in the elastic region that is called resilience area under elastic deformation. On the other hand let us say that the material eventually fails so there would be a total area that we can obtain at strain fracture. So this area which is under the overall stress strain curve this is called toughness area under the entire curve this is resilience and this is toughness.

So this is related to this elastic behavior of the material and this is related to the plastic deformation primarily to the plastic deformation of the material. So it is representing how much energy the material will or this component will absorb before failing. And here it is showing how much energy it will absorb before transforming to the plastic state? So it remains in the elastic state but if it goes to the plastic state how much energy will it absorb?

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So with that in mind let us say if you are given 2 different materials so let us say 1 material has a stress strain curve like this. While the other one and interestingly you can get both type of behavior in the steel itself. So clearly what we see is that this one will have fire resilience. Meaning the overall region area that you would get in the elastic regime for this red curve would be higher. So this one; will show higher resilience but lower toughness.

Because the total area under this curve would be much smaller than in the green one on the other hand this one will show higher toughness but lower resilience. So this; one is an example of medium carbon steel while this one is structural steel or high carbon steel. So this is sorry this is not the structural steel actually the medium carbon steel will be the structural steel.

And if you were to apply one of these for ball bearing and other for bumper in the car then which one do you think would be more suitable? So as you can imagine ball bearing it does not you do not want it to deform so it would not you want it to remain in the elastic regime. And therefore it you want it to be able to absorb more energy before it transforms into plastic state. Therefore this is the one which could be more suitable for ball bearing.

So yes high carbon steel is used for ball bearing on the other end this is the one that you would actually use for application in bumpers for automobile. So you want the steel which would be in the bumper to be able to absorb a lot of energy before it fails. So it has to get plastically deformed that is the purpose of the bumper, but then before it fails you want it to be able to absorb maximum amount of energy. And therefore this type of steel would be useful for bumper in automobile.

So interestingly both of them are steel but depending upon their different microstructure you can get different kind of application out of them. So these are the important characteristics that are related to tensile test. And it tensile test we started with tensile test because it very nicely shows the transition from elastic to the plastic regime. And also the tensile test characterization gives you loads of data which we have looked at over here.

And we also got introduced with the concept of true stress engineering stress and so on. So with that we will end this chapter and we will come back. But we still have few more things to talk about tensile test particularly from the point of view of the instrument that is used for testing the tensile characteristics. So we will end this session I will land this topic for now thank you.