Mechanics of Sheet Metal Forming
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Week- 01
Lecture- 02
Tensile test, effect of properties, exercise problem

So, let us continue what we discussed in the previous class. So, so today we are going to discuss briefly about strain rate sensitivity. We are going to continue you know this important property which we can evaluate from tensile test of a sheet. So, strain rate sensitivity as the name suggests this parameter is going to tell we tell us about the how sensitive as a materials deformation or flow stress with respect to the strain rate. So, generally you know that you know the rate as it is you know said in this term. So, the strain rate means it is defined with respect to some time is not it.

So, now this strain rate can also be related to cross head speed ok. So, strain rate is generally given by $\frac{v}{L}$ ok and this is true strain rate $\dot{\varepsilon}$ ok. So, $\dot{\varepsilon}$ is nothing but v, v is nothing but your cross at speed you can see here, v is nothing but the cross at speed, the speed at which you deform the material ok and L is nothing but your, you know the instantaneous gauge length because this is a true quantity you are going to have instantaneous gauge length ok. So, v you can say for example, $\frac{mm/s}{mm}$.

So, unit is of strain rate is nothing but s^{-1} ok. So, strain rate is defined by $\frac{v}{L}$ ok. So, where v is nothing but your cross head speed and L is nothing but instantaneous gauge length ok. So, now how sensitive is your flow stress or deformation ok with respect to change in strain rate is what will be quantified by strain rate sensitivity. But generally you will see that at room temperature it is generally said ok at room temperature material will not vary in its properties with change in speed ok or strain rate at which test are performed ok generally.

But suppose for example, you have a stress strain behaviour like this ok and you are starting your deformation of course from 0 strain and then you are deforming it I just drawn it in the plastically deforming zone you will see that you are deforming it in one particular strain rate $\dot{\varepsilon_1}$ ok. So, here we are saying $\dot{\varepsilon}$ now. So, here it is $\dot{\varepsilon_1}$ dot you are deforming it in one particular strain rate and you are suddenly changing the cross head speed. Let us say for example, you are changing the velocity by 10 times ok. So, accordingly there will be some change in the strain rate ok and you are continuing your deformation like this and let us say for example, you are coming back to your original strain rate and you are completing your test ok.

So, basically there is a jump in the cross head speed v ok or equivalently you can say that if v is changing $\dot{\varepsilon}$ may also change. So, you are taking the strain rate from $\dot{\varepsilon_1}$ to $\dot{\varepsilon_2}$ ok and there will be a corresponding change in σ_1 and σ_2 generally flow stress changes like this ok. When you strain rate when you change it from $\dot{\varepsilon_1}$ to $\dot{\varepsilon_2}$, σ_1 or flow stress is changing from σ_1 to σ_2 ok. So, this is going to be the effect ok. So, suppose if you want to capture this effect ok then you have to slightly modify the flow stress model which was initially $\sigma = K\varepsilon^n$.

Now I am going to include one more part $\dot{\varepsilon}^m$ ok, $\dot{\varepsilon}^m$ ok and this exponent is very important which is going to tell you the effect of your strain rate and it is called strain rate sensitivity index ok. Like you have σ which is nothing but flow stress and or true stress and ε is true strain which you have seen in yesterday's class K strength coefficient n strain on exponent we know that. Now we are going to add include this one more part $\dot{\varepsilon}^m$ ok where m is going to tell you m is actually called as strain rate sensitivity index m ok. So, how do you calculate this m which is going to tell you what is the effect ok which is what is given in this diagram of course this diagram already explained you. If you change the strain rate from $\dot{\varepsilon_1}$ to $\dot{\varepsilon_2}$ then there will be a slight change in flow stress from σ_1 to σ_2 and m can be calculated using this equation ok you can say $m = \frac{\log\left(\frac{\sigma_2}{\sigma_1}\right)}{log\left(\frac{\dot{\varepsilon_2}}{\dot{\varepsilon_1}}\right)}$ ok.

So, where σ_2, σ_1 and $\dot{\varepsilon_2}$ and $\dot{\varepsilon_1}$ are the corresponding change in strain rates and flow stress. So, this like *n*, *m* also affects the forming behaviour ok. So which we will see in next few slides. So, now I am moving to effect of this properties ok. So, for last you know couple of slides we are seeing you know how to calculate the load displacement graph ok.

We start with load displacement graph then we have engineering stress engineering strain graph when σ versus ε graph ok. So, from this we can get several properties for example your yield stress, UTS, uniform elongation ok total elongation then n value K value. In the last slide we have discussed how to calculate m. So, all these things can be calculated but what are this effect. Other than that you have plastic strain ratio which is going to quantify the anisotropy of sheets and this plastic strain ratio we said can be represented as $\bar{R}$ and ΔR .

So, what is the effect of all this parameters which we are going to see in next couple of slides in a very brief manner and in other than this slide in other part of the course also you will see the effect in a different manner. So, strain hardening if you see ok. So, this is actually a critical factor during plastic deformation ok. Is not it because only because of strain hardening you will see there is a jump in flow stress from between yield strength to UTS ok. And in a way your strain hardening exponent *n* is going to quantify how hardening the material is going to be ok.

So, it is generally understood that higher the strain hardening of the sheet better will perform in process with significant stretching ok. Wherever you have stretching ok there you need to have sufficient strain hardening in the material so that stretching can happen in a very successful manner ok. So, suppose for example you pick up n what is the effect of *n* ok. We will see the effect of *n* in due course in other chapters also but you will see that the effect of *n* if you want you can directly discuss you know connected to you can say strain distribution ok. Strain distribution means what we will elaborately study this in next couple of slides.

Strain distribution means what suppose you deform a material ok deform a sheet ok like I have deformed a sheet like this ok. So, I am going to calculate strains at each location in the deforming zone and in the undeformed zone. Of course in the undeformed zone there will be not much of strain distribution but from this portion to this portion there will be strain distribution right. So, what is strain distribution how to calculate we will see in due course but it is generally understood that there will be some strain distribution here ok. That means your strain is going to get distributed in a uniform and in non uniform way depending on how much displacement you have given here ok.

So, as long as the strain is uniformly distributed ok so you will see that the material will not undergo tearing or necking and *n* is going to be helpful for that ok and *n* is going to be helpful for that. So, the larger the *n* ok let us say for example you have material with 0.3 *n* ok 0.3 *n* value there is another material you have 0.2 *n* value and this 0.3 *n* value this material is generally preferred from formability point of view why because you may have uniform strain distribution from this point to this point for higher *n* value which also means that you can delay instability or necking ok.

So, now if you want to look into effect of σ_{ys} that is yield strength ok generally it will not affect the deformation behave directly except that the sheet is difficult to deform ok depending on you know what yield strength you have. So larger the yield strength it is going to be little bit difficult to push it plastic deformation ok and your total elongation E_{Total} or ε_t ok and uniform elongation let us say ε_u ok. I think you also know the fact that this uniform elongation is generally related to let us say for example I am just drawing here ok. So, you have σ versus ε graph ok you have like this so ε_u is related to this and ε_t is related to this particular point ok.

So, when ε_u is large let us say yield strength is here ok ε_u is large and ε_t is also large means ok you have you know greater strain hardening ability to that material that is one way can be connected and this ε_u $\varepsilon_t$can also be connected to *n* that you will study in due course ok. So, you may say that your *n* value is larger ε_u ok where your UTS is reach or instability is going to start that will also be little large ok so that your necking is actually delayed ok. So, your then comes your elastic modulus so Young's modulus it can also impact the performance mainly greater the modulus it is little stiffer to deform the component ok which is usually you know advantageous and this modulus will also affect spring back that I was discussing with you yesterday ok. So, that modulus will influence the spring back when forming spring back I think you understand ok there will be recovery of some dimensions once you remove the load that is because of some elastic properties one important property is your Young's modulus it is generally understood that a lower Young's modulus results in bigger spring back and in general it is going to create more trouble in controlling the dimensions ok. So, you have to be little bit careful with respect to the modulus of the material in this way ok.

So, while choosing the materials sheet materials one has to look for all these properties ok. So, what *n* value is going to have σ_{ys} how is it ok then this *n* can also be connected to uniform elongation and total elongation ok and then your other one comes your *E* ok Young's modulus ok all these parameters are connected to the selection of material for particular application. So, now comes the anisotropy ok in the previous section we have discussed how to quantify anisotropy say for example, you take a sheet any aluminum or steel sheet and assume that this is the rolling direction of the sheet I am just drawing RD ok and what you do you take a rectangular strip like the way I described in yesterday's class and by known procedure you can get a plastic strain ratio what is plastic strain ratio it is true with strain divided by true thickness strain. So, that you can calculate it in this direction. So, it is going to be R_0 , R_0 means the direction coincides with rolling direction.

So, I am putting 0 for that. So, you take the same rectangular sample, rectangular sample what I mean is this value rectangular sample means this particular you know sample I am referring to right. So, this sample you are deforming it and you are calculating the R value as I discussed yesterday. So, this is R_{90} going to be and at any other angle you can pick up 45 degree and this is also 45 degree you will get R_{45} 2 times this is 1 R_{45} this is another R_{45} you can get and from R you can get $\bar{R}$ ok by using R_0 R_{45} R_{90} ok. So, $\bar{R}$ you know that it is nothing, but $\frac{R_0+2\,R_{45}+R_{90}}{4}$ we said yesterday's class and ΔR is $\frac{R_0+R_{90}-2\,R_{45}}{2}$ we said ok. So, this also tells that this is like an average quantity you can imagine and I also told you that this equation you can use only if we have 3 rolling direction 0, 45, 90 ok. And ΔR is nothing, but how different it is the average of R_0 and R_{90} with respect to R_{45} So, $\frac{R_0+R_{90}}{2} - R_{45}$ you can say. So, how different is this with respect to R_{45} in a plane ok.

On the sheet how different is R_0 R_{90} with respect to R_{45} that will give you ΔR. So, this is we say average plastic strain ratio and this is going to be your you know your planar anisotropy ok. So, now what are these effects? I think you understand now what is ε_w , what is ε_t in the previous you know section we have described how to calculate it ok. If ΔR is large ok either positive or negative in circular parts asymmetric formation and earring will be noticed ok. So, earring is actually a defect, earring is actually a defect ok.

So, you can look into you know different resources you will see that when a cup is formed you will have this kind of waviness, you will have this kind of waviness at the edges. Let us say this is the cup edge, this is a circular cup you are made by deep drawing ok. This is a circular cup you are made by deep drawing ok. And you will see that this kind of waviness are seen at the edges this is actually called as a earring problem ok. So, this earring happens mainly because of ΔR ok.

So, that means as long as there is going to be less difference between your R_0 R_{90} with respect to R_{45} then ok your earring will be minimized, your earring will be minimized ok. You have to be little bit careful with this ok. So, ΔR is connected to earring. So, a lower ΔR earring can be minimized. This irregular forming know so here it is drawn less, here it is drawn more that is the meaning right.

So, if you pick up this line here it is drawn less the height is more and here the height is less right. That is why you are getting this waviness and that is because of the variation between this quantity and this quantity. Now, when it comes to $\bar{R}$ ok. So, $\bar{R}$ is connected to this R individual R values right. So, now a simple analysis will be helpful.

So, nothing but by *t*. Suppose I am taking $R > 1$ ok. Let us say $R = 2$ ok. So, $\varepsilon_w = \varepsilon_t$. That means what? That means you are giving deformation to the sheet and you are getting one thickness strain at a particular location and width strain you will see it is twice that of your thickness strain which means the thickness strain is smaller as compared to width strain which also means that this implies that better strength in the thickness direction. That is why it is strained less as compared to width ok which also means that it has got good resistance to thinning ok.

So, greater than unity it means that greater than 1 unity it means that thickness strain was greater than the width strain. This may imply that it has got better strength in the thickness direction which also means that it has got good resistance to thinning ok. Suppose if you take $R < 1$ ok which also means that $\varepsilon_w = 0.5\,\varepsilon_t$ ok.

It is just opposite to that ok. You will see that the thickness strain is going to be larger as compared to width strain which also if you compare it with this then this material is going to have less resistance to thinning as compared to this ok. So, here in this case your thickness strain is going to be larger which means that in the thickness direction the strength is larger ok which also indicates that it is not so easy to make the material to thin down ok because it has got good strength ok the opposing effect is there in the thickness direction ok. So, which also means that a higher value makes it possible to draw deeper parts when drawing deeper parts ok. Suppose if you want to draw deeper parts then higher value of $\bar{R}$ ok either $\bar{R}$ or R ok we take a cumulative value that is average value $\bar{R}$ which should be larger ok. So, $\bar{R}$ has to be larger why because you have good resistance to thinning and ΔR has to be lower why because it has to you have to avoid this earring problem ok.

So, now surface effects these are all certain other parameters which will have some effect for instance sheet surface roughness ok. So, that will have interaction with you know lubricants you know your you know your tooling you know it will have some impact on the performance, but it is very localized so one has to look into it ok. So, but this cannot be quantified by tensile test ok. So, that is not possible, but it has to be taken as a separate quantity ok one has to really look into it when you have what is the you know the sheet rough roughness at that time like that, but generally the sheet roughness when you compare to sheet thickness is going to be very very small ok. We speak sheet thickness of the order of 2 mm roughness generally is of the order of you know microns like that.

So, its effect is generally not much. Homogeneity generally it means for example, you take thickness ok suppose you take 2 mm thick sheet you measure at 100 different locations it may not have same thickness at all the locations so that may have some effect ok. Similarly a composition can slightly change here and there suppose you are taking tensile test sample and we expect that the gauge length let us say we say it as l_0 we should have uniform width, but it may not be ok it may not be. So, that can create some you know heterogeneity in the material that will also affect the formability. Strain rate sensitivity or strain rate sensitivity index we connected it to m is not it.

So, m is also very important for you. So, this m is like m is m is like n ok. So, like larger n is good for us is not it that is what I told in the previous slide larger n is good because the strain distribution is going to be uniform in the sheet and hence you can delay necking. Similarly m also plays a bigger role in affecting the ductility ok. Positive rate sensitivity typically enhances forming and produces a result that is comparable to strain hardening this is what I was telling you and you will see that this m is going to be is going to affect mainly the post necking behavior that is what is generally said. This *n* is going to affect the strain hardening behavior ok, but this *m* is going to affect the post necking behavior.

Post necking behavior means between ε_u and ε_t ok. This $\varepsilon_u - \varepsilon_t$ increases with the strain rate sensitivity ok. What does it mean? It means that suppose if you pick up a strain behavior where we have seen that somewhere here right. Yes, suppose you take this particular you know engineering strain curve for example, what I am saying ok this range $\varepsilon_u - \varepsilon_t$ this is actually controlled by *m*. This is actually controlled by *m* ok whereas before that in the strain hardening region *n* plays a vital role ok that is the meaning.

So *m* and *n* are generally of that nature ok. So larger *m* larger *n* would be better for you to you know have better formability. So ε_t it is you can say $\varepsilon_u - \varepsilon_t$ also increases ok with rate sensitivity or sensitivity index that is *m* which is actually good for us. Before reaching ε_u in the strain hardening region *n* plays a role. Just after that ε_u before ε_t post necking behavior ok *m* plays a role that is the meaning. In fact you know there are materials called super plastic materials which follows a phenomenon called super plasticity ok for those materials if you see m is going to be very very encouraging ok and that there are lot of details one should go into it and it may have the acuity of the order of let us say 500,000 percentage also if *m* is larger ok.

So we will stop with this and then now slowly we will do some problems but quickly I will open it ok so that we can complete this chapter and go to next one ok. So the first part which I was discussing is on introduction right so that will not have any problem. Now the second part where we have seen tensile you know tension test tensile properties how to evaluate. There are couple of problems I could bring here. So you get these are all simple problem which will make you to understand this.

Now let us take first problem Q1 ok. So Q1 if you pick up so you will see that a tensile sample ok is cut from a sheet of steel of 1 mm thickness right from a sheet of 1 mm thickness and the sample has got initial width of 12.5 mm and gauge length of 50 mm right. So you pick up a tensile sample I just drawing the gauge length only this gauge length they say it has how much 50 mm ok and you will see that this width has 12.5 mm and it has got a thickness of 1 mm let us say from the side view it is 1 mm ok.

So a sheet you can you can say like this. This is a gauge region only know so I am just picking up like this. So now the initial yield load is 2.89 kilo Newton P_y is given and extension at this point is so small ok 0.0563 mm. So you can imagine that in a stress strain curve this extension 0.0563 you may reach a yield load. So this is a point to be noted how small the dimension the extension is going to be to get the yield load. Determine the initial yield stress and you need to get E ok that is your elastic modulus. So how is how is going to be the first part? Initial yield stress is pretty straight forward is not it? It is nothing but $\frac{P_y}{A_0}$ which you already discussed $\frac{P_y}{A_0}$ right. So P_y is a yield load and A_0 is the initial area of cross section. So you can directly use initial area of cross section from this dimensions.

So P_y is already given 2.89 kilo Newton divided by A_0. A_0 is what A_0 this fellow is 12.5 and your thickness is let us say 1 mm.

So 12.5 into 1 mm is 12.5 millimeter square. So and you can calculate it I just calculated it seems to be correct so 231.2 MPa. So you have to be careful with the units. This is a kilo Newton per mm square is not it? So accordingly you need to have units here.

So 231.2 MPa. So it is very simple to calculate it. So now if you want to go for elastic modulus E ok. So this elastic modulus E if you want to zoom it let us say in general stress strain behavior if you want to zoom it you can go like this a little bit of I am writing. This is your $\left(\sigma_f\right)_0$ which is what is given here right. So now you need to get elastic modulus which is nothing but the slope of this part, the slope of the initial part right. So I can directly write $\left(\sigma_f\right)_0$ divided by the corresponding strain.

Corresponding strain is what is e_y or ε_y you can say ok. So now σ_f is known to me that is nothing but my 231.2 and what is e_y? e_y is not known to me ok because e_y is nothing but the X axis which is nothing but your strain. So if you want to calculate strain you can go back to original definition which is nothing but $\frac{\Delta l}{l_0}$, $\frac{\Delta l}{l_0}$ that we have seen in the previous slide. So l_0 is 50 that is already given here. Δl you have to get and Δl is what is given as extension at this point is 0.0563 which you are substituting here and you will get such a small strain you can imagine that how small it is 0.00112 ok. By that strain but that time it actually crosses the yield point that is the meaning 0.00112. So that you substitute in the denominator and 231.2 divided by 0.00112 will give you Young's modulus generally it is represented in GPa, generally it is represented in GPa. So yield strength in MPa, strain you know that it has got no unit mm/mm and Young's modulus generally represented in GPa. It is 205.33 GPa ok and this is you can imagine that 205.33 is like for typical steel. Generally we use 210 GPa like that ok and you can see that it is also given in the question. This could be a real data which people might have evaluated. So one has to be careful in that also and we will get some idea of how the values. Now let us go to part b. Now part b is about calculating R value that is your plastic strain ratio which is going to quantify anisotropy of the sheet.

So when the extension is 15 percent they have already given extension is 15 percent, width of the test piece is 11.41 mm ok 11.41 mm ok you can say. So you have to determine the *R* value. So *R* value is known to you, so *R* value is nothing but $\frac{\varepsilon_w}{\varepsilon_t}$ that we already know which is what is I have given here $\frac{ln\left(\frac{w}{w_0}\right)}{ln\left(\frac{w_0 l_0}{wl}\right)}$ ok and this also we derived in the last class ok.

So this is nothing but $ln\left(\frac{t}{t_0}\right)$ and this $\left(\frac{t}{t_0}\right)$ can be connected to width and length instantaneous length and original you know dimensions in this way ok. So now it is all about substituting the values which is given in this particular problem. So now there is one point to it that your new width is already given the width of the test piece when the extension is 15 mm that means let us say for example you take this gauge length ok which is 50 mm ok and it is increased to one particular length which is going to give you 15 percent you know extension. At that time you will see that this width is something and this width is reduced is not it this width is reduced.

Let us say this is 12.5 it is given that has become this fellow has become 11.41 right but this fellow is not known to us this fellow is not known to us ok this dimension is not. But then strain is given you have to convert that ok. So that we will do it here ok.

So w is given 11.41 initial w naught is given that is 12.5 this already noted here $ln\, w_0$ you already know l_0 is gauge length 50 w is already known 11.41 and this fellow your l ok this l_0 know it has become l know this length you need to get this length you need to get. So for that you have got 15 percentage. So you have to see that 15 percentage means let us say $0.15 = \frac{\Delta l}{l_0} \times l$, l is 50 let us say it is going to be your probably 7.5 and you add it with 50 it is going to be 57.5 that is a new length that is a new length ok. So, new length l is nothing but $\Delta l + l_0$ know. So l_0 is 50 ok this Δl is what you will get it from the 15 percentage ok. So you need to get this for what new length you will get 15 percent strain that is the meaning.

So for what new length of this 50 you will get 15 percent strain that will be 57.5 you can calculate it and check it and if you substitute all these things and properly calculate you will get *R* value as 1.88 which means that actually this steel sheet is actually anisotropic in nature because it is not equal to 1 it is greater than 1 it is anisotropic in nature ok and it has got good resistance to thinning you can make deeper components with this ok. These are all some simple problem you can imagine and let us go to the next one ok which is also relatively easy for you when you do tensile test.

Let us say Q2, so what is the question at 4 percent and 8 percent elongation the loads on a tensile test piece of an aluminum alloy or 1.5 kilo Newton and 1.66 kilo Newton ok. So you take a stress strain behavior let us say σ_ε and I am just drawing typically like this ok. So at 4 percent elongation and at let us say 8 percent elongation very closer to that ok this is in percentage let us say elongation. The loads are given ok this fellow is going to be 1.59 ok anyway load is given I am just written it as stress but you will see 1.66. So you can take it as P ok take it as P and maybe is elongation is given now let it be strain no problem ok. So now what is the question dimensions are given the width of the you know sample is 10 mm thickness is 1.5 gauge length is 50. So you can always draw diagram like this ok and thickness is this this cross section.

So thickness is 1.4 mm and this fellow is going to be a 50 again gauge length is 50 and width is let us say initial width is let us say 10 mm thickness is 1.4. So what is the question you have to calculate K and n directly you have to get K and n. So how will you proceed actually? So let us go ahead with n ok how do you calculate n*?* So n as we discussed in the last class you will say that n is nothing but when you draw a graph between $ln\,\sigma$ and $ln\,\varepsilon$ ok. So you have a load displacement graph you have engineering stress strain graph and you have true stress strain graph and then engineering stress strain graph and then true stress strain graph from this you get $ln\,\sigma$ and $ln\,\varepsilon$.

So you can directly get this and then you can get this right and this generally you plot it in the strain handling zone that is what I was telling you. So you get a straight line slope of that is nothing but your n value that is what we discussed in the last class. If you remember it we derived this equation $ln\,\sigma = ln\,K + n\,ln\,\varepsilon$, is not it that is what we discussed right. So now so if you want to get the slope of this so you can write $ln(\sigma_A) - ln(\sigma_B)$ and the corresponding strains $ln(\varepsilon_A) - ln(\varepsilon_B)$ is not it. So there will be you take two Y coordinates and two X values and then you can get A and B point or this these two points A and B points are this point and this point the corresponding sigma values correct.

So this will give you my $\frac{ln(\sigma_A)-ln(\sigma_B)}{ln(\varepsilon_A)-ln(\varepsilon_B)}$. Now the question is how are you going to calculate σ_A , σ_B , ε_A , ε_B . So n is nothing but slope of a graph between $ln\,\sigma$ and $ln\,\varepsilon$ that is all we are saying and you pick up any two point you should be able to calculate n value accurately and that is what we are giving here the two points already given in the problem. So one is at 4 percent elongation other one is 8 percent elongation. So now how are you going to get σ_A , σ_B , ε_A , ε_B is the main question here.

So now σ_A let us directly go to the formula $\sigma_A = \frac{P_A}{A_0}\frac{l_A}{l_0}$. So basically $A_0 l_0 = l_A A_A$ ok. So instead of A_A I am putting $\frac{l_A}{A_0 l_0}$ correct. So now all are known to us we have to just calculate it ok.

P_A is already given to you which is nothing but 1.59 kilonewton and A_0 what is A_0 initial area of cross section is not it. So it will be 10 into 1.4 is not it so which means 14 right. So and l_0 is 15 fine.

Now 52 you get 52 you get because it is 4 percent elongation because it is 4 percent elongation. 4 percent elongation means what 50 has to become 52 to have 4 percent elongation ok. So then you can calculate it ok. So I hope it should be correct and accordingly you will get 118.11 MPa right. So now correspondingly you get a true strain at A point which is nothing but $ln\left(\frac{l_A}{l_0}\right)$ directly original definition of that is you can get.

What is l_A? l_A already calculated I think 52 divided by l_0 is 50 so you will get true strain as 0.0392 we can say 0.04 ok. Same calculation do it at 8 percent elongation ok. Load is going to be different initial dimension is going to be same 14 length is also same only thing is 8 percent strain ok 8 percent elongation so 50 will become 54 ok.

So that you can substitute here you will get of course a larger stress because of strain hardening. This is the meaning of strain hardening right when you move from point A to B you need larger load for deformation correct. So you need 1.66 here ok as compared to 1.59 here so there is an increment in load which is also reflected in σ, σ_A to σ_B which is nothing but because of strain hardening ok.

So, 128.06 you will get $\varepsilon_B = ln\left(\frac{l_B}{l_0}\right)$ so l_0 remains same only l_B is going to 54 so you will get naturally larger strain here ok it is 0.0769. So all are known to you ok so you can just substitute it here so what is n? n is nothing but the slope of logarithmic plot of σ versus ε. Slope is nothing but you pick up one point get this value which you already calculated and this point you already calculated correspondingly there is one point here already calculated correspondingly your one point here already calculated and you go and check it.

It is going to $\frac{ln(\sigma_A)-ln(\sigma_B)}{ln(\varepsilon_A)-ln(\varepsilon_B)}$ you will get n as 0.12 ok. So you can also understand the typical value of n ok so 0.12, 0.2, 0.25 you know the better the n value it is better for formability ok in due course you will understand that. And how do you calculate K? Ok so K this n and K actually you can calculate it better from a full stress strain behaviour. If you have full stress strain behaviour data given ok $ln\,\varepsilon$ this then between your yield strength to UTS equivalent of true stress you can calculate the slope ok and it will give you n and then your intercept ok will give you you know like here. So this point you can keep it as 0 so that your σ becomes K right so K can be obtained now but here you have got only two points ok. Here you have got only two points this is one way to calculate K but then one should not use this method of calculating K better to use it from the full stress strain data like we have described previously.

So this K is obtained from this equation only so the previous you know the part of you know this equation is $\sigma = K\varepsilon^n$ which we discussed in the previous class so $K = \frac{\sigma}{\varepsilon^n}$. So you pick up any one point A let us say $K = \frac{\sigma_A}{(\varepsilon_A)^n}$ is known to you $\frac{118.11}{(0.0392)^{0.12}}$ it will give you 174.2 mega Pascal it is near about 174 mega Pascal ok. But one should not use this equation so freely but because we do not have any data one can evaluate in this way ok.

So this is another easy problem one can think about and then this one problem it will take little you know longer to calculate but then you know one can do it and check this is you know typical test data they have given third problem ok. So you can see that the following data pairs one is load other one is extension right. So load extension or displacement you can say this is load this is extension you can say Δl ok this fellow will be in mm and this fellow they have given it in kilo Newton ok. I am trying write like this the data is given were obtained from plastic part of a load extension file for a tensile test on a extra deep drawing quality steel EDDQ it is called as EDDQ ok.

There is a steel like that with a particular carbon composition you can look into it and it has got a thickness of 0.8 mm and the initial test piece has got a width of 12.5 gauge length see this is standard dimensions everywhere we are using you know 50 is a gauge length that is what I was telling you before and 12.5 is the width of the gauge region and thickness can vary this is a standard dimension.

So this could be your load and this could be your extension right. So you start from 0.08 this is the load 0.76 this is the load 1.85 this is the load so it will keep on you know increasing in this way right. So all are given here.

So now the question is what they are asking is you have to get the you know this is continuing 2.9, 8.92 and 2.93, 11.06 ok. So it is continuing here ok and you can see 1.9, 1.85 it is increasing 2.57 2.92 2.93 ,2.94 9 this 2.92 this could be we have to check this ok anyway this is 2.x you can neglect this data point also you can directly 2 point ok fine fine it is decreasing 2.94 then 2.92 ok then you have 16.59 ok then 2.86 ok then 2,61, 2.18 you have 22.69 ok. So basically you have to get the engineering stress strain behaviour true stress strain behaviour then log stress log strain curves ok and from this you can get yield strength UTS true strain at maximum load and then your K and n ok this is a typical test data you have and from here you can get all the data ok. So we have just roughly calculated it ok. So what you need to do is basically you need to get engineering stress strain curve first ok I think if you know load extension data so then from here you can get engineering sorry S versus e ok.

Load divided by initial area of cross section from this initial area of cross section is known to you 0.8 into 12.5 you can put load is already given and your load versus engineering strain. Engineering strain you can keep in decimals which is nothing but $\frac{\Delta l}{l_0}$, Δl is already given and l_0 is 50. So you get engineering stress strain curve that is found out and from engineering stress strain curve you can get true stress strain curve or from that you can directly get this also ok because your P is known P is already given and then you need to get instantaneous area of cross section for that you can get $A_0 c = Al$. So $\frac{A_0 l_0}{l}$ will be your A right will be you're A. So that A this this this entire thing will give you your σ ok and here also your l is no l can be obtained from Δl because initial gauge length l_0 is known to you so you can get l so you can get A this can be obtained and this fellow ε is nothing but $ln\frac{l}{l_0}$.

So l_0 anyway you know here you can get here you can put 50 here and you can get ε ok so that will give you true stress strain data and true stress strain data directly you can get logarithmic of stress and strain curve it generally it is a straight line and from here you can get initial yield stress it is also given obtained from the plastic part of the load extension file which means that there is no elastic part. So which which is comfortable for this because the first data point itself can be assumed as your initial yield stress which is what is to some extent we have calculated here you can see this is engineering strain behavior ok. The first data point here and you know true stress strain behavior is also evaluated and slope is also evaluated here ok you can just check it ok. So your yield strength is how much is coming is 156 mega Pascal ok. So 156 mega Pascal is somewhere closer to here you know you can see this closer to this slightly less than 160 you have is not it so you have 156 mega Pascal.

Ultimate tensile strength that is your UTS so you can just check your engineering strain graph UTS means you have to go to engineering strain graph because that has got a maximum stress. So you can say that is about probably this could be somewhere here so you have to accurately get it once you draw this graph you will know so which is nothing but 294 true strain at maximum load ok. So what does it mean true strain at maximum load means what does it mean ok so like whatever maximum load that is UTS is reached corresponding to that you get engineering strain and convert that into true strain. So this is engineering strain ok the e you should convert that into engineering true strain nothing but $ln(1+e)$ like that you can convert that will give you true strain value ok.

Total elongation is about we say 45.4 % we are saying 45.4 you can say that yeah near about 45 you can see that total elongation is generally up to full fracture know so you can say about 0.45 is coming here so which is nothing but in percentage 45.4 ok. And K value and n value can be calculated like the way we discussed in the previous problem ok n value you know now ok. So n value can be calculated directly from the slope of the logarithmic plot which already drawn now which is for example is given here you can check it ok. So probably you need to leave this initial point because there are actually two slopes just be careful pick up a point where you have one slope and then get n value and from there onwards you can get K value ok you can just check it ok. So this is a long problem one has to actually use a graph paper and then you know excel sheet or something like that and then you can calculate it properly this will help you to do that ok. So these three problems will help you to understand what kind of calculations that we make for the second part of the first chapter that is your tensile test ok.

So with this we will stop this chapter we will start the next chapter in the next portion. So what you have done essentially in this is basically introducing the sheet forming process and then tension test which is a very basic test used for characterizing the sheet material properties mostly mechanical properties and those are required to give as input to your modeling ok. So in that way we know load displacement graph then engineering stress strain graph, two stress strain graph calculating all the properties including K and n and then m strain rate sensitivity index and then there is a separate you know section on calculating plastic strain ratio which quantifies an isotropy of the sheet ok some standard method of doing it and then in problem also we did some little you know calculation in one of the problem to how to get R value. And then finally a small part is discussed in you know how n, yield strength, your elongation R value, m then surface roughness then let us say homogeneity ok and then you know these are some important quality of a sheet that is going to affect the forming behavior. So how it can affect elastic modulus that also we have seen ok. So it is better to have larger n and m to have better formability generally and $\bar{R}$ is better, larger is better because you have large resistance to thinning and you can make deeper components, ΔR should be small to avoid earing problem ok and then m it is better to have larger m to have large ductility and then you know the surface roughness generally it plays a little role in evaluating the final components performance and then strength ok so that actually decides the stiffness of the component that is the only thing then elastic modulus is going to control the spring back of the sheet in one way it is going to affect the spring back of the sheet which also should be as minimum as spring back should be minimized and accordingly you have to choose the materials Young's modulus ok. So just to summarize this is what we have done and then we will move on to next chapter in the next class. Thank you.