Plastic Working of Metallic Materials
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Module No # 01
Lecture No # 06
Deformation zone + worked examples

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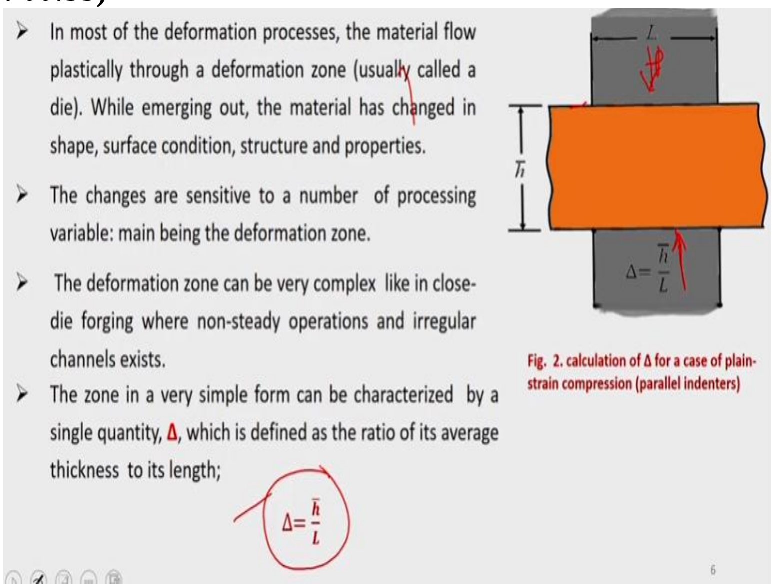

Now another important factor which one has to consider is the deformations zone geometry. And in most of the plastic working say materials cannot deform with the help of a die or a tool that is necessary because we have to apply some load into our work piece material so that it shape changes by plastic deformation. So there is a need for a die and between this die, inside this die the metal will be deforming.

So there is a deformation zone, which is going to come into picture okay, so the material flow physically through the deformation zone which is called as the die in this particular case a material is here and it is being compressed, maybe, I can apply like this here it is compressed between this thing. So typical case is the plain strain compression test between the parallel plates or intender what you call it as okay.

So that is typical case of if this is your load P. Now the thing is this is your billet so here this deformation shown, so when the shape is going to change. So when you are applying the force between the die the material will start deforming in this case may be material may be moving in this direction or in the subsequent slides you will see that how the metal deforms and other things. So while emerging out of the die, the material has changed its shape and it is surface condition as changed, maybe work hardening as taken place its structure, maybe different its properties will be different because of the work hardening behavior and depending upon the temperature the amount of strain the strain rate all those matters come.

So you will find that the materials has its properties also and shape also. The changes are sensitive to a number of processing variables and one the main one being the deformation inside that deformation zone how the shape as changed that is the most important thing which decides the properties of the material and the shape of the material. And you will find that in many of the cases the deformation zone can have a very complex shape like suppose if this is a case of the can so open die forging.

But if it is an impression die forging where the metal will be flowing confined to inside the die and it is no flowing out then based on the shape of the die the this deformation zone will be very complex, okay. The deformation itself will be very complex, so in such cases at some places you may find non study operation taking place and at some places irregular section thicknesses are coming so channels are coming.

So all these things brings into a very complicated shape impression die forging. But in a general way when you are telling say simple compressive forming. So something as to be there characterize this deformations on geometry. So in a complex shape it is very difficult but in a simple shape we can just characterize the deformation zone geometry maybe by a term which is called as a deformation zone geometry which is characterized, which is defined as the ratio of the average thickness to the its length okay.

So which is given by this delta which is equal to $\bar{h}$, where $\bar{h}$ is the average thickness maybe in this case it is constant but in some cases where there are different things you may have to consider the average thickness divided by the L which is the contact area length between the work piece and the die. One is the thickness of the work piece say, if it is a convergent zone, then you may have a you can get a very like you know extrusion of the wire drawing operation then you can find out the average of that.

And then the contact area between the work piece and the die so that is what is the length of the your this one. So this deformation zone geometry can be characterize by this Δ = h / L.

$$\Delta = \frac{\bar{h}}{L}$$

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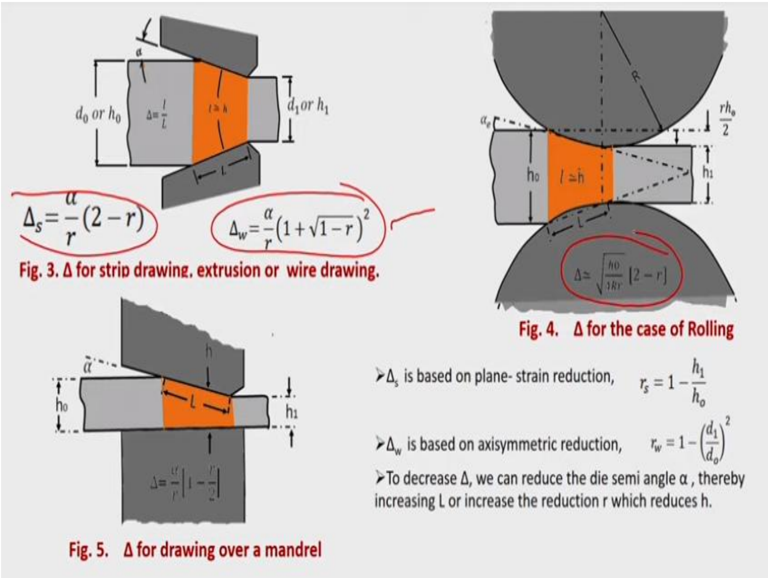

So if you look at different conditions, say for example, for a strip drawing operation where or extrusion or a wire drawing these are the typical case. So in this case you have a converging die in this case whether it is if it is drawing you are just pulling it together, if it is extrusion you are pushing through that okay. And if it is strip drawing also it is a strip plain strain drawing, you can say that and then you are doing.

So what is going to happen is that here the compressive stresses are there and this shaded region this yellow colored this shaded region is what you call it has a deformation zone. So beyond this region, it is not deforming and once it exit out of that it is not deforming but the metal in constrained to deform inside this material. So initial shape may be this when it comes out it is this size is may be here but in between, you see that material flowing in a convergent way and other thing.

So in this case you have this delta S is basically for plain stress reduction plain strain reduction case where rs, r refers to your reduction in the height okay which we have discussed earlier. So or it can also be written in terms of strain also. So you can get it by this shape, plain strain reduction but if it is a for axis symmetric reduction when you tell that, for example a cylindrical piece you are just excluding through a small size or a cylindrical piece you are drawing it to a wire form then you get this this particular relationship, so deformation zone is defined by this it is all geometry derived cases.

So there is nothing much in that, so under this cases you can get it and say may be, for drawing over a mandrill say may be tube drawing when you wanted to do that or drawing over a mandrill so then this is the deformation length and this is the $h_0$and h1, the average height you can just find out from this converging area so in the deformation zone this shaded area is again the deformation zone.

So you can always show it has $\Delta = \frac{\alpha}{r}$, where r is the reduction into $1 - r\ /\ 2$, so α is a semi die angle of this okay. So here also you will also find that α is semi die angle. 2 α is your basically this included angle okay. So half of that will be your semi die angle and similarly for the case of rolling operation, say from h_0 to h1 when you are doing it with a radius of r, the you can derive that say if you take the average thickness of the material and the length L.

So base from that if you just do that you derive at this relationship okay, Δ is equal to root of h_0 / $4rr$ where R is the radius of the role and r is the reduction which you are going to get into $2 - r$, so that is you are getting for this. So to decrease, from all these things when you look at it to decrease the Δ, we can reduce die semi angle α in this cases, thereby increasing the length so when you are decreasing the Δ value you are increasing the length or increase the reduction r which reduces the h.

$$\Delta_s = \frac{\alpha}{r}(2 - r)$$

$$\Delta_w = \frac{\alpha}{r}\left(1 + \sqrt{1 - r}\right)^2$$

$$\Delta \cong \sqrt{\frac{h_0}{4Rr}}[2 - r]$$

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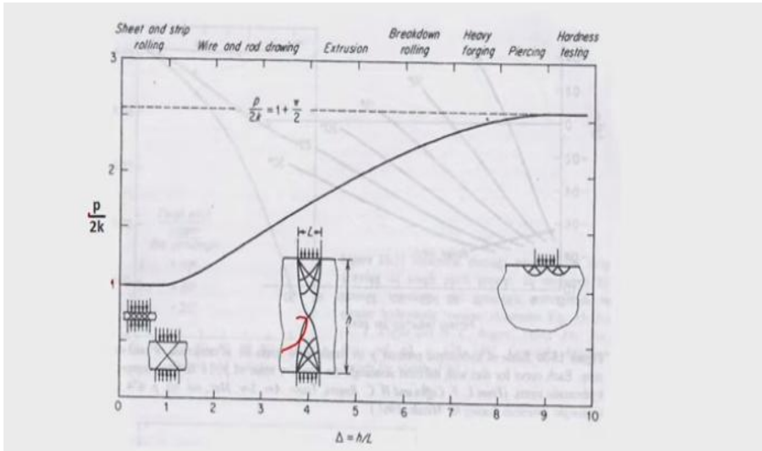

Fig 6. Dependence of yield pressure on deformation-zone geometry for frictionless plane rain deformation of a rigid plastic materials

Figure; Courtesy: W.A. Backofen, "deformation processing". Metallurgical transactions, (4), 1973, pp: 2679-2699.

So that is the thing. Now what is the importance, this is from the textbook, I have just scanned it and taken it. So the dependence of yield pressure on the deformation zone geometries depending upon the type of metal working, you say that for sheet and strip rolling, your delta is very small okay. So you have the $p\ /\ 2k$ where p is your normal load and K is your shear load. So external load which you have to apply is very low in this case so may be up to the delta value of 1 or 1.5 it is very low value you will find $p/2\ p$ is equal to almost equal to $2k$ so that is what.

But when you increase this delta value, where by which either h is increase or reducing the length whatever it be, by changing the angle or maybe if it is rolling by changing the roll diameter and other things you can increase this. So in this case say from sheet and strip rolling to wire and road drawing, when it increase may be at this range you will find that it is increasing wire and road drawing the $p/2k$ it is increasing, maybe from 1 to 2 and for extrusion it is still increasing and say break down rolling and other thing it is higher.

And when you go for heavy forging the $p/2k$ around 2.5, 2.6 it is coming, it is increasing and hardness testing it is typical case where it comes you know it an indentation on the surface also while you are indenting the surface. In that case so you can see that, typical case so $p/2k$ becomes much higher so your external load pressure which you have to apply is going to be very high higher than that you shear yield strength of the material.

So that is the thing, so depending upon this when delta value is high, then you will find that your pressure the which you are going to apply is going to be very high okay. And for delta which is you know so vice versa that is what is going to happen so that is the basic application of this.

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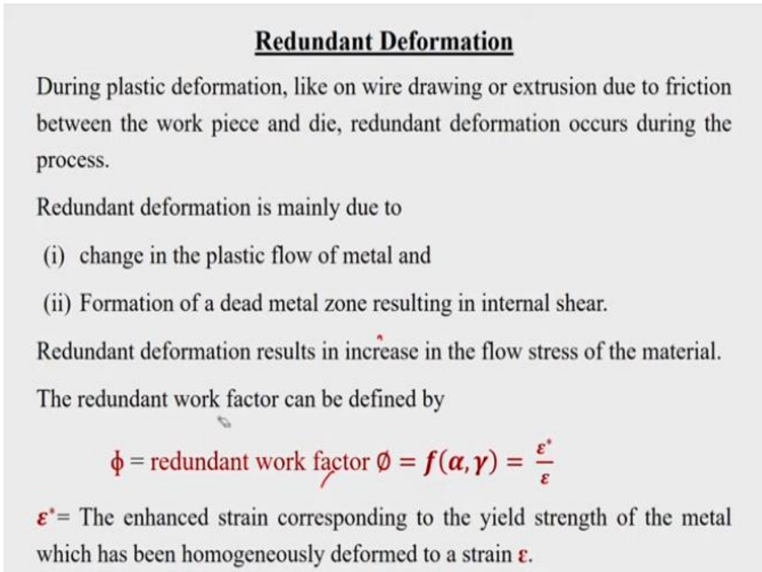

Now another factor which you have to consider, other than this friction or deformation on geometry are, is the redundant deformation say for typical example when you are finding out that the material is flowing plastically inside a die, inside the deformation zone. For example, if I just take let me just see that okay, this is a extrusion line or it can be a wire drawing also it depends upon that.

So initial metal, you see that metal flow how it flow will be, it will be like this. So you will find that in this case there is something called as the dead metal zone. Similarly here also, where the metal will not be deforming because of the geometry and the friction which comes you will find that, this is the dead metal zone which it is not going to deform but the metal flow direction, you see that okay it is in that direction it is flowing like this.

So here when the metal is moving in this maybe let it be extrusion or it may be drawing. So when the metal is moving, it generates into deformation zone and then there is a change in the direction of the metal flow okay. And when it comes to that it will come here, so here, since this is the region where metal is not going to deform it is called as the dead metal zone. Here at this region, there is a type of internal shear which is taking place in the material itself, will have to shear and go.

So this that is a some sort of deformation redundant deformation. So metal changes its direction there is an internal shear, all this comes together and then you call it as redundant deformation. So redundant deformation many cases it is very difficult to avoid because specially with wire drawing or extrusion and other things, it has to be there and to some extent redundant deformation will be there and rolled operation also many of the cases you will find there.

So it is mainly due to plastic flow of the metal and this, because of the redundant deformation the flow stress of the material will be increased. So due to what which what happens is that you will have to apply higher load for the deformation to continue with it. So that means okay your energy which has to be given will have to be very high and so one way of characterizing this redundant deformation is basically by calculating the redundant work factor which can be defined by φ say function of your die angle and your reduction it is not gamma it is reduction okay.

$$\varphi = f(\alpha, \gamma) = \frac{\varepsilon *}{\varepsilon}$$

So that is what comes and then this will be given by this redundant work factor is given by ε star by ε which we clear from this figure, what is it.

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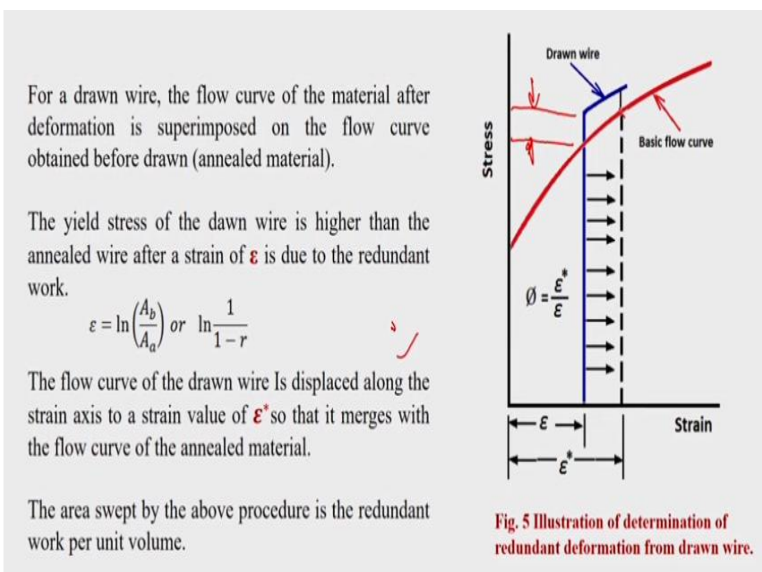

So this red line indicates the flow curve of fully annealed material, fully annealed material of the flow curve is like this and now the same material you take it, you subject it to some deformation, maybe ε a strain of this one you can write it in terms of reduction also to some value of ε you strain it inside the die. Say if it is a drawing operation, you draw it up to certain reduction, so that it is cross sectional area is reduced or if it is an extrusion also you extrude it so that the required reduction is obtained.

So that strain which is taken place, suppose if it is ε you take the drawn wire or extruded wire and find out a, do a tensile test, then you will find that instead of being deformation from here you will find the flow stress as increased by some value which is equal to this. So there is an increase here flow stress so and then you will that as if it is moving along the slide so that is the difference in that so may be due to the internal this one some extra energy has been carried out so this is the strength.

So how to find out this ε star, okay. So there is the reduction is given by the cross sectional or by reduction, we can find out the strain okay. If you find out the there is difference in that your yield strength of the drawn wire as higher, when you are given a strain by this method then the way how to calculate the redundant work factor is you just shift this blue line drawn wire stress strain curve towards the right.

So that this part will coincide with your basic flow curve. So how much it has been translated okay, so how much displacement has taken place that is that we can get it by ε star by ε so that is the thing. So let it matches with that so due to that internal shear and the redundant of work this is the energy for this is total redundant work which have taken. So redundant work function we can define by the previous relationship which is nothing but is equal to ε star / . So now you can get it.

You just slide it and wherever it is matching so you find out the ε star and then you can find out, the area under this will be the total energy redundant work which has been carried out. So area swept by the above procedure is the redundant work per unit volume which you are going to get.
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Experiment Technique for Metal Working Process

Experimental studies in metal forming is carried out by measuring forming loads and deformations.

- Measurement of forces can be carried out using load cells.
- Measurement ram displacement, velocity and accelerations are measured using transducers.
- Some cases, high speed photography is also used for measuring displacement at the surfaces.

However, Measurement of strain during deformation is very complicated.

Now we are coming to this introductory part, so before going that what are the experimental technic for metalworking process. So as I said, metal working is a vast area, you have say rolling, you have drawing, you have forging and axis symmetric or symmetric drawing, whatever it b,e you have all those axis symmetric cases also will be there, which are not axis symmetric curve are also there.

So sheet metal work is there, all those comes into picture in that many times, you wanted to know say most of the case you should know that what is the strain up to which you can deform, so that the material is not failing that is one important thing. Now what is the easiest way for the metal to deform, what are the condition these are the things one has to look for that. But when you are conducting some experimental, experiments. The experimental studies is generally carried out by measuring the load necessary for the deformation and the amount of deformation which has taken place.

So one is load and another is the deformation or strain which has taken place. Many times these are not uniform throughout, specially for a shaped component when you are making these strains are not uniform may be the total load you can find out, if you are connecting a load cell to that the ram, displacing ram if you connect it then you can find out the load which is coming but load at any instant of at a particular place, may be very difficult to find out.

Similarly then problem is that, measurement of displacement, velocity and acceleration. You know may be, displacement is the most, velocity and acceleration is not important but by transducers, you know you may measure these things and get back the measurement of displacement that will also is possible. But in a metal which is taking place the deformation, may not be uniform in many of the case axis symmetric cases are different but in other case where you wanted a shaped component like a impression die forging.

For a sheet metal operation which is taking place, in such case, the strains will be different in different region and the region where the strain is going to be the highest is the part, which is going to fail first. So these things, you should know. Now not only strain, what are the type of, say may be tri axil state of stresses also comes and straining also may take so these things as to be very carefully look into that.

So in that case, how to find out what is the strain which is taking place at a particular spot, you have to measure it. In sheet metal operation it is difficult but inside the material what is happening it becomes very difficult. So sometimes, you know you may, use high speed photography but from that at the surface the deformation, we can study that is what. But measurement during the deformation which is happening inside the material, which is very difficult but still people carry out experiments.

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a) **Metallographic technique**

In this the microstructure of the heavily deformed grains wee grains have been distorted during the deformation and this is compared with the unreformed grains. Generally this is carried out in using an optical microscope.

Recent developments are by investigating the preferred orientation of the grains after deformation. This is compared with that of the undeformed material.

One is by metallographic technique, you deform the material under whatever conditions are there and take the section, polish it, look under the microscope, etch it properly, look under the microscope and then the microstructure before the deformation, you study it and the microstructure after the deformation, you study it, so that how the individual grains where distorted, may be after giving some amount of reduction or some amount of strain how the individual grains deform you have to study.

But on an average level only you will get it individual one grain as such, you may not be able to because grains are not oriented in a particular way that is another difference. So these are this type things are done in an optical microscope but you get similar good result, but it is time consuming. And another is by with different x ray technique or now a days, you know selective area diffraction pattern and other thing EBSB.

So ES by EBSB you know you can always study the preferred orientation of the grains before deformation and after deformation you get orient. As I mention earlier the preferred orientation is that when you are passing plastically deforming certain crystallographic planes, will get aligned along the some particular direction at all the individual grain that is what is called as the preferred orientation.

So that the advance technique are there by which, we can study that before and after the deformation and then after the deformation is compared with the undeformed material and the orientation and other things that is one way of doing it, okay.

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Grid network

- In sheet metal forming, a square or circular grid networks are obtained on the surface by either electrolytic etching or chemical etching. The photograph of the undeformed sheet as well as the deformed sheets are compared. By this technique, the strains at most of the regions on the sheet an be determined.
- In case of strains or metal flow at interior of the bulk material is required, the specimen is sliced in to two. A grid network is affixed to the two faces. They ae then fastened back together, machined to symmetrical shapes and then deformed. After deformation, the pieces and split open and the grid distortion is investigated.
- In some cases grid network using lead is made and after deformation, the parts are radiographs to reveal the distortion of the Lead network.
- Use of model material like plasticine or synthetic clays.

Now but extensively used one is the grid network and grid network technique is used very successfully for studying the strain at each and every region in that domain of deformation zone, is basically for sheet metal operation. So that way it is very useful, you make a grid network maybe square or circle or by etching electrolytic etching or chemical etching on the surface, very thin layer you do it with a circle.

If you just circle it much easier and when you are deforming it, the deformation around certain the circle circles will change into the shape of an ellipse. So you can measure the minor axis and major axis of the ellipse and then find out along this direction ε 1 and ε 2 these are the strain which are taking place and what is the critical strain before failure, that also you can study.

So that has been sheet metal working, it has been very big success, so specially know if you are just trying to find out in a car body how to deform it. You know you can study that at which area the maximum strain is taking place and which area is will be more prone to failure. So that studies can be carried out by grid network in, for sheet metal operation but in bulk material also like if you wanted to know how the material is flowing inside a converging die, maybe like an extrusion or a wire drawing operation then this axis symmetric cases becomes much easier, a cylindrical piece we just section it into half then affix to what is that a grid network into that.

And then join together and again put it inside this the die and then do that compression, so after the straining after the deformation you take it split open it and see how the grid as distorted from that you will have an idea about how the metal is getting strained or deform metal flow takes place you have an idea what is the extend of strain which is taking place that also you can have it.

Now certain cases are there, now you may drill small holes very fine holes through that millet itself and then fill it up with the led, okay and then after the so before that you just take an external radiograph and after that deformation, maybe after the cross sectional has changed that also you take the radiograph. So from that the lead is there you can get easily the radiograph which are there it will be just looking very dark and other thing.

So from that pattern you can have an idea about how the metal is deforming. So in all this grid network, it has become very successful now another case of study is say use of a model materials like plasticine or synthetic place, So this plasticize and other thing that advantage is that okay it is not very high strength but it is not very plastic. So you can just approximately bring the, say it will it will force similar to that a metal which is under the hot working condition where it is very highly plastic.

So in that case this plasticine, using of plasticine and other place you know has become where very successful, those where the earlier stages of resource and now like you have very advance technique and other things okay. But still, this technique are time taking and other thing for deformation processing.

So **so** far we have discussing about the deformation zone and this module 1 is getting over, so before we proceed to module 2 let us just try to solve some simple problems a work load problem so that, the students who are attending this lecture will have a feel for this so let us just start doing some work out examples okay examples let us work it out.

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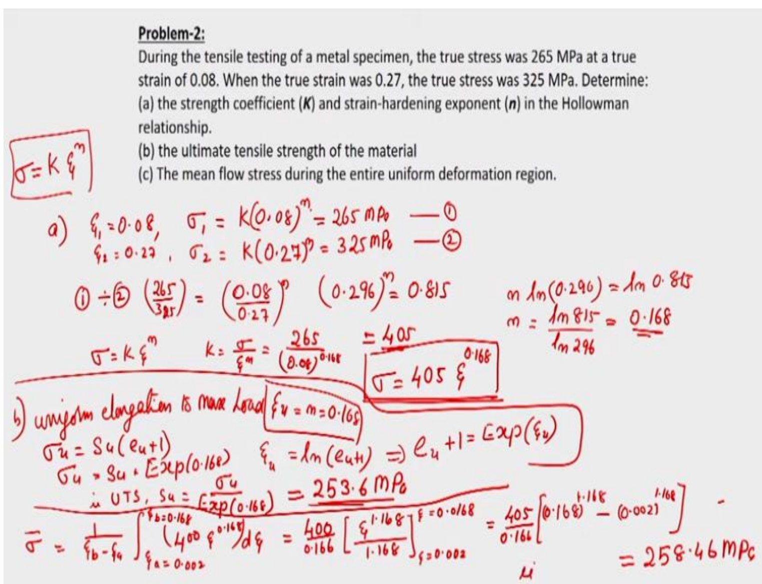

During the tensile testing of a metal specimen, that true stress was 265 mega Pascal at a true strain of 0.08. When the true strain was 0.27, the true stress was 327 mega Pascal determine the strength coefficient and strain hardening exponent in the hollowman relationship the ultimate tensile strength of the material and the mean flow stress during the entire. This is very simple the hollowman relationship is sigma = k epsilon raise to n this is the relationship now it is a two conditions are given at least.

Though you may have to take a lot of data point but from this data, if you assuming that logarithm of if you take that it is a straight line equation then, we can take this value. So first condition is, say let us try to solve a, so ε_1 = 0.08 then σ_1= k into 0.08 raise to n and ε_2 = 0.27 then σ_2 = sorry here k into this one k into 0.27 is the power n.

So if you just dividing each other, so from this relationship so here σ 1 = 265 mPa and here it is 325 mPa. So this is equation number 1 this is equation number 2, so 1 divided by 2 will be 265 /325 = 0.08 / 0.27 is the power n. So that is you will get 0.296 to the power n = 0.815 or if you take at n log 0.296 = log 0.815, so from that you know n = say we can get it has log 815 / log 296 you will get it as 0.168.

$$\sigma = k\varepsilon^n$$

$$\varepsilon_1 = 0.08, \sigma_1 = k(0.08)^n = 265mPa$$

$$\varepsilon_2 = 0.27, \sigma_2 = k(0.27)^n = 325mPa$$

$$1 \div 2 \quad \left(\frac{265}{325}\right) = \left(\frac{0.08}{0.27}\right)^n$$

$$(0.296)^n = 0.815$$

$$n \ln(0.296) = \ln 0.815$$

$$n = \frac{\ln 815}{\ln 296} = 0.168$$

So that means σ is equal to, if you substitute into any one of this equation so you can get it as k sorry if it is ε raise to n so $k = \sigma / \varepsilon$ raise to n. So that is equal to, if you take the first condition 265 / 0.0.8 to the power 0.168, so that is equal to 405 so our equation is σ= 405 into ε raise to 0.168, this is the hollowman relationship for this condition we are getting. Now the second case is the ultimate tensile strength of the material, that means you have to assume now up to the maximum load okay.

So that means uniform elongation to maximum load, ε_u = n = 0.168, this is the condition for tensile instability okay. So for the condition for tensile instability ε_u = n, that is what we have discussed. So in that you know you can find out what is the true stress, so now you can use that this is engineering true strain, you have come it so that means σ_u = S_u into e_u + 1, engineering strain + 1 that is what.

$$\varepsilon_u = m = 0.168$$
$$\sigma_u = S_u(e_u + 1)$$
$$\varepsilon_u = \ln(e_u + 1)$$

So now if you look at it that ε_u = log e_u+ 1 the true strain relationship ε = log e e+ 1 so for this condition for the ultimate tensile strength, so you are taking this particular case and this you know so from this you can find out what is your $e_u$okay, so that means e_u+ 1 = exponential of ε_u. So that means this will be Su into exponential of 0.168, so or that is of ultimate tensile strength S_u = σ_u / 168 so you will get it has 253.6 mega Pascal.

$$e_u + 1 = Exp(\varepsilon_u)$$
$$S_u = \frac{\sigma_u}{Exp(0.168)}$$
$$= 253.6\, mPa$$

Now the mean stress, mean flow stress this is very important because many of the metal working operation we have to calculate the mean flow stress. So mean flow stress is $\bar{\sigma}$ = 1 / ε – ε_a into integral form ε_a = 0.002 to ε_b = 0.168 into 400 ε raise to 0.168 d ε is what we have to do okay. So that we can write it has this comes to 0.166, so 400 / 166 where ε is this one, okay, into if you take the if you differentiate it 1. ε raise to 1.168 / 1.168 between say ε = 0.002 to ε = 0.168 okay.

$$\bar{\sigma} = \frac{1}{\varepsilon_b - \varepsilon_a}\int_{\varepsilon_a=0.002}^{\varepsilon_b=0.168}(400\ \varepsilon^{0.168})d\varepsilon = \frac{400}{0.166}\left[\frac{\varepsilon^{1.168}}{1.168}\right]$$
$$= \frac{405}{0.166}[(0.168)^{1.168} - (0.002)^{1.168}]$$
$$= 258.46\, mPa$$

So that is a coming to 405 / 0.166 into 0.168 raise to 1.168 – 0.002 to the power 1.168, so which we will be getting it as 258.46 mega Pascal okay so if it write it here if you do a simplification if you calculate it you will find it as 258.46 mega Pascal. So this is the average flow stress, so which is very convenient to determine the average flow stress, if you know the stress train relationship for flow curve relationship which is very easy to find out what is the strain you are giving for that you calculate the average flow stress and then multiply by the cross sectional area will give you a total stress.

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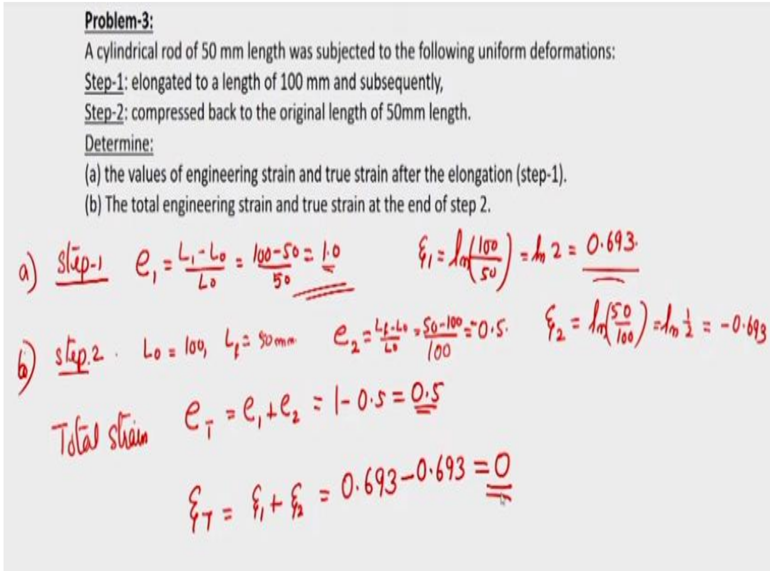

So next problem, let us see that it is a cylindrical rod of 50 mm length was subjected to the following uniform deformations, is just to have a an idea about how the true strain and engineering strain various and what its significant okay, what is the significance of engineering strain sorry true strain compared to the engineering strain. So cylindrical rod of 50 mm length was subjected to following uniform deformation. Step 1 it is elongated to length that means it has been elongated from 50 mm to 100 mm.

So double the length and step two is that after reaching that 100mm it is again compressed back to a 50mm length. So what is the determine the values of engineering strain and true strain after the elongation that is after step 1, so that is very simple your engineering strain that is step 1, so engineering strain e_1 = L_1 - L_0 / L_0 that is equal to 100 – 50 / 50 so it will come to 1, okay and if you look at epsilon 1 is equal to, that is log 100 / 50 okay so that will come to log 2 that is equal to 0.693.

$$Step\ 1 \qquad e_1 = \frac{L_1 - L_0}{L_0} = \frac{100 - 50}{50} = 1.0$$

So these are the two cases now let us take the case of step, problem 2 total engineering strain and true strain at the end of the step 1. So you are starting with the 50 mm you elongated to 100mm again you compressed back to 50mm, whether the total sum of this strains is the same that is what we wanted to find out. So let us say step 2, in step 2, that is compressed back so here step 2 L_0 = 100mm and L_1 is equal, let me say L_2 = or a L_f = 50mm.

So engineering strain, so maybe e_2 = L_f– L_0 so that is 50 – 100 / 50, you are getting as no divided by 100, 50 /100 that is 0.5, whereas the true strain epsilon 2 = log of 50 / 100 = log of 1 /2 which is equal to -0.693, now total strain e total = e + e_1 + e_2 = 1 + 0.5. so this should be minus, this is minus so 1 – 0.5 = 0.5 whereas ε total = $\varepsilon_1 + \varepsilon_2$so that is equal to 0.693 – 0.693 that is equal to 0.

$$Step\ 2 \quad L_0 = 100,\ L_1 = 50\ mm$$

$$e_2 = \frac{L_1 - L_0}{L_0} = \frac{50 - 100}{100} = -0.5$$

$$\varepsilon_2 = \ln\left(\frac{50}{100}\right) = \ln\frac{1}{2} = -0.693$$

$$e_T = e_1 + e_2 = 1 - 0.5 = 0.5$$

$$\varepsilon_T = \varepsilon_1 + \varepsilon_2 = 0.693 - 0.693 = 0$$

So from this you will find true things, one is if you look at the strain history the true strain when you are deforming the material from an initial length to a final length and then again bringing back to some of the initial length, the strain is considered to be 0. Because it is in the initial position itself of course these are under the assumption there is no barreling and other things okay. So here you are telling uniform deformation is there is no barreling.

That means the same condition is, there the strain is assumed to be 0 only thing is that we are not going to discuss about what are the things which are happening inside the micro structure. So mechanical factor if you look at, it if a country of mechanics point of you the strain is 0, true strain is 0 whereas if you look at the total strain from in engineering strain, so you will find that though it has reached the initial stage size it is true strain total strain is not 0 but it there is given be as some value so that is the thing.

So engineering strain, the total strain is not equal to sum of the incremental strains. I wanted to bring it back that is why this problem was taken. Whereas in true strain the total strain is the sum of incremental strain, this will be useful when you go for say the plastic deformation and other thing are know you need a precise strain history. So that for that taking the true strain will be of much use.

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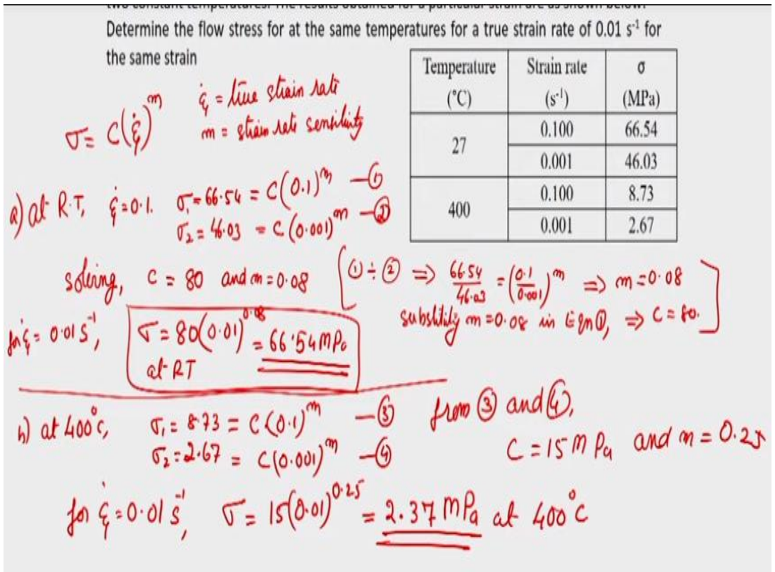

So let us come to problem number 4, this is for the condition where 2 test where conducted at true strain rate, so this is true strain rate test okay. So basically this is to discuss with the strain rate dependency of the material different at a different temperature, so the strain rate dependency so we can write it as σ is equal to may be c into $\dot{\varepsilon}$ where raise to m where $\dot{\varepsilon}$ is the strain rate true strain rate we have discussed about it true strain rate and m is the strain rate sensitivity.

$$\sigma = c(\dot{\varepsilon})^m$$

So we can take at this condition okay, so at room temperature 1 $\dot{\varepsilon}$= 0.1 so σ = 66.54 = c into 0.1 raise to m σ2 = 46.03 = c into 0.001 raise to m okay. So from this if you do that in the previous one case problem no 2, I think okay problem number 2 or problem number 3, problem number 2 similar to that if you solve it so solving we will get c = 80 and m = 0.08, so that means this is 1, 2.

So 1 / 2, m = 0.08 in equation number 1, and we will get c = 80. similarly we can get that and what is question m = this one we get it for a true strain of 0.01. So that means σ = for strain rate = 0.01 per second, σ = 80 into 0.01 raise to 0.08 = 66.54 mega Pascal at RT. Now b at 400 degree centigrade, so we can σ_1 = 8.73 into 0.1 to the power m and σ_2 is equal to 2 sorry 8.73 that is equal to c into 0.1 to the power m.

So σ_2= 2.67 = c into 0.001 to the power m so this is 3 and therefore so from 3 and 4, c = 15 mega Pascal and m = 0.25. So for strain rate = 0.01 per second σ = 15 into 0.01 to the power 0.25 so that we will get it as 2.37 mega Pascal at 400 degree centigrade. You see that in the case this is more sensitive at higher temperature the material is more sensitive to strain rate specially at higher working temperature, so that is what it shows at because in this case with at a low strain rate is 2.67 but when the strain rate is increased by two orders of magnitude you will find that it is more than 4 times approximately.

$$at\ RT, \dot{\varepsilon} = 0.1 \quad \sigma_1 = 66.54 = c(0.1)^m$$

$$\sigma_2 = 46.03 = c(0.001)^m$$

$$Solving, c = 80\ and\ m = 0.08$$

$$1 \div 2 \qquad \frac{66.54}{46.03} = \left(\frac{0.1}{0.001}\right)^m\ Substituiting\ m = 0.08, c = 80$$

$$for\ \dot{\varepsilon} = 0.01s^{-1}, \sigma = 80(0.01)^{0.08} = 66.54mPa$$

$$at\ 400℃,\ \ \sigma_1 = 8.73 = c(0.1)^m$$

$$\sigma_2 = 2.67 = c(0.001)^m$$

$$c = 15mPa\ and\ 0.25$$

$$for\ 0.01s^{-1}, \sigma = 15(0.01)^{0.25} = 2.37\ mPa\ at\ 400℃$$

Whereas in this case, the first case when you do it you see that the difference is very less only. Here at 0.1 it is 66 and here at 0.001 very low strain rate is 46.03 so difference is very less only okay. But here it is 4 times whereas here it is only around 2 maybe we can say around 50% increase only is there that is the different. So at higher temperature the material is more sensitive to strain rate.

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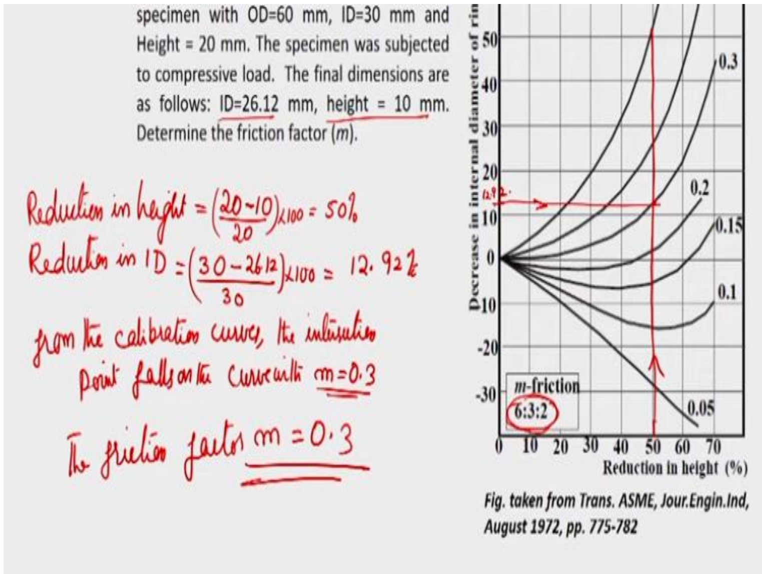

Now let us do the last problem number 5, so here this figure I have incorporated from the taken from the transaction ASME journal of engineering and industry, August 72, so that is the diagram which has been from that we have taken it so for doing this this as ring compression test, how to do this that is what is important. So the problem no 5, when you do it was told that in the ring compression test if the frictional stresses are less you will find that the radius is not inner radius is not reducing.

But with higher condition, the outside metal will not be able flow outside so rather inside diameter will get reduced. So reduction so this calibration curves are obtained for reduction in height and see decrease in the internal diameter of the ring to the reduction in height that is plotted and this calibration curve comes for different values of geometry. So this is the case for 6 is to 3 is to 2 and our specimen dimension is 60mm OD and 30mm ID and height is 20 which satisfies with this condition, so that is why this curve has been taken.

And the specimen was subjected to compressive load the final dimension which you got after compressing by some amount is ID = 26.12, height = 10mm and how to find out the friction factor m. So in this let us find out the reduction in height = 20 – 10, initial height was, sorry initial height was 20 final height is 10. So divided by 20 into 100. So you will get it as 50% and reduction in ID initial ID was 30 – 26.12 / initial 30 into 100.

So that you will get it as 12.92 %, so now what we have to look is from this calibration curve so reduction in height is 50% correspond to this line, 50% line is this vertical line and 12.9, so 10 this is around 50 so this is around 13 so if you draw a line like this where it may (()) (49:10) doing with the hand only. So it is coming to intersection point is somewhere around 0.3. So from the calibration chart the intersection points falls on curve with the m = 0.3.

$$Reduction\ in\ height = \left(\frac{20 - 10}{20}\right) \times 100 = 50\%$$

$$Reduction\ in\ ID = \left(\frac{30 - 26.12}{30}\right) \times 100 = 12.92\%$$

So hence the friction factor m = 0.3. So this is how we do so it is demonstration how it is done so this is 13 say 12.92 we can assume this is 12.92 we are assuming it and this is 50% so I think with this one should be able to do the solve the problems in this whatever portion we have been taken so far thank you very much.