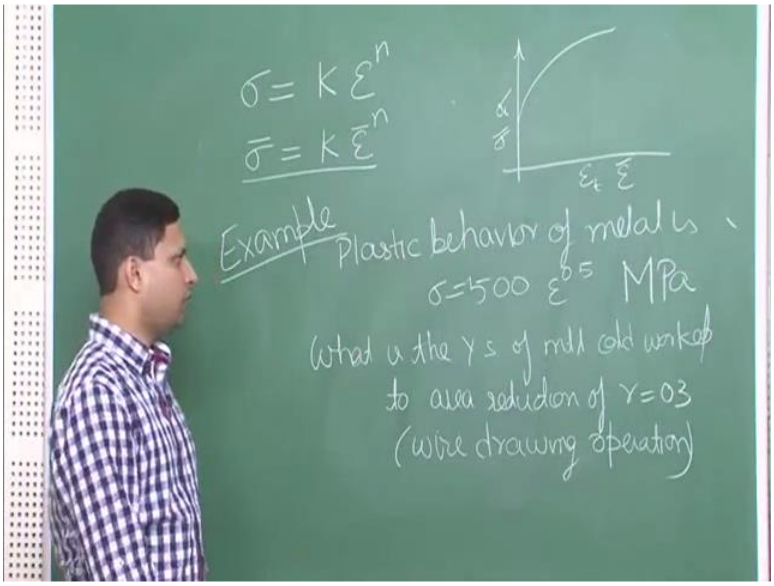
Fundamentals of Materials Processing (Part- II)
Prof. Shashank Shekhar and Prof. Anshu Gaur
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Lecture - 08
Effect of Strain Rate

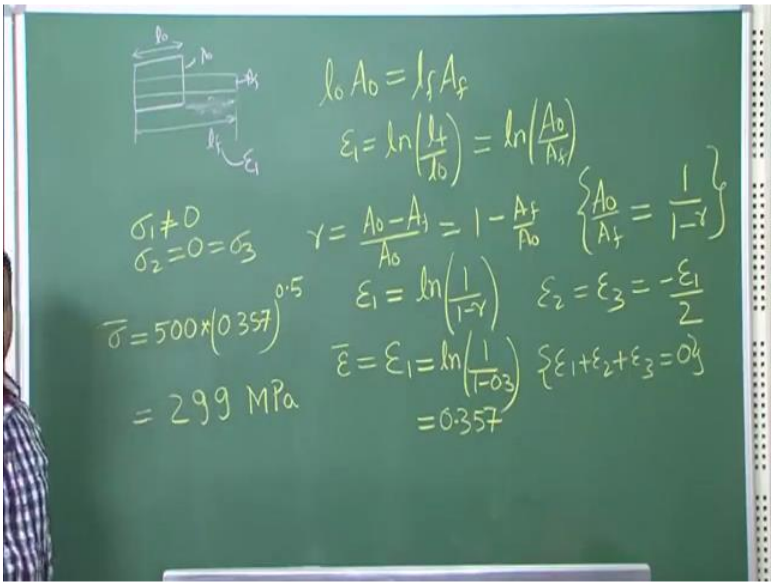
(Refer Slide Time: 00:14)



I am hoping that you have given a try to solve this problem and at most of the class examples, this is also very straight forward, just to make the problem more precise, let me, this was understood because when we have multi access stress and strain. So, this will be effective stress and this will be effective strain. So, now, we have this problem, where we are given the flow behavior, this will be called the flow behavior and you have to find out that after a given strain, the exact strain value is not given, what is given is area reduction so 0.3 area reduction or which means 30 percent area reduction, what will be the new yield strength or the stress value after that?

Let me draw rough sketch of how this will look like.

(Refer Slide Time: 01:05)



Let us say, we have a wire like this to begin with and this is the wire after reduction. So, let us say this is l naught, this is lf, final length, this is A naught and this is Af. Now if we call this as stain 1 in this direction strain, this is not the; let me let me not confuse you, so whatever strain in is happening in this direction is related to strain 1. So, now, I can say that l naught A naught is equal to lf Af, again this comes from volume incompressibility, the volume cannot change. So, the total volumes over here are same as the total volume over here and remember we are talking about wire drawing kind of operation, so this is, you can assume circular in shape.

Now, if I want to get epsilon 1, it will be equal to ln lf by l naught, but lf by l naught is what is related to is equal to ln A naught by Af. What you are given is now remember these are I am doing it in a very small step by step, but when you are solving it, you these steps can actually you can ignore the steps you can these things would be known to you and you can come directly to some of the or second step or next step.

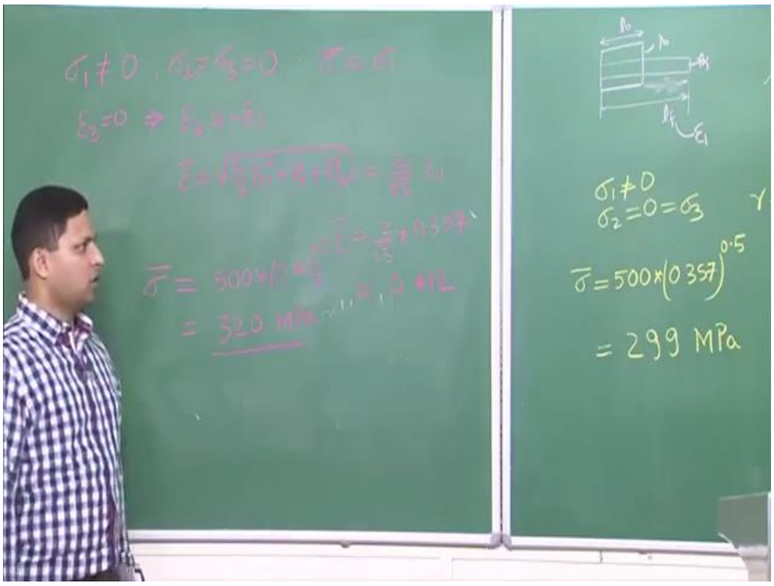
Now, here if we have this now r is given this is nothing but A naught minus A by A, A naught and this is given as some value now this is 1 minus A by A naught, A is actually now here Af. So, our A naught in terms of Ar becomes 1 over 1 minus r, this is from here, we can get this and therefore, epsilon 1 is equal to we have the same ln. So, next time when you see area reduction, you can straight forward say that strain 1 would be equal to ln 1 over 1 minus r so that is what I meant that this time to show the steps explicitly, I am doing all each and every small steps, but in future when you are trying solve you can come directly to some of these and you did not go through each and every step.

Now, that is not all, what about epsilon 2 and epsilon 3, they will be equal and it will be equal to minus epsilon 1 by 2, why because we have to have incompressibility which is epsilon 1 plus epsilon 2 plus epsilon 3 equal to 0. So, when you put this together, you remember, we also get the same thing for tensile test and over there we saw that this implies epsilon bar is equal to epsilon 1, what about sigma? You have sigma 1 not equal to 0 and other 2 sigma are actually 0. So, from here, now you can just directly calculate which will be equal 1 over r is already given which is 0.3. So, what you will get is actually 0.357. So, this is the strain value that we are very interested in and you put it in that equation sigma bar equal to 500 into 0.357 to the power 0.5 and you will get something like 299 mega Pascal.

What did you say is that if you have reduced the wire from this size to this size, earlier you may have a you may be requiring much lesser yield stress, but after this reduction you will require a higher yield stress some things like 299, do not get confused by this 500, this 500 does not represent any physical value, it does not represent the original yield stress or something like that.

The original yield stress of the material must have been much lower than 299, it is now increased after the cold working to 299. Now let me give this problem a little bit of twist, instead of wire drawing, let us say that it was a rolling operation, how would things change like operation was rolling instead of wire drawing what are the things that change.

(Refer Slide Time: 07:03)



What about sigma 1? Sigma 1 still is not 0, sigma 2 equal to sigma 3, they remain 0. So, the stress part does not change implies effective stress remains equal to sigma 1.

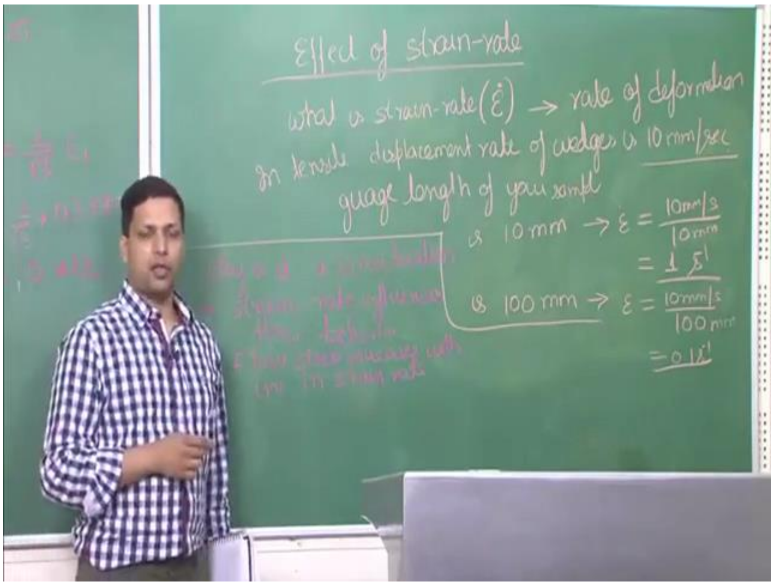
However when we look at the strain part here, in the rolling we assume that epsilon 3 is equal to which is in the perpendicular direction transverse direction is equal to 0, this implies that epsilon 2 is equal to minus epsilon 1 and therefore, if you apply the rule for effective strain what you get? So, here we have epsilon 1 square epsilon 1 square. So, this is 2 epsilon squares. So, 4 by 3 epsilon 1 square and this is 0. So, this comes out to be 2 over root 3 epsilon 1.

Now, the epsilon 1 value that what we calculated over there as 0.357 was actually epsilon 1 and therefore, effective strain is now equal to 2 by root 3 into 0.357. Now the effective strain as actually increased or in terms of when you are doing the rolling operation with same amount of area reduction, the effective strain value is higher and it is equal to 0.412 and when you put this to get effective stress what you get is 500 into 0.412 to the power 0.5 and this comes out to a little higher value of course, because the strain was higher. So, if you were assuming wire drawing kind of operation, the yield stress after that kind of area reduction is 299 and yield stress after this kind of area reduction in rolling comes out to be 320.

If we assumed same effective stress in both of them then there will be no change. So, you have to be careful what we have not saying that for the same effective strain rolling will be give rolling will give you higher yield stress, what we have saying is that the same amount of area reduction strain is higher in rolling compared to wire drawing and because of that yield stress value that you are obtained here is higher.

We have looked at stress strain and stress strain behavior quite a bit, now it is time to move onto another parameter that is important to deformation and now let us look at this another parameter of deformation can you guess what it would be, it is strain rate, when you first here that if you are hearing the word strain rate for the first time, you would assume that it has only to do with the rate at which the material is deforming.

(Refer Slide Time: 10:37)



And it should not take much of a difference to the overall stress required for deformation or to the material behavior or the material properties, but that is not true. First of all let us understand what is strain rate? It is usually denoted by dot over here because dot represents del epsilon by del t. So, it is actually in that sense rate of strain or we can say rate of deformation to get a feel of it, again we will take help of uniaxial tensile stress, let us say in uniaxial tensile test, the displacement rate of the wedges which hold the grips. So, the rate at which it can move is 10 millimeter per second.

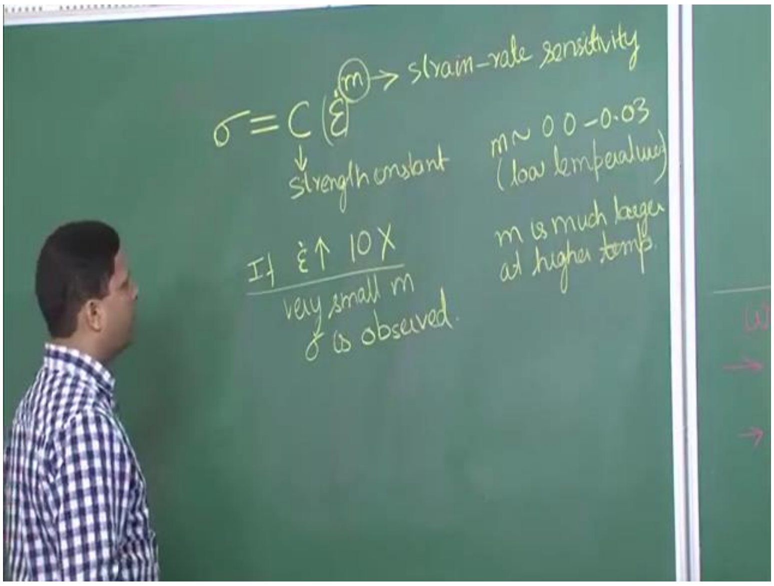
Remember this is never the unit of strain rate. So, never confuse that this displacement rate is same as strain rate, I have to explicitly mention is because I know that at earlier stages student do get confused and put strain rate in terms of millimeter per second. It is not the unit of strain rate, it is just the displacement rate from this displacement rate, we will get strain rate. Now let us say the guage length of your sample is for that first case let us say this 10 millimeter. So, if the sample is small and your guage length is 10 millimeter so that whole deformation is occurring in that 10 millimeter length and your displacement rate of the wedges is 10 millimeter per second so, all the deformation that is taking place is getting divided in that 10 millimeter and therefore, the strain rate is actually given by 10 per second, by this 10 mm which is 1 per second. So, this is the actually the unit time in inverse time that is the unit of strain rate.

Now, let us say the guage length is 100 millimeter, you are taking a much larger sample then strain rate is equal to 10 millimeter per second by 100 millimeter which is 0.1 per second. So, the larger a sample, it is getting divided into a much larger length, the displacement rate is where getting, you can say absorbed or distributed for a in a larger length and therefore, the strain rate comes out to be smaller. So, that is what is strain rate, the rate at which the straining is occurring straining is occurring in that whole guage length and that is what divide it by the whole guage length.

Now, why should we at all the concerned with strain rate, why is it a consideration meaning what kind of influence does it have. So, it may not appeared by intrusion, but when you are talking about strain rate, strain rate also influences your flow behavior, specifically if we increase the strain rate, the flow stress increases, you can do a very simple experiment at home - take a polythene bag now try to stretch it very slowly, you would see that you need have a very small amount of load to stress the plastic, now in the second attempt take a very similar plastic or if you can divide it with the same plastic in 2 part so that you can do 2 experiments. In the first one, you have done this at very slow rate where you will experience that you can deform it very easily, in the second one try to do it in snatch just try to break a part.

So, you would see that the same amount of deformation the second one will be require it to a much higher strength from you a higher load from you. So, that translates to higher stresses requirement now the origin of this increment in strain stress flow stress because of increased strain rate is different in different materials for in crystalline materials it is different and in plastic that I just described it is different; however, you can get a good feel of what or how the strain rate can influence the flow stress the simplest way to express this is this relation a relation very similar to what we have already seen for stresses.

(Refer Slide Time: 16:56)

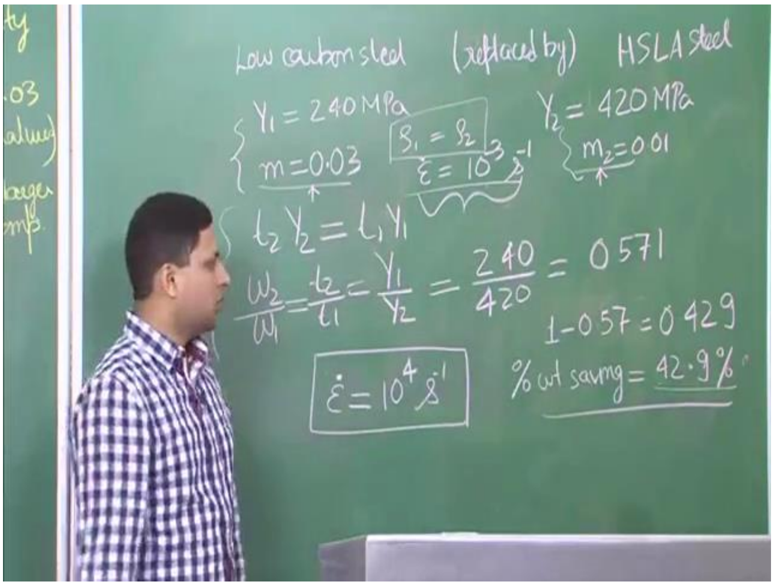


Now this time instead of stresses; instead of strain over here what we have is the strain rate, this is now quantity strain rate and m is the m is strain rate sensitivity and C is called strength constant, how much this strain rate will influence the flow stress. So, this is the stress required for flow behavior meaning you can again say this is the yield stress of the material after given deformation. So, how much different flow stress is required for a given amount of strain will depend on this value m and you can say fortunately for us, this m is usually very small of the order of 0.0 to 0.03, but that is only at low temperatures, at higher temperatures the value of m increases drastically and we will see a schematic schematically how this m changes, but for now it is suffice to say that m is much larger at higher temperature.

Now, what is the significance of this very very small value of m? The significance is that if you increase the strain rate, if strain rate is increased by let us say 10 x 10 times, even then a very small change in flow stress is observed and because of this you would see that most of the time when people are talking about metal forming, metal working then strain rates are usually given on a log scale because you change strain rate by let us say from 10 to the power minus 3 to 10 to the power minus 2, 10 minus 0.11 10. So, you change it in orders of by factor of 10, you do not change it just by say from 1 to 2 or 2 to 3, in that case you will not see almost you will see almost no change on the flow stress only when you change the strain rate by some very large factor 10 or 100 that you would see it is influence on the flow stress.

Now, we will solve 1 example related to the strain rate to get understanding of what is the importance of this. So, let us in automotive industry you know that people are always trying to reduce the weight of the car because you are reducing the weight of the car leads to improve mileage which a very important goal of the automotive industry. Now how do they reduce the weight they use materials which have higher strength, if you have materials with higher strength you can use even a thin guage of the material and do with even less weight material and of course, the other way is to use material which have low density, but low density material like titanium they are very expensive even magnesium they are very expensive and so the thing that people apply is taking still itself, but with higher strength.

(Refer Slide Time: 21:07)



Let us say, we have 2 different materials, low carbon steel which is currently used in most of the automotive industry by it is to be replaced by high strength low alloy steel. So, that is the target you want to reduce low carbon steel by high strength low alloy steel. Now how much will the gain d or how much will be the change in the weight that is what we will measure or try to guage from here.

Now let us say Y 1 or the yield strength for this material is given as 240 mega Pascal and Y 2, this certainly is a much higher strength material and it is 420 because if you are replacing this by that it must be that it should have higher strength and both of them are steel. So, mostly iron if in that case, the density for both them will remain same.

The density of the material is approximately same. So, if you take same volume then the way to of both of them will be same, but then you will be able to applying much higher stress over there because the yield strength is higher. So, you would what you would do? I really do is you will have much thinner guage of material when you are using second material.

Now, here let us say this yield strength for both of these were obtained at a strain rate of 10 to the power minus 3 per second and you have also measured the strain rate sensitivity. So, here the strain rate sensitivity is 0.03 and in this case the strain rate sensitivity is 0.01. Now the first question is that if you are assuming that this is the strain rate that is required how much weight percentage you will gain.

Let us say we have t 2 which is the thickness Y 2 is equal to t 1 Y1, how do I get this because if I am using the say if I am replacing 1 material by the other then the load that is being carried by that material must be the same as the load being carried by this material. So, let us say whatever thickness t 2 was, it was for this material and t 1 is the thickness of this material then the load carrying capacity for both of them should be same and that is why I will reduce the thickness for that 1.

Given that t 1 is the thickness of this 1 and t 2 is so, this 1, in this particular case, t 2 should come out to be thinner. Now we can say t 2 by t 1 is equal to Y 1 by Y 2, now since we have already said that density is same therefore, the weight for the tool should also be proportional to the thickness ratio. So, W 2 by W 1 will be equal to t 2 by t 1 equal to Y 1 by Y 2 and here you can put in the values and get 240 by 420 which is equal to 0.571.

What did you saying is that weight of the second material is only 0.57 of the weight of the first material and still it will carry the same load or it will be able to bear the same load therefore, at a much thinner guage or at a much lower weight you are able to get same kind of performance which means that how much are you saving you are saving 1 minus 0.57 which is equal to 0.429. So, the weight saving is equal to 42.9 percent. So, you are able to get reduce the weight of that particular component, I am not talking about the whole car, but for that particular component if you change from this material to this material you have reduced the weight by 42.9 percent, not only that even so that will lead to of course, improved well efficiency less pollution.

But also a lower cost because most of them both of them are steel based iron and probably this is not as much expensive compare to this one. So, by reducing the weight you have also cut down on the cost so that is their aim or the goal for most of the automotive industries as of now because that they are under severe clock to reduce the weight and improve fuel efficiency and so on, so that is the one part of the problem.

Next part of the problem is that here we assumed strain rate equal to 10 to power minus 3, but in reality when the crash takes place or when the mat or the car crushes, the strains or of the order of 10 to power 4, now you see how much is the difference from this strain rate to this strain rate, it is 10 to the power 7 times higher. So, that must make a difference to the yield strength of the material and therefore, we will have to do a calculation again. Now you will have to do this calculation assuming that the material deforms at a strain rate sorry this is not a strain rate strain rate like just like here. So, this is you will have to do the calculation assuming that the strain rate is equal to 10 to the power 4 and I will leave it to you over here to again try to solve this on your own because next step is again like I said just plug-in the values and you would be able to get the answer.

I have already given you the steps for this one, the next step all you have to do is for these strain rates calculate the new yield strength for the 2 materials and then with new yield strength again calculate what will be the weight ratio. Now just looking at it what would you think would the weight saving increased or weight saving should decrease? Now here what are the things that you should look at, should we look at the strain rate from where to where we are going or should you look at this value?

Now, what you notice here is that this m value is smaller than this m value which means that at higher strain rate, this will not increase as much, but this will increased by a larger fraction and therefore, what it would mean is that the difference between the yield strength for the 2 would not be as much as you see right now which in turn would imply that the W 2 by W 1 ratio should decreased when you were a look at a problem you should try to get a feel of it so that when you get the answer you can cross check it. So, from this when you solve it what you should get is a smaller saving in weight percent.

Try to solve it and anyways I will be solving it in the next class, but it will be a good experience for you trying to solve it. So, I will leave you with this problem and we will come back on it with the next class.

Thanks.