Principles of Metal Forming Technology

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Lecture - 18
Strain rate effects on flow properties

Welcome to the lecture on Strain Rate Effects on Flow Properties. So, we have discussed about the true stress true strain curve. And we have seen that how these you know how the there is behavior of the true stress true strain curve. You have the point of maximum load you have the point of fracture. Now this is for we are not we have not talked about the strain rate, because you have many parameters which affect these flow characteristics of the material. And in that basically one of the important parameters which effects the flow properties of the material or the flow stress of the material is the strain rate.

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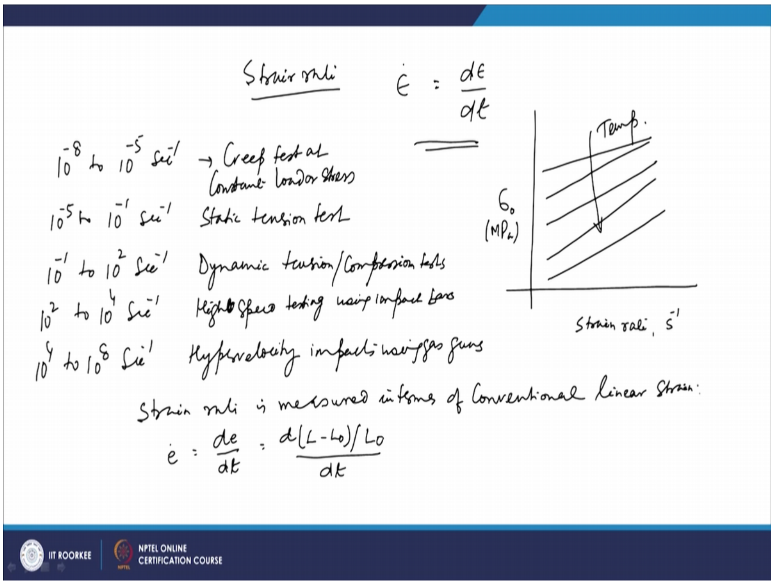

So, what we define the strain rate so, strain rate basically we defined it as this epsilon naught, epsilon this is dot and that is basically the way you the rate of straining, so, that will be de epsilon by dt. And it has effect on the flow stress value is the point where the yielding will occur or the point at reach the fracture will start. They are affected because of the strain rates, and basic specially it is effect is there on the yield strength of the material. So, it is unit as you see so, it is unit will be per second. So, because the strain has no unit so, ultimately the strain rate has unit of per second here as it looks like.

Now, the in general, it you can understand that when you are increasing the strain rate, then it increases the flow stress value, and that can be found out by a normal, you know, a curve which talks about these strain rate dependence for the yield, value. Now what we see in that this these values move like this. And they are with increase in the strain rate values, you know, they the yield strength will go on increasing certainly as this is for different temperatures.

So, you have this way I actually temperature is increasing. So, as we know that as the temperature is increasing, the flow stress requirement is smaller and, but the as the strain rate is increasing, this sigma naught that is the yield strength of the material in mega Pascal that basically increases. So, yield stress and the flow stress at lower plastic strains are more dependent on this strain rate, rather than the tensile strength. So, when we are in that load plastic strain zone, in those cases the strain rate is very much important.

So, now if you try to see what is the implication of what is the basically importance of these strain rate how they affect. So, just have to have a feel, if you if you see the range of strain rate normally if you see the 10 to the power minus 8 to 10 raise to the power minus 5 per second.

So, this is such small strain rate is what it is normally for the creep's test at constant load or stress so, this is for the creep test. Similarly, if the value is from 10 raise to the power minus 5 to 10 raise to the power minus 1 per second. Now this is normally for the static tension test with a hydraulic or screw driven machines so, this is for static tension test, where we have the hydraulic or screw type of driven machines which do the testing. You have also the tension test or compression test the dynamic tests, and for them it goes from 10 raise to the power of minus 1 to 10 raise to the power 2 per second and this is for the dynamic tension or compression tests.

So, this is basically increasing, you have these values go like this. Then if you go further, 10 raise to the power 2 to 10 raise to the power 4 per second if you see there is further increase of this strain rate. And that is basically for the high speed testing high speed testing using impact parts.

So, basically you have if you if you considered the wave propagation effects, when you do the testing with, you know, impact bars in those cases the extended values further increase and they become 10 raise to the power 2 to 10 raise to the power 4 per second.

And further if you go to further high value 10 raise to the power 4 to 10 raise to the power 8 per second. This is a further higher value and this is known as hypervelocity. So, normally they these are encountered in the case of hypervelocity impact using gas guns so, this is hyper velocity impacts. Using gas guns, or you may have the expressively driven projectiles so, these are the examples of the strain rate different strain rates which are applied when we are trying to deform the material.

So, normally is static tension test we go for the strain rate values in the range from 10 raise to the power minus 5 to 10 raise to the power minus 1, and otherwise once you go dynamic tension you have further and then high speed testing using impact parts and then hypervelocity impacts using gas guns or the expressively driven projectiles where you have the propagation of shock waves. So, in those cases your strain rates are even quite higher. Now when you apply the higher strain rates, in those cases are the materials which ordinary do not show the yield point, they also show the yield point like, you have if you do it on the low carbon steel which in ordinary case.

They do not show any yield point under the ordinary state of loading, and if you use these high strain rate then they show the yield point. So, that is what the difference of these strain rates are on the behavior or shape of the stress strain diagram. Now you must understand what is this strain rate.

So, if you look at the strain rate, what we see is that normally you have when we do the testing of the cylindrical specimen, you have one and fixed another from another side we are straining it. So, another side is basically attache to the this is a movable jaw one is fix jaw another is movable jaw, now that is the movable cross head of the machine. Now this cross head which is straining it, it is going at certain velocity, so, you have this strain rate. So, this strain rate it is basically measured in terms of the conventional linear strain. So, strain rate is measured in terms of conventional linear strain. So, what we see is if you look at the engineering strain rate e dot, now this e dot it can be written as de by dt. Now de we can write as d of L minus L naught by L naught, and then this will be dt.

So, L naught is the original length and L is the final length. So, de will be d of L minus L naught by L naught and then you have dt. So, L naught being the constant. So, it will go as 1 by L naught, and then this will be dL. So, because dL naught L naught is fixed so, it will be dL by dt. Now dL by dt is nothing but; so, that will be rate of change of this length, and this is actually expressed as V by L naught now. So, what we see this V is nothing but the cross head velocity.

So, what we see that this is conventional strain rate so, we found the conventional strain rate.

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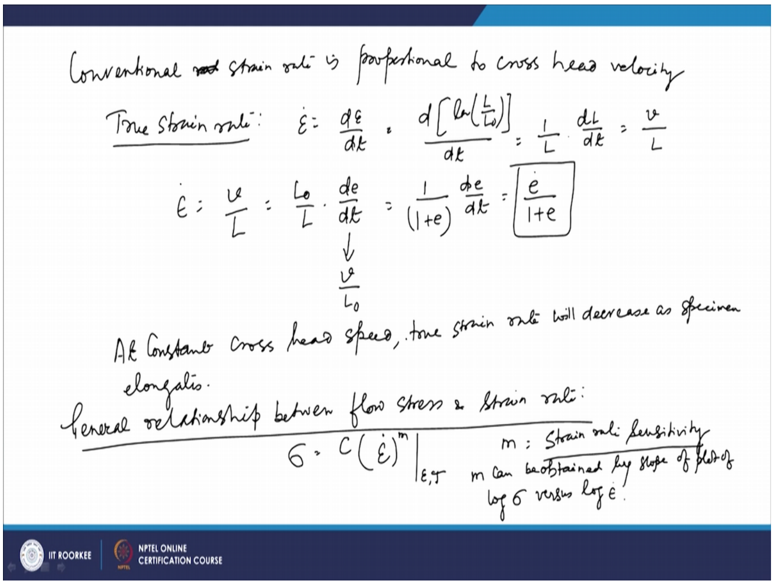

And conventional strain rate we found as V that is cross head velocity upon the gaze length; that is, the original gaze length that is L naught so, it is proportional to the cross head velocity. Now this is how we see you measure, this conventional is strain rate, now in the modern testing machines these cross head velocity can be controlled. And this way, you can control the value you can do test or you can perform this testing at a specified strain rate. Now if you try to find the true strain rate.

So, true strain rate will that will be talking about the instantaneous length, rather than the L naught so, it will be talking about L. Now in this case this is defined as d epsilon by dt. So, that is in case of engineering conventional strain linear strain; that is, e dot and it is epsilon dot that is d epsilon by dt. And if you try to see the by definition this value of the you write d of ln L by L naught that is what the value of the d epsilon is you get the ln of L by L naught divided by dt. So, so, we get 1 by L, and then we get dL by dt.

So, this way you try to find the value of the true strain rate, and that will be basically equal to V by L. So, there you got V by L naught, here you got the expression V by L.

So, this is very clear that here it will be 1 by L by L naught and then 1 by L naught will be further multiplied. So, one L naught will be, you know, anyway it will be cancelled.

So, you will get 1 by L into dL by dt that is V by L. Now what we see that if you can further try to, you know, have the correlation between the true strain rate and the conventional strain rate. So, you can say that true strain rate will be V by L. So, you can further write them as L naught by L into de by dt. So, so that is how you can write this expression as the further what because we have already found the de. So, e equal to de by dt is basically V by L is there V by L naught. So, L naught the again here it comes over in the picture. So, this L naught will be changing because this is nothing but de by dt is equal to V by L naught. So, that way L naught will comes b by L will come. Now that can be further be written as 1 by 1 plus e.

So, we know that there is expression relationship between the true strain and the engineering strain so, that way it will be de by dt. So, L naught by L will be so that will be 1 plus e. So, so, we can get 1 by 1 plus e into d by dt and de by dt is e dot so, that way. So, once we know once we know the, you know, engineering strain rate or conventional strain rate, and we know the conventional strain, then you can find the true strain rate. So, what we see that at constant crosshead speed so, at constant crosshead speed, now as you as you see that when you have a constant crosshead speed. In that case the true strain rate if you look at with the e will be more, if e will be higher than this will be going on decreasing.

So, the true strain rate true strain rate will decrease as specimen elongates. So, that is what, you know, as the specimen will elongate the true strain rate, to is the material is or the specimen is subjected to that will further where will be decreasing. Now you have to maintain that if you have to maintain this true strain rate, then certainly you may have you have to go for the, you know, open loop control in which your deformation velocity has to be increased. So, that way you can increase the deformation velocity from here.

So, de by dt is basically V by L or not so, the V has to be increased. So, otherwise you have to also see that how you have to in close loop control methods ultimately in the later part you have to adjust so that your true strain rate becomes the same. So, you for maintaining this true strain rate to be uniform, you have to do the adjustments you have to change the cross head speeds. Now in this case you have a general relationship between, you have a general relationship between flow stress and strain rate.

So, as we discussed that to have the constant true strain rate, you will have to either go for the open, you know, loop control or the close loop control, and in those cases the V that is set will be a function of the epsilon naught that is your true strain rate multiplied by the, you know, length of the original, you know, original gaze length that is L naught. And then exponential of the epsilon naught t. So, so, that way you try to have the constant, you know, velocity that value of the true strain rate. Similarly, when the plastic flow becomes localize. So, you have the non-uniform flow of I mean along the gaze length.

So, in those cases the open loop control is no longer satisfactory, because at that time the specimen elongates there is non uniform, you know, deformation that way. And in those cases you have the close loop control and they are again you have to adjust the; and the a, based on the a how you see that how the a is changing, so, based on that your true strain rate is to be controlled. Now the gender relationship between the flow stress and flow with the strain rate, that also has been suggested for a that is sigma is C of epsilon dot m, and that is at a constant strain and the temperature. So, for a constant strain and the at a constant strain and at the constant temperature, this relationship holds good sigma is C into epsilon dot m. Now in this case this m that is exponent, this m is known as the strain rate sensitivity.

So, that will affect the flow stress of the material, and again similar to the power law curve. You can find this value of m by having the log plot of the true stress and true strain rate, and from their by binding the slope of the curve you can find this m. So, this m can be obtained by slope of plot of log sigma versus log epsilon rate that is the log epsilon naught dot that is your true strain rate. And this way you can have the value of the strain rate.

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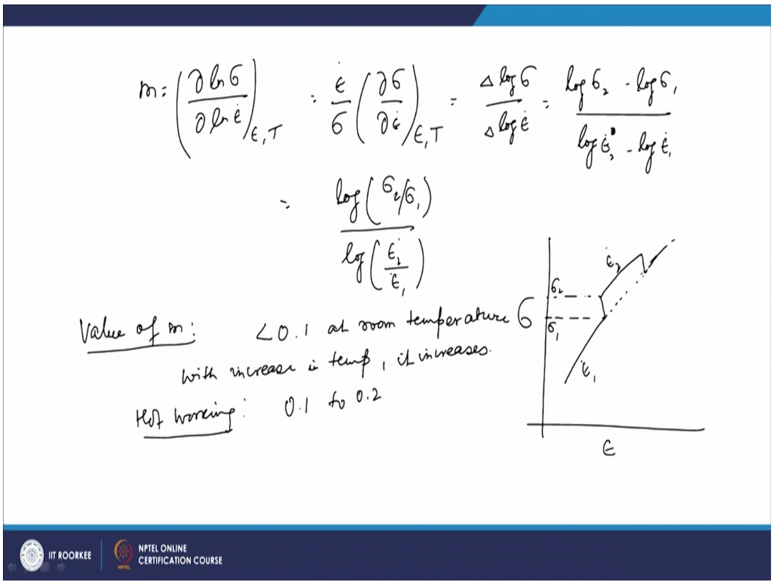

So, you can further see that this m is nothing but you have del of log sigma ln sigma by del of ln epsilon. That is what naught this is the value of the strain rate sensitivity m, and this is at constant strain and temperature. So, again log sigma will be 1 by sigma and d sigma. So, so, it will be 1 by sigma will come and this way epsilon dot will come so, it will be epsilon dot by sigma. And then you will have dou sigma by dou epsilon naught dot. That is true strain rate and this is at a particular or fixed strain as well as at the temperature.

So, this is nothing but you have this is nothing but your change in the log sigma by change in log epsilon naught. So, so, that way you can find if you have the graph you can find log sigma 2 minus log sigma 1 by epsilon log epsilon dot 2 minus log epsilon 1 dot. So, that way you get log of sigma 2 by sigma 1 divided by log of epsilon 2 dot by epsilon 1 dot. So, this way you find the strain rate sensitivity of the material. Now it is value is normally quiet low at room temperature so, if you find the value of this m strain rate sensitivity. Now it is quite low at room temperature so, it is value is less than 0.1 at room temperature. But it is basically increasing with the increase in the temperature.

So, with increase in temperature it increases, so, specially the when the temperature is about above of half the absolute, you know, melting point at that time this value of m will be increasing. And if you go for the hot working conditions hot working is done about the reutilizing temperature and reutilizing temperature as we know, it something point 4 to point so, 6 times the absolute melting temperature. So, in those ranges it is value is comes 0.1 to 0.2.

So, this is something which talks about the strain rate, you know, the effect of the strain rate on the flow properties. So, that can be understood by so, if you have the stress strain curve. So, true stress and true strain curve, and if suppose you have put the strain rate and you have varied it along the testing. So, if suppose it goes initially like this and so, you have one strain rate, and then further you have changed it.

So, and then further it is going like this, now in those cases if you look at this is the epsilon dot 1 dot, and another value is epsilon 2 dot. So, what we saw, this is what we have done for this expression, in this expression and we found the value of these m. Now for this basically you have this is the sigma 1, and this is the basically sigma 2.

So, that way if you have the sigma 1 and sigma 2 non and epsilon, 1 dot and epsilon 2 dot non. In those cases, you can find the value of the strain rate sensitivity by referring to this expression log of sigma 2 by sigma 1 divided by log of epsilon 2 dot by epsilon 1 dot. So, that way you find this value of m, now for many materials such, you know, equations do not hold good sigma equal to C into epsilon dot m, at constant epsilon and on the temperature. Now so, many times these strain rate dependence of the materials.

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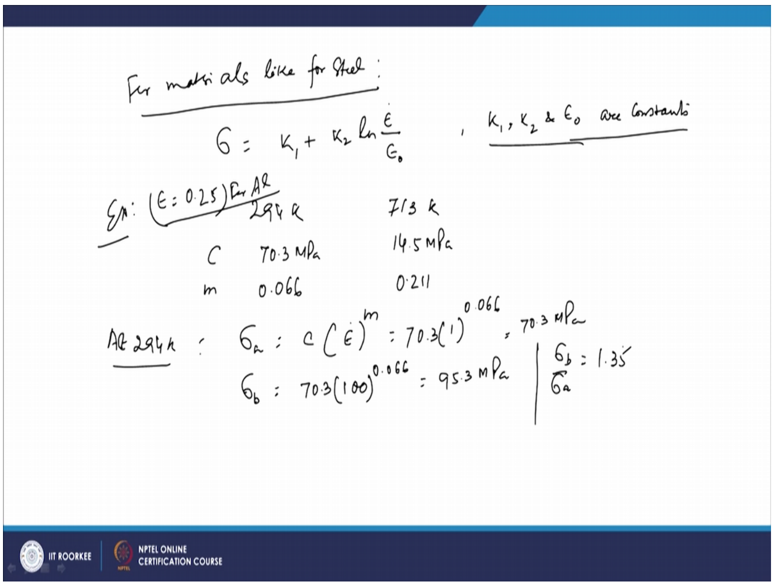

So, for many materials for materials like for steel; suppose, when we see that expression is not very, you know, complete that is not so completely in accordance with the with the flow stress behavior. And here you have a semi logarithmic relationship that a holds good, for the flow stress and strain rate. So, there it comes like sigma equal to k 1 plus k 2 ln epsilon naught by epsilon, epsilon dot by epsilon naught. So, this type of expression is seen to fit good. For some materials as far as the strain rate dependence is conserved. And here this k 1 k 2 and epsilon naught they are the constants values.

So, this way we try to find the we try to understand the importance of these strain rate sensitivity in the case of the flow stress determination, and that way we can have the value of, you know, these parameters, they because when we do the, you know, deformation. Many deformations are done at very, very high strain rate and what will be it is effect on the on the flow stress values, they are required to be understood.

Also when there will be there maybe you may be dealing with certain cases, like there are suppose you have some parameters given. Suppose you are given with you are given with some true strain values for some material. And also you are given with the constants like C and m, m is the strain rate sensitivity. So, if you are given with the C and m; so, in those cases you can find you know the stress values, you know, the stress ratio of the stress values in those cases and, you know, what will be the change in the flow stress value at when the temperature is suppose increased or decreased for the temperature.

So, that can be, you know, calculated for example, suppose you have you are given with an one example; like, you are given at different temperatures suppose there are temperature of 294 k and 713 k for aluminium for aluminium whose at true strain rate of true strain of 0.25 suppose, and for aluminium you have some conditions given. And suppose your C and m values are given, like this is 7 point 70.3 mega Pascal C and at higher temperature it becomes less. So, this will be 14.5 mega Pascal. Similarly, at the m value is 0.066 and the strain rate sensitivity value will be more at higher temperature. So, it will be dealing with 0.211. Now if you try to calculate the; you are told that what will be the change in the flow stress value for this change in the strain rate.

So, so, you can find that and for that you can see that if you calculate if you calculate this at 294 Kelvin, now this is I will be see of and epsilon dot raised to the power m. So, your C is given that is 70.3, and the epsilon dot that is. So, for a 2 order change of magnitude so, for a 2 order change of a magnitude means signified you have to test for first the value of one and then it becomes 100. So, you can go for one raise to the power m, m is given that is 0.066. So, that comes as the 70.3 mega Pascal. And but if you go for the 2 order of magnitude higher values of epsilon, you know, dot. So, sigma b you can get as 17.3 into 100 raise to the power 0.066.

So, that way it comes out to be 95.3 mega Pascal. So, what we see that you can find the flow stress ratio value and sigma b by sigma a you get it as 1.35. So, that can when we computed for the higher temperature side, and this way you can say that what will be the changes in the this ratio of the these flow stresses change in the flow stresses as the, you know, strain rate value is increased. So, similar problems can be tackled, and as the time progress is we will try to understand it is significance for when we deal with the metal forming processes, that how this is strain rate is sensitive how this strain rates are, you know, having the meaning towards the deformation characteristics of the material. So, even that can be done at even all this temperature also.

Thank you very much.