Principles of Metal Forming Technology

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Lecture - 19
Temperature effects on flow properties

Welcome to the lecture on Temperature effects on flow properties. So, we will discuss the effect of temperature and how it effects the flow properties of the material. Because many a times what we see that we do the test and we draw this stress strain diagram, and we are also interested to find the flow properties finding the flow stress values or the fracture (Refer Time: 00:56) fracture stress and all that.

So, basically we do it at the room temperature, but that testing is also done at the different temperatures may be in the temperature higher than the room temperature at that or even the temperature at which I mean it is below the room temperature. So, basically the selection of temperature at which the test is conducted it has its effect on the stress strain curve as well as the flow and the fracture properties.

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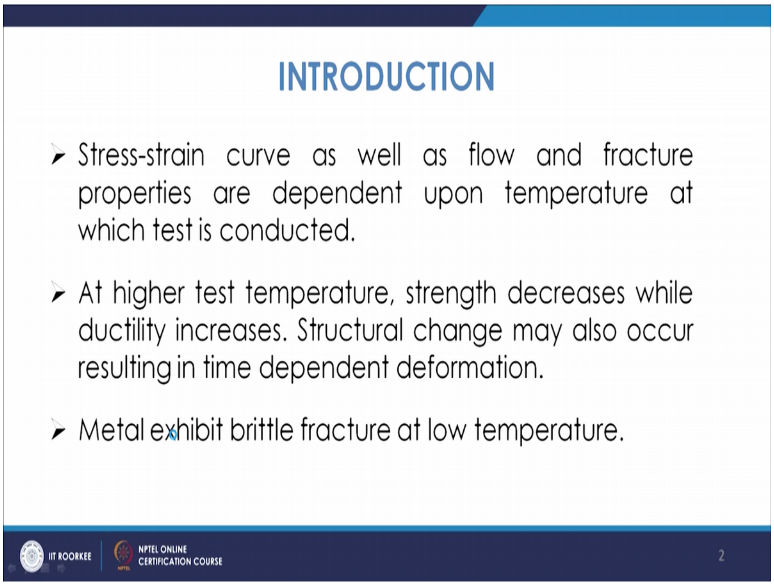

So, normally what we see that when there is higher temperature then the strength will be decreasing and the ductility will increasing. So, normally in the normal strain when we go to the higher temperature then there are many kind of a structural changes also occur. Like you have the strain edging which take place, then you have precipitation taking place, recrystallization taking place and that also has the you know effect on these properties.

So, we will try to see that how this temperature has the effect on the flow properties. If you look at if you try to see the you know properties of the material at higher temperatures, then in those cases if you try to draw the you know stress strain diagram for typical materials like this is the stress and this is the strain. Then what we see that if you do it for mild steel, now for mild steel it will go and it will go and behave like this; if you are doing the stress strain diagram at very low temperatures.

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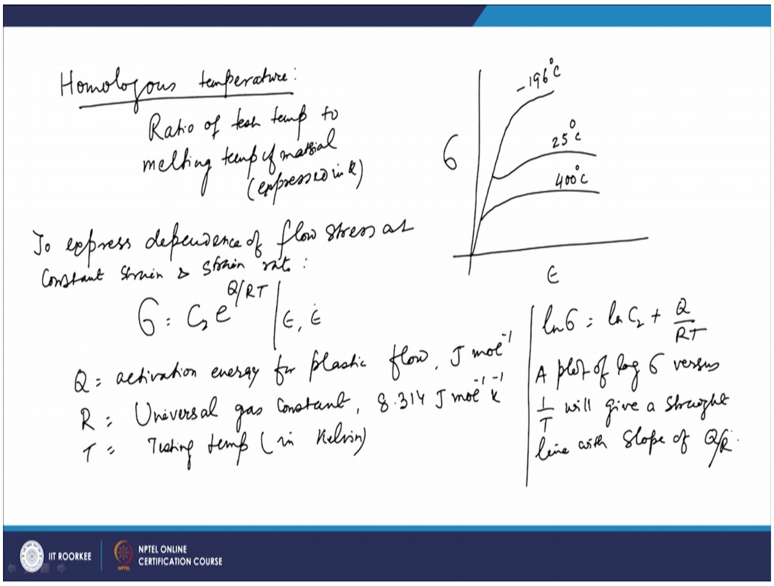

So, suppose you do it at minus of 196 degree centigrade; if the temperature is too low below the 0 rate centigrade temperature. If you go to minus of 196 degree centigrade you see that this is the stress strain diagram. Whereas, if you try to draw it at the room temperature something close to 25 degree centigrade then it looks like this so, it goes at about 25 degree centigrade. Whereas, if you further increase the temperature in those cases what you see is that this curve goes like this.

So, this will be about 400 degree centigrade. So, what we see that normally there will be the variation in the yield strength of the material you know with the temperature. Now, if you try to see the variation of the properties like if we try to see these curves.

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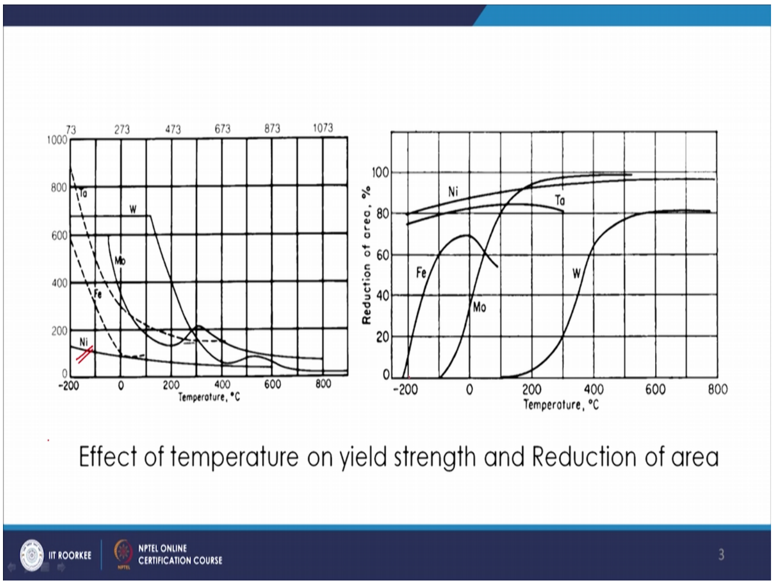

What we see in these curves? Now, this is for different materials the yield strength is shown. Now, if you look at this curve this is the curve for the tungsten. Now this tungsten, this is tungsten, this is tantalum, this is molybdenum iron and nickel.

Now, what we see that these materials tungsten, molybdenum or the iron or the tantalum they are the body centered materials. And what you see that as you increase the temperature there is drastic increase there is drastic decrease in the yield strength of the material; this is the yield strength in mega pascal. So, what you see is that once you increase the temperature at higher temperatures the yield strength decreases drastically. While, if you look at the material like you have nickel, nickel is the face centered cubic structure and here you do not see that many that much of appreciable change.

The certainly there is decrease in the yield strength value, but then that is not that much prominently decreasing as is happening in the case of the body centered cubic materials as its clear from this graph. Now, if you see the reduction of area also in these cases what you see is that again similarly we see the nickel which is the you know (Refer Time: 05:57). So, here also, but the it is increasing, but if you look at these materials like iron, molybdenum or tungsten you see that as the temperature is increased the reduction in a area is quiet appreciable.

So, basically that effects the you know ductility of the material. So, basically what happens that when you are this is a normal finding that the material materials you know property I mean changes. Its strength will decrease as the temperature is increased or ductility is you know increased when the temperature is increased. So, strength decrease is and ductility is increasing in the case of the increase in the temperature. Now, the thing is that so, we have already seen that the abscise materials they are not showing that much of the dependence on the temperature. But the strain hardening exponent that basically will be decreasing with the increase in the temperature.

So, what happens that if you look at their you know strain stress strain diagram that will be flattering towards the later part. So, that is what to the normal trend is. Now, there is another parameter which is normally another terminology which is coming into the picture and this is regarding the temperature at which these test are carried out. And basically it is a I mean ratio is basically represented that temperature at which you carry the test and the melting temperature of the material and so, ratio of that is known as the homologous temperature.

So, you have the homologous temperature. So, this is basically ratio of test temperature to melting temperature of the material. So, basically this temperatures are expressed in Kelvin and this ratio is known as the homologous temperature. So, normally when we compare the flow stress of two materials at equivalent homologous temperature then we have it is advisable basically to correct for the effect of the you know temperature on elastic modulars by comparing the ratios sigma by e. So, normally that is the you know so, homologous temperature is normally defined and then that way we compare the flow stress value for the two different materials.

Now, if you we try to analyze about that the dependence of this you know flow stress on temperature then normally when we try to talk about. So, to express dependence of flow stress at constant strain and strain rates. So, as we know that normally the flow stress will be depending upon the temperature strain and strain rate.

So, when we try to analyze about their dependence of the flow stress on the temperature in that case we assume that the strain and the strain rate is constant. And that can be expressed as sigma equal to C 2 into e rate to the power Q by R T. So, this is at constant strain and strain rate. Now, in this case Q is the activation energy of the plastic flow. So, activation energy for plastic flow and its unit is joule per mol. Then R is the universal gas constant and its unit as we know this is standard value that is 8.314 joule per mol per

Kelvin. And T is the testing temperature that is in Kelvin. So, what we see that if you look at this curve this is sigma equal to C 2 in C 2 constant and this is exponential of Q by R T.

So, if you take the log function log on both the sides then log sigma will be log C 2 and plus Q by R T. So, that will be so, you will be taking the l n as exponential of function. So, you can have so, from there basically you can have the expression for Q. So, if you take you can you can see the if you take the log it will be l n of sigma, it will be l n of C 2 plus then Q by R T. So, so that way we get so, you have what you see is that Q by R again. So, you can have the expression so, you have one Q. So, what you do is now you have 1 by T here and then you have log sigma. So, you can have plot of log sigma and then you have can have a plot versus 1 by T.

So, it will have the slope of Q by R. So, what is there? So, in this case plot of log sigma versus 1 by T. So, y equal to m x plus c so, you have x as 1 by T. So, m is slopes this is Q by R. So, that will give a straight line with slope of Q by R. So, this way you can have the expression and you can find you can see the co-relation between the log sigma and the 1 by T. Now, you can further find this value of Q which because if you have a temperature T 1 the stress flow stress value is sigma 1 and if you have temperature T 2 the flow stress value is sigma 2.

So, from there you can find the value of these you know Q. So, how can find that Q?

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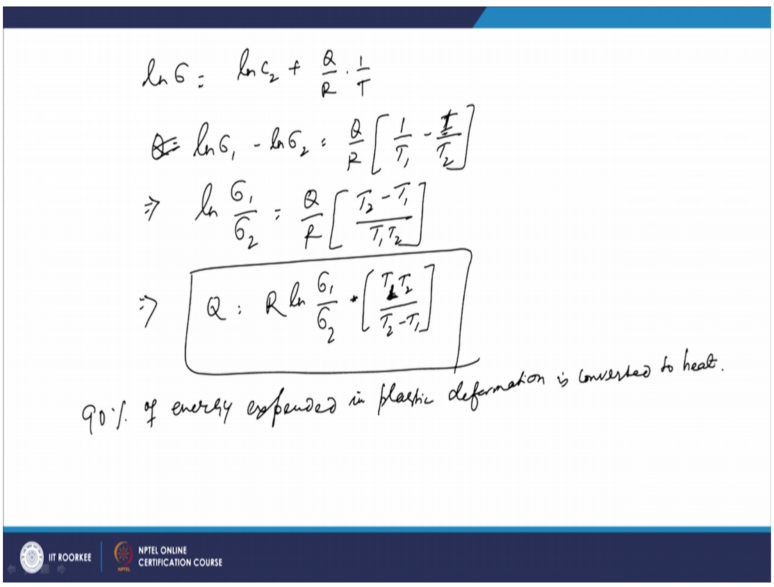

So, what we found is that l n of sigma will be l n of C 2 plus 1 Q by R into 1 by T. So, suppose you want to find the value of Q so, now, Q can be found. So, if you have sigma 1 at sigma 1 flow stress I mean if the flow stresses is sigma 1 at temperature T 1. So, log sigma 1 will be log l n sigma 1 will be l n C 2 plus Q by R into 1 by T 1 and similarly l n sigma 2 will be l n C 2 plus Q by R into 1 by T 2.

So, if you subtract from this equation to the first equation to second equation there in that case this l n C 2 term will cancel. So, l n of sigma 1 minus sigma 2 that will be equal to Q by R into 1 by T 1 minus 1 by T 2. So, what we say we can find is that l n of sigma 1 minus l n of sigma 2 will be Q by R 1 Q by R into 1 by T 1 minus 1 by T 2 1 by T 2 ok. So, what you get from here is l n of sigma 1 by sigma 2 it will be Q by R into T 2 minus T 1 divided by T 1 T 2.

So, you can find Q. So, Q will be R and into so this R will go here R into l n of sigma 1 by sigma 2 into you will have T 2 T 1 T 2. So, it will go like T 1 T 2 divided by T 2 minus T 1 this is T T 1 and T 2 into yes. So, this way you can find this activation and at the so, you can have the test and you can if you measure the flow stress at the two different temperatures. Then in that case you can find the Q and once you know the Q so, that Q is determined from here that well.

Now, further what we see normally that when we do the plastic deformation; now 90 percent of the energy which is expended which is spend into the deforming the material that is basically converted to heat. So, basically 90 percent of energy expended in plastic deformation is converted to heat. Now, thing is that normally when you go for the plastic deformation of the material so, in most of the plastic deformation you have the in homogeneous flow.

So, what happens that the deformation will be localized and the temperature rise will also be localized. So, what happens that only in the local region the temperature will increase. Now, since because of the you know homogeneous flow so, since they are the deformation takes place so, you will have increase in the temperature. Now, further what happens that if the temperature has increased into that region so, because of that the flow stress value will be cherished. So, flow stress value will decrease because in that particular location where the there has been inhomogeneous flow there has been more plastic reformation.

So, there the temperature will increase and further with the increase the flow stress value will decrease. So, what happens that that process basically continuous and it continuous and ultimately fracture occurs there. So, that is why you have a localized place where this fracture occurs in the case of this plastic deformation. Now, there are some other you know conditions like when you have very high rate of deformation there you have very less time basically and in those case the there will be less times so, for the heat flow to occur.

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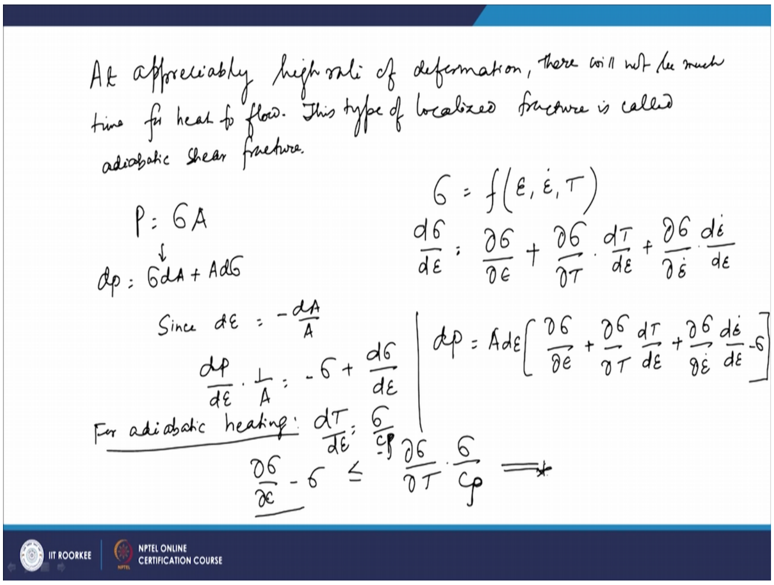

So, at appreciably high rate of deformation. So, those cases there will not be very much time there will not be much time for so, for the flow of for the heat basically. So, in those cases you know the heat flow to occur there will be not much time for heat to flow. So, in those cases you have a basically a adiabatic condition and that is why the fracture which occurs under the those conditions. So, these are known as adiabatic shear fracture. So, this type of localized fracture so, normally is called adiabatic shear fracture. So, we have such cases occur whenever you apply the very high strain rate. So, that have occurs in those cases also normally when you do the temperature at low test.

So, such conditions occurs and there is a drop in the flow curve and also you will see that you will have the (Refer Time: 19:59) in the flow curve that is found in certain cases. Now, there has be certain finding by some of the researchers and Backofen has basically suggested for basically uniaxial loaded specimen. Now, we see is we can see that you we know that P equal to sigma into A and also we know that the flow stress is a function of a strain, strain rate and temperature.

So, what can be written? Now, if you try to see from this expression we can write d p will be sigma dA plus Ad sigma. So, we can write that now, this also if you try to get its derivative with respect to epsilon. So, d sigma by d epsilon if you try to find now, there will be dou sigma by dou epsilon and then it will be you can have all these factors one by one.

So, it will be dou sigma by dou T into dT by d epsilon. Similarly, you this time you can take for epsilon dot that is strain rate. So, dou sigma by dou epsilon rate dot into then you have d epsilon dot by d epsilon. So, this way you can write these expressions.

Further now, what we get is because we know that d epsilon is basically minus d A by A. So, that we know because either d l by l or it is minus of d A by A. So, what we get is we can write the expressions d P by d epsilon we can write because 1 by A so, this 1 by A will come this side.

So, d P by d epsilon into 1 by A can be written as minus of sigma plus d sigma by d epsilon. So, this is the expression which we get for from by substituting this value into the both the sides. Similarly, you can have the another value under expression we get d P as Ad epsilon into dou sigma by dou epsilon.

So, that is what we get from here and then you will have dou sigma by dou T and d T by d epsilon and then plus you have dou sigma by dou epsilon dot that is strain rate. And then this will be d epsilon naught by d epsilon and then you have minus of the sigma value. So, this way this sigma value will come here from so, that will be minus sigma and the d sigma by d.

So, this has this term and then an that way you have minus of the sigma value. So, a d sigma d P by d A sigma is there already. So, you can write these expressions. Now, from here what we see that if you look at for the case of adiabatic heating. So, for adiabatic heating now we can write the expression like you have d T by d epsilon that will be sigma by C P.

So, this is not P this is rho. Now, in this case as we know the C d T and this will be sigma d epsilon that will be the you know energy which is a spent for that. So, which is going into it now that will be basically C into d T temperature raise a because of the plastic deformation. So, plastic deformation that will be the energy which is you know spent for that will be sigma d epsilon. And similarly this is the specific heat of the material and this is d T is a change in the temperature of the material because of this plastic deformation and this is your density of the material.

So, so this way what we see that for the you know for the low temperature deformation the strain rate dependence of the flow curve can be neglected and the flow curve basically the instability will occur when what we see is. So, we can tell that this dou sigma by dou E this dou sigma by dou E and minus sigma. So, if you look at these curves and if you are basically for the low temperature case the, if you neglect these strain rate you know dependence and so, in those cases this dou sigma by dou E minus sigma this comes here.

Now, this has to be less than equal to you have these dou sigma by dou T into sigma by C P. So, this way this is expression which is valid in the case of these adiabatic shear fracture. So, what is clear from this curve this expression is that the load will drop due to this adiabatic heating and this is more pronounced at the low temperature. So, normally the specific heat will decrease at low temperature what we see is so, this is the C. So, the normally this as specific heat value that will decrease at the lower temperature values and you have the strong dependence of the you know temperature on the flow stress.

So, normally when the temperature becomes on the lower side you will have the dependence of the flow stress on the temperature is becoming more prominent. Whereas, when you have the you know in other conditions now, the this can be further seen in a way that when we talk about these temperature effects. So, normally you know that you have different working conditions in the metal forming, you have the selection of temperature.

Like if you take the temperature on the higher side you have the definition as the hot working or the cold working or the warm working where the you have the temperature in between the hot working and cold working. And in those cases these flow stresses can be predicted based on this the temperature and also you have other parameters like strain or strain rate.

So, certainly we have neglected certain parameter in this case, but then dependence can be checked by analyzing these equations. So, I mean you I hope that you are able to understand that how we write these equations. You must be able to understand all the terminologies. Here what we do is that since we have got the d T by d epsilon is sigma by C rho and then for the load to you know for the instability or the load drop in those cases you have one term is dou sigma by dou epsilon minus sigma.

So, that is here and another term this term we are neglecting. So, you have these term dou sigma by dou T into d T by d epsilon. So, d T by d epsilon is again that is your sigma by C rho that is why this comes here. And in those cases your this term dou sigma by dou epsilon minus sigma, if that is lesser than this dou sigma by dou T into sigma by C into rho.

So, this condition comes here and based on that you have this condition. So, that is why we can say that this expression tells this is the expression which is responsible for telling you that why the load is decreasing. Load is dropping due to adiabatic heating and it is more pronounced at the lower temperature site.

So, that is what we will discuss about the effect of these temperature on the deformation behavior, then that time this concept may be utilized.

Thank you very much.