Fundamentals of Materials Processing (Part- II)
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Lecture – 09
Combined Effect of Strain, Strain Rate and Temperature

So, welcome back friends, I hope you tried solving the second part of the problem that we discussed in the previous class. So, let me try to solve it for you and you can check whether you get results same as those.

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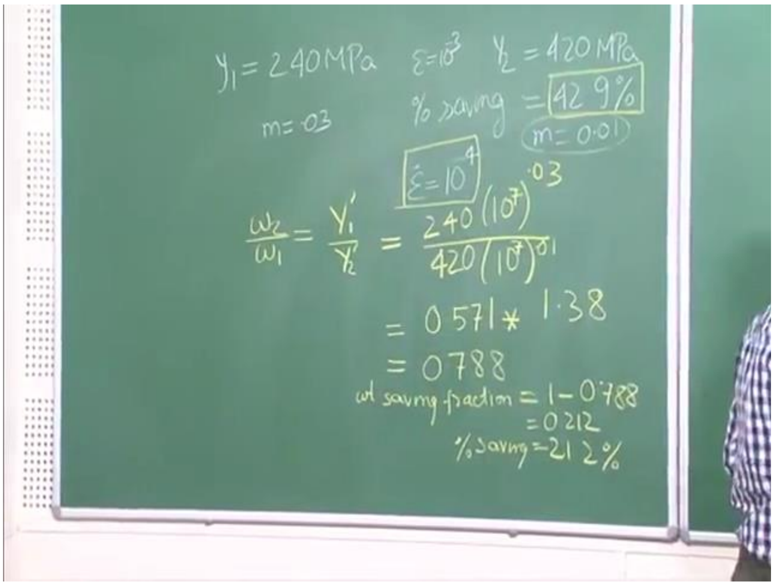

Now what was the problem? Problem was that you are given 2 different material and it was given the yield strength of one of them is 240 MPA which is the low carbon steel and then there was a high strength low (Refer Time: 00:42) steel the yield strength for which was 420 mega paschal.

So, based on that first we solved a simple problem that how much will be the weight percent saving and at this particular juncture we did not consider the effect of strain rate; in effect whatever way this yield strength was measured which was at a strain rate of 10 to the power minus 3 that is what we considered and we found that weight percent saving was 42.9 percent.

Next part is where we see the effect of strain rate; now we are seeing that crush of a car or (Refer Time: 01:26) when it take place then the deformation is at a strain rate of 10 to the power 4, which is 7 orders of magnitude higher than at which we measured their yield strength. Fortunately for us we have m value; m value for this was given as 0.03 and m value for this was given as 0.01. So, now, we what we need to do is basically just like in the previous problem we will w 2 by w 1 that is the weight for this second material by the weight of the first material, is in the same ratio as the thickness t 2 by t 1 which means it is in the ratio of yield strength of 1 by yield strength 2, but now we will not be using yield strength value as it is, what we will be using is the yield strength value measured or calculated for a strain rate of 10 to the power 4 and we know how to do that, you have to just use that equation y equals to c times strain rate to the power m we already know the m value.

Now if you put this together you would see it comes out something like this, this 10 to the power 7 is basically 10 to the power 4 which is this, divided by 10 to the power minus 3. So, this is the ratio 10 to the power 7 divided by 420, again 10 to the power 7 to the power 0.1. Now is remember I also told you that just by looking at the problem you should be able to guess whether the percentage saving will increase or decrease, now it is said that since this is 0.03 which is higher than 0.01 therefore, this yield strength will increase to a much larger value then the increase in this one and therefore, the difference between the yield 2 yield strength will come down will decrease and therefore, the percentage saving would also go down.

Now, here is what we will see. So, this you can see that it will come down to and this come will come out to be. So, this is 10 to the power 7 by 0.03, divided by 10 to the power 7 to the power 0.01. So, it will be 10 to the power 7 to 0.03 minus 0.01, and if you calculate you would see that it comes out to 1.38. Now if you put this, this is 0.788. So, now, weight ratio has now come closer to 1; if it were 1 it would mean that both of them required same amount of materials same amount of thickness. Now it has come closer to 1 then it was earlier and therefore, the weight saving fraction is equal to 1 minus 0.788, which is 0.212. So, percentage wise saving is 21.2 percent.

So, now we had earlier a saving of 42.9 percent, if you had not taken into consideration strain rate which is the strain rate at which the actual deformation will take place then you would have used much less material for this or much thinner material for this particular citric low alloys steel, but if you know the effect of strain rate and we have the parameters to calculate the effect of strain rate, we can now judge in a much better way that actual saving must be 21.2 percent and the thickness of using this material should be 0.788 of the original one; while if we had calculated just assuming the previous one, it would have been it came out to around close to 5 7. So, in that case we said we have to use only 57 percent of the thickness that we would use in high strength low alloys steel. So, that is the importance of understanding the effect of strain rate.

Now, this m value that we see over here is not a constant, we have already mentioned that, but it the variation that you would observe is also not very straight forward and we see a variation of m with temperature, now at this point let me introduce you with what I have been called (Refer Time: 06:18) homologous temperature.

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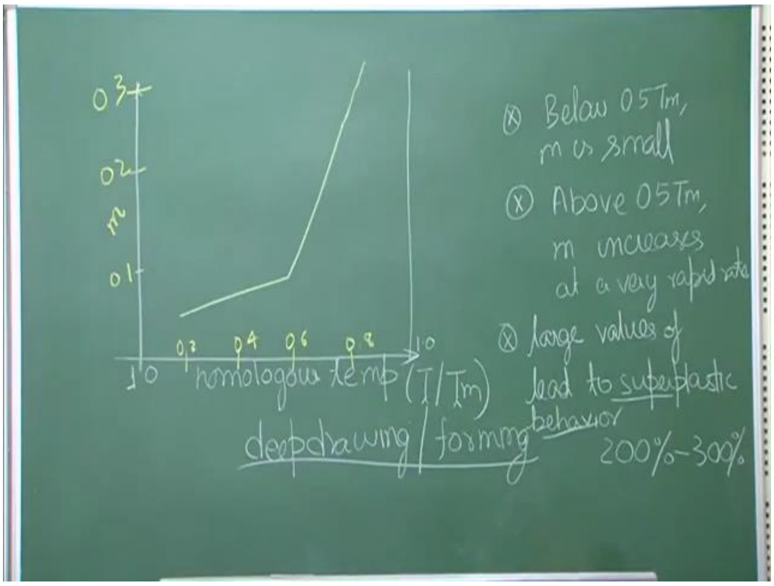

So, this is what is homologous temperature, if you are considering a particular material let say aluminum which as a melting point of 660, then you convert that temperature in Kelvin and whatever temperature you put that material act, so you do divide that by the melting temperature. So, this is T by T m.

So, T is the temperature at which you are interested, let say it is 25 degree Celsius, but even have to convert to Kelvin and it convert melting point to Kelvin. So, the ratio of that is what is called homologous temperature, and it has a very it has got significance why because one that you can see that now your temperature range has been reduce to 1 to 0 right now the range for this homologous temperature is 1 to sorry 0 to 1; on the other hand if we are taken absolute temperature it would have gone for a very wide range for different material, but that is not the main reason that we are using homologous temperature.

Homologous temperature used because with respect to melting point, when melting point is taken in Kelvin most material shows similar behavior and this is what you will also observe over here. So, let say I put a scale over here and this is m. So, what people have seen is that it follows a relation something like this for almost all materials, for almost all materials you would see the variation in m like this. So, up to a temperature close to 0.5 Tm, m is very small it increases with temperature, but not by a large magnitude, but beyond 0.5 T m it just shoots off, there is a very very rapid increase in the m value, which would mean that if you are doing the same experiment now here you remember we did the calculation of yield strength, but we have not taken into effect that temperature effect for example, we have assumed of everything is happening at room temperature, now if we can make it a little bit more complicated for example, if we were talking about components in error space in or a error space material then the temperature would be much higher or for example, a nuclear reactor the temperature would be higher and therefore, the m values would be again very different.

So, here the calculation would again change by a large magnitude therefore, temperature is also another important parameter. So, this is all right now we will talk about temperature, we will come back to effect of temperature in a little bit, but for now just let me point on 2 things: one is that below 0.5 Tm, m is small and above 0.5Tm, m increases at a very rapid rate and another Tm will add over here, you might have heard about super plasticity.

Now, the super plasticity is related to m value, large values of m something like 0.5 need to super plastic behavior; what is super plastic? We will go into detail, but I will just give you the working definition: super plastic behavior is when the material where able to deform a material to a very very large strains without causing defects into it, just imagine again let us gets back to our tensile test, will this time take a compressive test, if you try to do compressive test and if you keep doing the deformation, what will happen? At certain point the material fractures it breaks, but if it was super plastic if it were showing super plastic behavior and these are the usually done at very slow strain rate, you can keep doing the deformation and it will not break it will just keep on deforming as you keep increasing the load the deformation will keep taking place and we are talking about strains of deformation of the order of 200 to 300 percent or even in tensile test it is very seen commonly and as much as up to 1000 percent. So, for example, let say you started with a gage length of 10 millimeter and 1000 percent means, it will increase to 10 times.

So, from 10 millimeter it will become100 millimeter, if you just keep along it in the sample. So, that is the super plastic behavior and in usual case what you will see that the material break at 40 percent, even that is if you start with 10 mm so as soon as you get to a total elongation of 14 millimeter, the material 14 or at the most17 18, but never more than 100 percent the material breaks, but in super plastic behavior it can go usually of the order of 200 300 percent that is 10 to 20 to 30 millimeter and some in some cases it can go up to 100 millimeter. So, that is what super plastic behavior is and there is application to it also for example in deep drawing.

For example, if you see some components which have been drawn; drawn means you would see kind of embossment on to the surface, but very very deep. So, you cannot call it embossment any more, you have put the (Refer Time: 13:02) and the material as elongated along from steel metal into something particular shape, that kind of drawing or forming is called deep drawing and deep forming and over there you need very large plasticity.

So, again we cannot calculate the strain in a very simple way like uniaxial tensile test, but we can take each and every element and there will be several elements inside that component, which will show very large deformation and that will be possible only when the material is showing super plastic behavior. So, super plastic behavior is also very useful and you will be able to predict it by knowing the value of m.

Now, at this point we have seen both strain effect of strain and strain rate. Now let say we are changing not only the strain, but also the strain rate in that case what will be the form of the equation.

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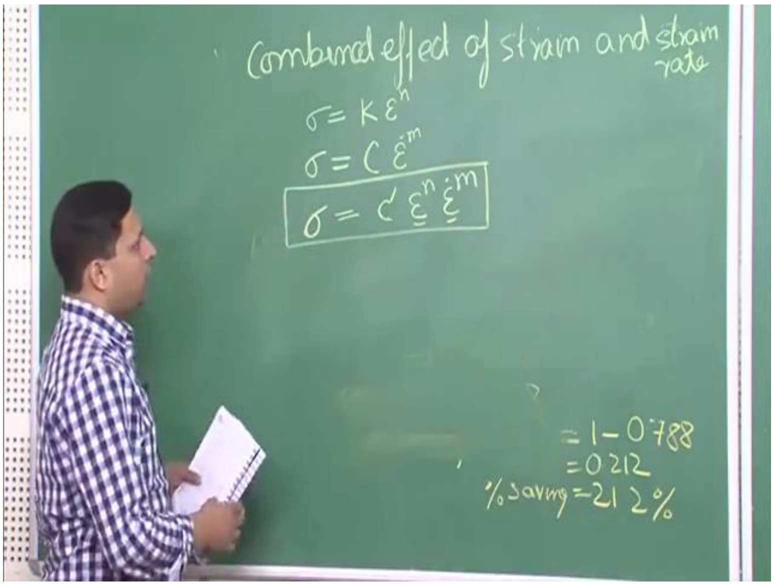

So, let us get to a mode where we have combined effect of strain and strain rate. So, we saw that if you had only the effect of strain meaning the strain rate was kept constant then we get power law kind of equation, which is written like this and when you have only strain rate that is influencing meaning strain is kept constant then we used equation like this. When we have both strain and strain rate that have varying in the 2 different test, that we are carrying out or through when we are compare trying to compare 2 different conditions, then in that case test is given by equation like this.

So, this equation combines the effect of strain and strain rate and again C is another constant it is not one of these constant, you will have to determinate in this separately, but if this equation over all once you have been able to determine the value of c prime you will be able to estimate or predict what will be the stress value, yield strength value for a given strain at a given strain rate. So, this is a very useful again equation that can be utilized. So, I will leave it leave this effect as strain and strain rate at up to this point, we will now move on to the effect of temperature, again we have let us look at we have already seen one effect of temperature over here and that is on the value of m, but that is not all, temperature has independent effect on the material for example, just imagine that you are doing the deformation at low temperature versus high temperature, never mind what is the value of m.

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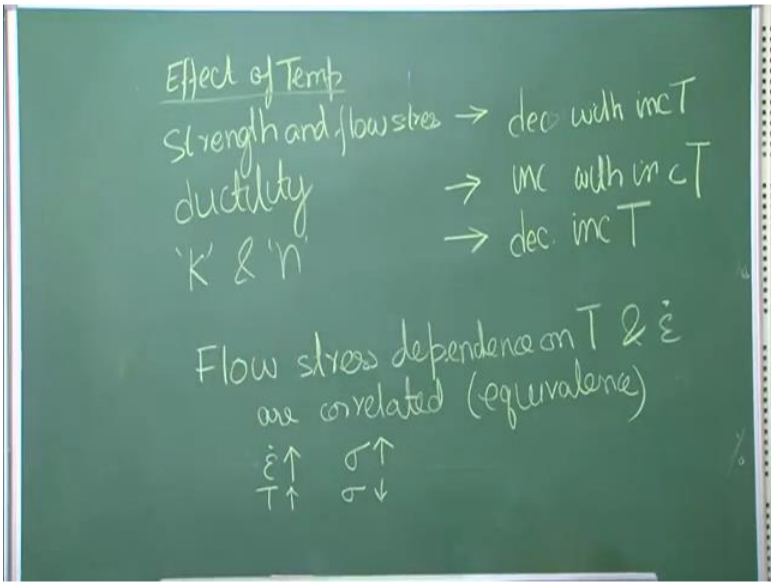

What would you think would happen to strength and flow stress? So, we are looking at effect of temperature.

At high temperature what will happen to the strength and flow stress of the material? Do not worry about what will be the m value, we are let us will come back to that later on, but for now what do you think would happen to the strength and in a flow stress or something like ductility or if you are doing using a power law equation, what happens to k value and n value? Do they remain constant or do they change? Now for this most of you would know that if you increase the temperature, strength of the material as well as the flow stress of the material decreases. So, if you increase decreases with increase in temperature.

Ductility: we have already seen that m increases, but even if m or n 2 remain constant, we know from material properties that the material will be able to deform for a longer region or the deformation ductility will improve under is micro structural explanation for that will come back to that to that after we are completed with effect of temperature.

So, ductility if this increases with increasing temperature; what happens to k and n? Now directly from that equation we see that since the strength decreases. So, probably something over that decreases, either k or n and it is so happens that both k and n decrease with increasing temperature. So, we have these are some of the important effects of temperature and we are not even we are not looking at it from the point of view of the strain rate sensitivity factor m, in general what will happen to the material and its properties when the temperature is increased.

Now there is more deeper correlation between temperature and another parameter that we have studied which is strain rate. Flow stress dependence on temperature and strain rate are correlated or there is a equivalence, the better word will be equivalence although you would see that their effect is inverse to each other. So, when we increase the strain rate the flow stress increases on the other hand when the temperature is increased flow stress decreases, but the origin for both of this phenomena not even similar they are same, they are both related to the this location movement we will we are not talking about again we are not getting into the in depth understanding of mechanical behavior of material, but (Refer Time: 20:13) to say that the origin for both these are same and that is why 2 scientist name Zener and Hollomon came up with the parameter which can give an equivalence between these two.

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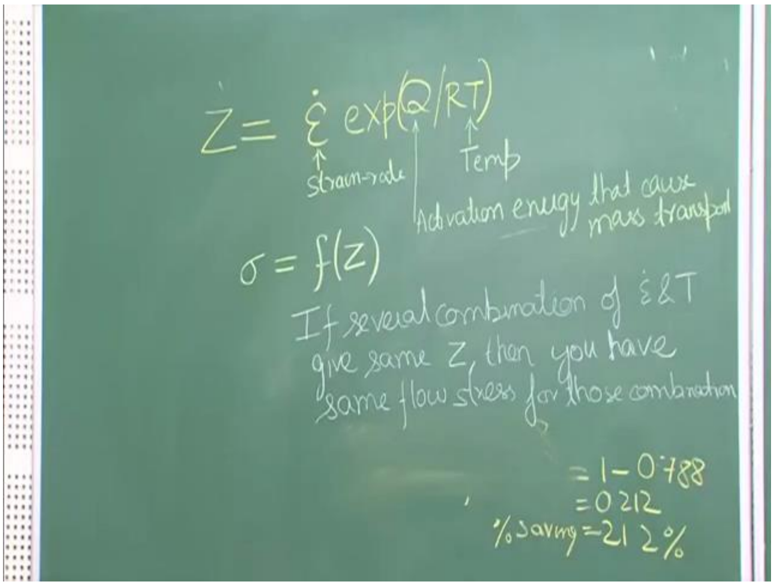

And therefore, this is also this parameter is also called as Zener Hollomon parameter and this is written as. So, this is your usual strain rate, this is your temperature, this is your gas constant and Q is the activation energy for the phenomena that is leading to the mass transport.

So, for example, if we are doing a deformation where grain moderate is dominating, when this Q would be the activation energy for diffusion through grain moderate; if you are talking about single crystal and doing the deformation then Q would be the diffusion through the lattice. So, depending on the condition, configuration and the temperature range the Q would be different it will depend on. So, you will have to have advance understanding of what particular mass transfer process is taking place, but we will not again get digress on to that. So, what we want to look at is that there is a equivalence. Now what you see here is that this parameter Z, is giving strain combining strain rate and temperature, but this is just one part of it the important part is that the sigma value the e flow stress is actually a function of this parameter Z.

What this means is that there may be several combinations of strain rate and temperature which give you the same Z value and since flow stress is a function of Z therefore, for all that combination of strain rate and temperature you would get same flow stress value. So, that is the important aspect, now you are able to get for different strain rate of course, at the same time you will have to change temperature under still get the same flow stress value. So, let me write it down in words, if several combinations of strain rate and temperature give same Z which is the Zener Hollomon parameter, then you have same flow stress for those combinations. Now based on this let us say we take a constant Z value, you can also predict that if you plot strain rate verses 1 over T strain rate in log term because one of them is in exponential form and other is out of the exponent.

So, if you were to plot or before that let me even make it simple since we have written Z equal to strain rate times exponential Q over r t.

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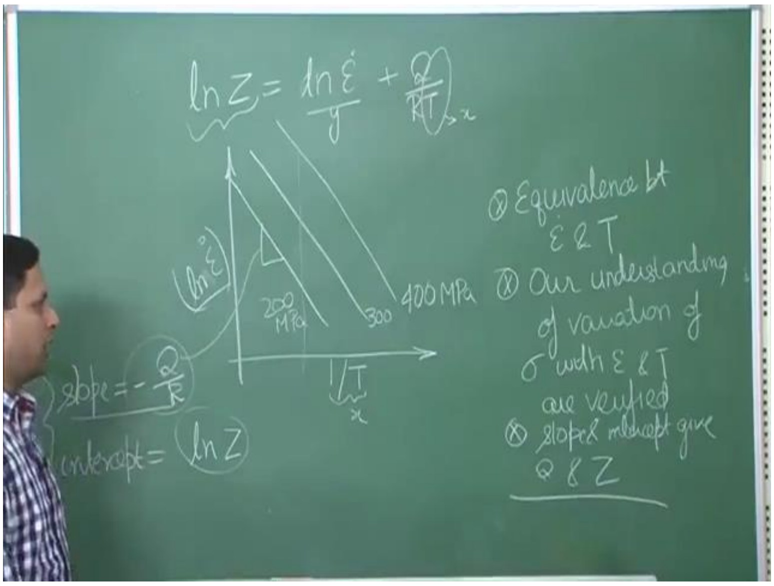

Now, we will simplified as ln Z is equal to strain l n strain rate plus Q over RT. now from here what you see is that if you plot strain rate on the y axis ln strain rate on the y axis and 1 over T on the x axis, you would get a straight line. So, this is of the form of a linear equation. So, you have y equal to mx plus c where this is y, this will become your m, this will be your x and this will be a constant c and therefore, what you would get or equation or lines like this. So, this is your y like we said this is your y, 1 over T is your x, now you will what you will get or straight lines like this and each of this straight lines represent actually of unique stress unique flow stress.

So, for example, this side it will be increasing. So, it is 400 mega paschal, it could be a it is just a schematic I am not giving you absolute values just take it as schematic of how the flow stress is changing. So, this is your like I said y axis there is x axis and since this is your slope, the slope would give you the value of Q over R. Actually it will be minus Q over R because y is over here. So, you will take this on the other side and therefore, it is minus Q over R and that is why you see the slope is negative. So, the slope is equal to minus Q over R and intercept also has if you remember from your high school geometry in the when you have a y equal to m x plus C kind of equation, the intercept is equal to this constant value which is ln Z.

So, we are once you are able to draw a plot like this, you are able to see not only the equivalence between strain rate and temperature to we do see that there is a equivalence between strain rate and temperature although it is clearly saying that once you increase that. So, the temperature is increasing in this direction. So, if increase the temperature the yield stress is decreasing; on the other hand the strain rate is increasing in this direction. So, if you go along a particular temperature like this. So, when you increase the strain rate, your yield stress increases.

So, all the things that we know are true this plot is also saying that there is (Refer Time: 27:50). So, that is a kind of you can say secondary verification that what we have drawn here is right and at the same time we are talking about l n strain rate and not absolute strain rate therefore, the order of magnitude increase in strain rate has to be very large something like 2 or 3 orders of magnitude to get are very substantial increase in flow stress. So, second is that our understanding of variation of sigma with strain rate and T are verified and another important aspect is that we are able to get into this slope sorry. So, we are able to get the values of Q by R and l and Z from this slope and intercept.

So, let say you are able to get this plot experimentally, then from this experimental plot you can measure the slope and from the slope you will be able to measure minus Q by R and since R is a universal constant you will be able to get Q. So, you see we do not need to get into the (Refer Time: 29:17) of what particular process is taking place, but just by looking at or measuring the slope you can find out Q and. In fact, you can predict from this or understand from this what kind of mass transport phenomena is taking place. So, the final one is that slope and intercept give Q and Z values.

So, we will leave it at this point and will come back to our understanding of or to improve our understanding of effect of temperature where from this it must be clear that temperature has influence or effect in more than one ways. So, we will come back to this in next class.

Thank you.