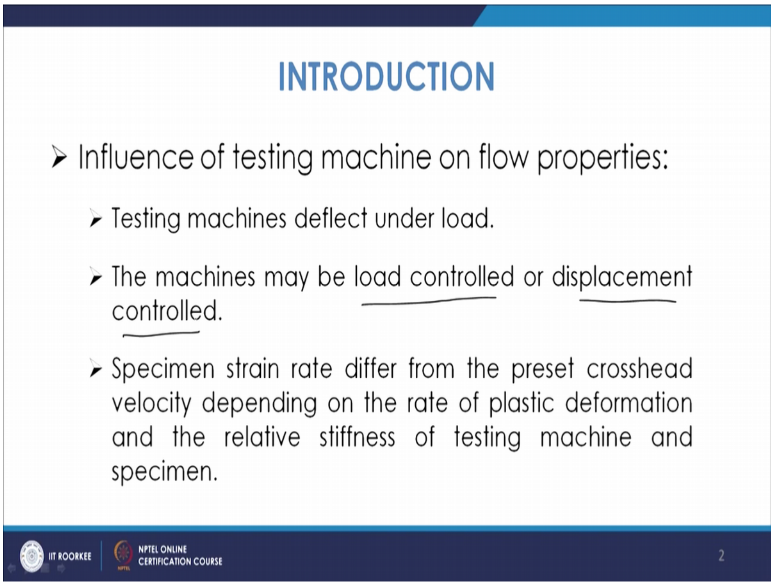
Principles of Metal Forming Technology
Dr. Pradeep K. Jha
Department of Mechanical & Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture - 20
Influence of various parameters on flow properties

Welcome to the lecture on Influence of various parameters on flow properties. So, in this lecture we are going to discuss about certain other parameters other than the temperature which affect the flow stresses values or the stress strain behavior of the material. So, in that first of all we will try to study about the influence of a testing machine.

So, the machine on which we are testing you have the cross head velocity is there which is given certain velocity to you know to do the tension, you know test of the specimen. Now, if you see that even the testing machines also they are deflecting under the load. So, the testing machines normally of are of two types you have the load control machines.

(Refer Slide Time: 01:24)

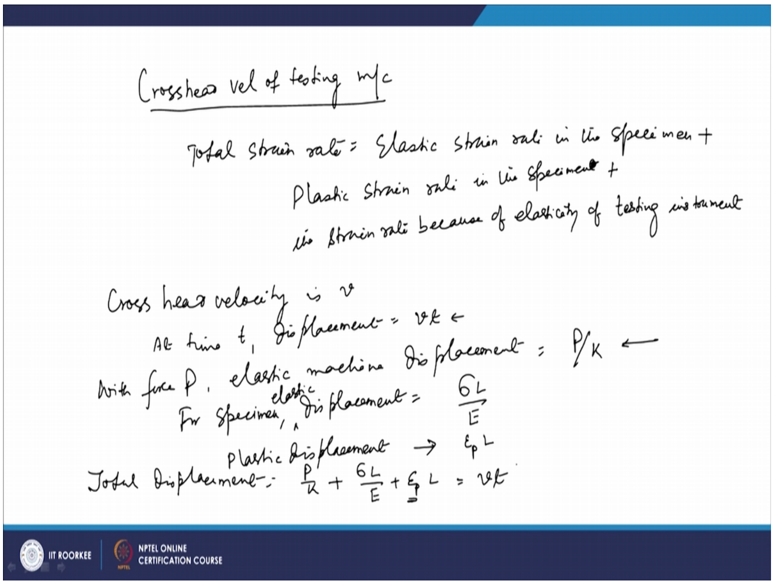


So, you have the either the load control machines or the displacement control machines. Now, in this load control machines you know the load and you do not have much control on the displacement so, you will have to live with whatever displacement comes. Now, in the another case when you have the displacement controlled machines so, you know the you have to have certain displacement for that it will adjust the load.

So, you have different type of mechanisms for controlling that and that way you have the earlier which were the hydraulic driven machines which were working they were the load control machines. Whereas, the screw driven machines are there which are the displacement control machines; nowadays you can control more accurately in the modern era where you have the computer control, you can control the things more accurately. So, basically the specimen strain rate will be differing from the preset cross head velocity depending on the rate of plastic deformation and the relative stiffness of testing machine and specimen. So, we will discuss how this comes to be true in such cases.

So, if you try to analyze the situation what we see that most of the testing specimen testing machines they will be deflecting under the load and that is to be you know taken into account, because you cannot directly convert them you this crosshead velocity into the deformation of the specimen. So, you will have to do the appropriate corrections in the system.

(Refer Slide Time: 03:21)



Now, if you look at the cross head you know velocity. So, if you look at these crosshead you know velocity of the testing machine. Now, these are applying the strain rate basically so, the total strain rate which is applied. So, total strain rate applied it will be sum of so, it will be sum of basically the elastic strain rate in the specimen plus the plastic strain rate in the specimen and the other part is that the strain rate which is resulting from basically the elasticity of the testing machine. So, the strain rate because of elasticity of testing instrument or machine.

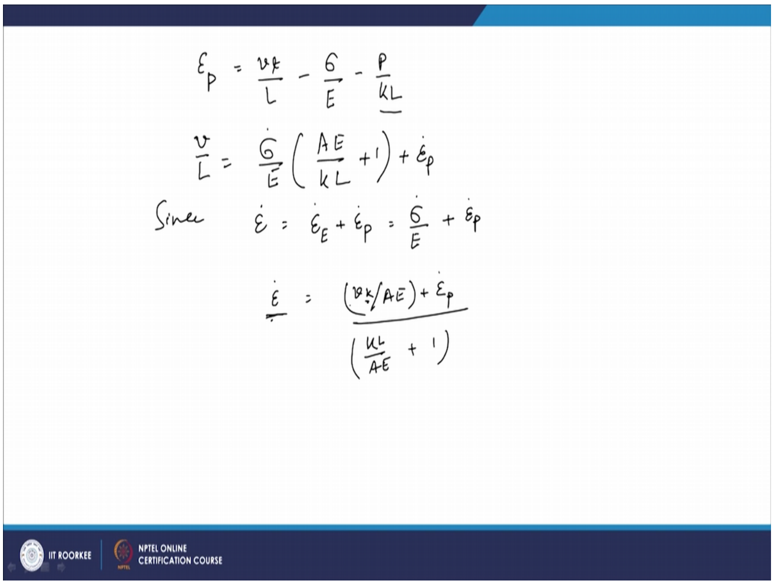
So, you have two things one is the elastic strain rate in the specimen that in the elastic zone similarly, you have the plastic strain rate that is in the so, this is specimen and then the then again you have the strain rate because of the elasticity. So, there will be that deflection with there because of the load and because of the property of the instrument itself it subjected to certain load. So, that way it will have the effect on the strain rate and that is to be basically taken into account while we deal with that. Now, if you take the crosshead velocity as v if the crosshead velocity is so, we have already seen that crosshead velocity is taken as v. Now, so, at a at any particular instant I mean at particular time t the total displacement will be v t.

So, at time t is displacement will be v t. So, now, actually when we are applying the load P, now this force P will be creating the on the specimen it will be causing the you know you have the elastic machine displacement also; if the machine is there which is subjected to that load. So, with force P so, when we are applying so, that it basically acts on the machine also and in that case the elastic machine displacement it will be depending upon the machine stiffness. So, it will be the P by K. So, that is your because of the this machine properties then if you come to the specimen for specimen displacement will be sigma L upon E. So, that is basically for the specimen in the elastic region.

So, this is basically the elastic displacement. So, we can write these elastic displacement because we are talking about in the elastic region and in the elastic region you have the application of Hooke’s law. So, you will have sigma L upon E similarly, if you have we are talking about the plastic displacement. So, plastic displacement so, plastic displacement will be epsilon P into L. So, so, you have three components one is for the machine that is P by K, you have for the elastic displacement of the specimen that is sigma L upon E and then you have plastic displacement for the specimen and that will be epsilon P into L.

So, what we see that the total displacement if you look at the total displacement will be the summation of the two these three components. So, total displacement it will be summation of this P by K then you have sigma L upon E and plus epsilon P into L. Now, what we see is that you have to take this epsilon P. So, this epsilon P you know you can it can be taken from the load time chart on the constant crosshead, you know velocity testing machine and you know that has to be corrected. So, you must have this as a constant value and for that all these are corrections required.

(Refer Slide Time: 09:01)



So, if you go to the expression what we get is you get the epsilon P and that will be coming as v t by L. So, if you look at this earlier expression now, this expression this is nothing, but the total displacement what we discussed the displacement v t so, this v t it will be similar to this. Now, if you go to further so, if you take epsilon P on one side you will have v t by L minus the two terms will go on other side. So, it will be sigma my by E and then you will have P by KL. So, epsilon P will be so, we have we have seen this expression epsilon P into L. So, L will be divided on both the sides and that way you will have this expression v t by L minus sigma by E minus P by KL.

So, that is what sigma by E L will go away and then you will have a P by KL. Now, what we see is that from here we can write so, what we see that there is a major influence you know of the machine and the specimen interactions. So, this is because of the machine interaction and you have a specimen interaction and they have effect basically on the strain rate. So, if you are treating that stress you know stress rate as sigma dot and the strain rate as epsilon dot.

So, we can write so, we can write actually v by L as sigma dot by E into AE by KL plus 1 plus epsilon dot P. So, if we take the you know rate component now, if you look at this. So, this will be epsilon P plus sigma by E plus P by KL now, if you keep the v by L on one side then in the in that case this will be sigma by E and plus P by KL and this t will be you know because that way sigma t will come. So, that will give you this sigma dot that is your stress rate and similarly you will have this term as the strain rate and then all the terms will come in between. So, that way you can have this v by L as the this term sigma dot by E into a E by KL plus 1 plus epsilon P dot.

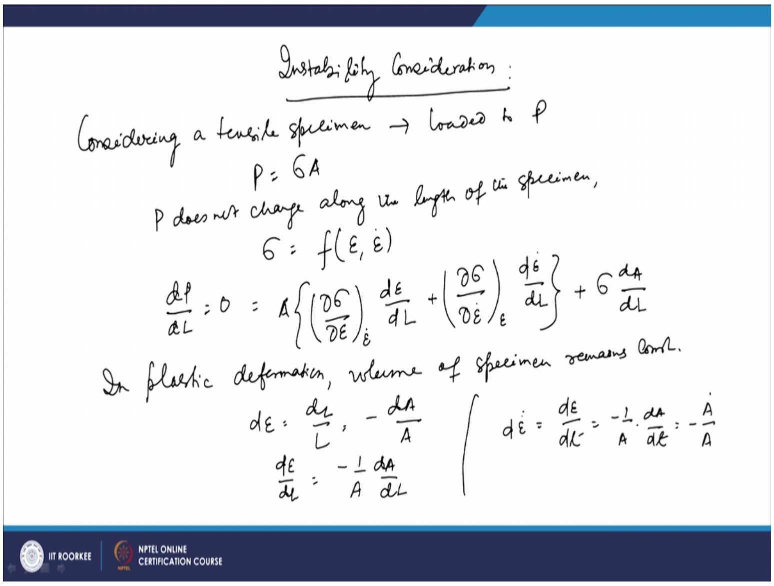
Now, as we know further since so, what we see that if you talk about the strain rate values now this is nothing, but you have in the elastic part plus you have the plastic part. And that can be written as the for the elastic part you have this by the elastic modulus and then you have the plastic part of the strain rate. So, if you talk about the strain rate finally, that that come can be written as v K by AE plus E P. So, that will be epsilon P dot divided by KL by AE plus 1.

So, this way you can have the value of these strain rate which can be controlled and this is to be control. So, once you have this K value know you must know that. So, what we say that for having the proper strain rate value these you know parameters have a say on non attending or the value which we try to achieve for calculating or for analyzing or for drawing the proper flow stress curve, flow curve or so.

So, now it is clear that this strain rate what are the specimen strain rate that will be basically differing from this v. So, this is the crosshead velocity and that is preset. So, if you have a given a preset crosshead velocity and that is not actually the actual strain rate basically, that is changing because of the stiffness of the machine. Now, the machine which has the you know more stiffness they are known as hard machines. Now, for the you know you have hard machines as well as the soft machines. So, hydraulic driven machines are known as the soft machines and screw driven machines are known as the hard machines because of the you know value of the K and K it will be ranging from 7 to 32 basically meganewton per meters.

So, based on that you will have the other you know this values that you know corrections which is to be there, it is to be incorporated and you will have the different you know impressions, different type of characteristics will be there in those stress strain curve when we do for on the hard machine as well as on the soft machine. Now, basically we are going to discuss about the different criteria that is the constriction of constitution of instability.

(Refer Slide Time: 14:52)



So, we are talking about the instability considerations. Now, we have already discussed about the stability in the criteria while, necking and normally we assume that the flow stress will be depending only on the strain. But we will see that how it is sensitive to the strain rate so, that is to be understood. Now, suppose you are considering a specimen so, considering a tensile specimen which where you apply the load value so, loaded to P.

So, we are loading them to a value of P now, any instant of time it is assume that the cross-sectional area is A so, P will be sigma A. Now, actually P is not changing while we are basically doing the tensile testing on the specimen. So, P does not change along the length of the specimens along the length it is not changing not during the specimen I mean testing, but along the length of the specimen and the flow stress value we are assuming that it is a function of strain and strain rate.

So, so, you can write that since it is not changing with the length of the specimen so, dP by dL will be equal to 0 and that will be basically if you look at so, it will be dou sigma by dou E and that will be at constant strain rate. So, dE by dL so, that is with respect to L and then you have also dou sigma by dou epsilon dot that is with respect to strain rate and then further you have at this is at constant strain and then d of epsilon naught by dL.

So, that is what we are doing for the sigma so, sigma at this time A this is d sigma and similarly you have sigma dA so, sigma into dA upon dL.

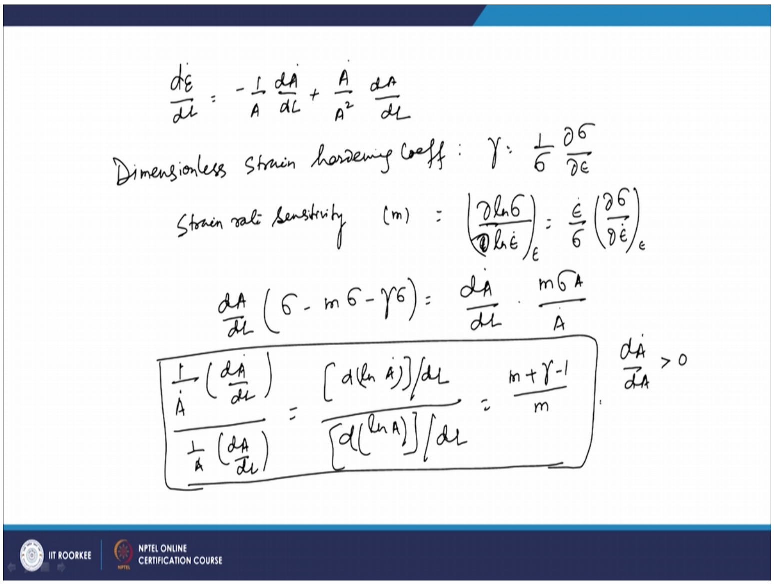
So, that is what I mean you are getting dP by dL so, dP will be sigma dA plus Ad sigma. So, Ad sigma if you find the d sigma it will be dou (Refer Time: 17:57) first of all since sigma is a function of it depends upon the (Refer Time: 18:03) the strain and the strain rate. So, we have a separately done this you know find the derivatives.

So, first with respect to epsilon at epsilon naught at a constant value of strain rate then at a constant value of strain with respect to the strain rate, then d epsilon naught by dL plus this so, this can be found. Now, when we are talking about the plastic deformation so, the there is no volume change. So, so, in plastic deformation volume of specimen remains constant. So, what we write? We write d epsilon as dL by L and that is minus of dA by A.

So, we can write further that d epsilon by dL will be minus of 1 by A into dA by dL. So, so, this is to be further used when we go to that now, this equation that is d epsilon equal to dL by L equal to minus dA by A. So, that can be written further and we can write that d epsilon naught so, we have to convert we have to express for the strain rate. So, d epsilon naught will be actually d epsilon by dt that is what so, you have d epsilon you know we know it; now that can be minus of dA by A. So, it will be minus of 1 by A into dA by dt.

So, we can write this as this is dA by dt is A dot that is you know rate of change of the area. So, it will be minus of A dot by A. So, this d epsilon naught can be taken as minus of A dot by A. So, if you substitute this further so, in the expression for the d epsilon dot by dL; in those cases we can write that d epsilon dot by dL, it will be minus of 1 by A and then dA dot by dL plus A dot by A square and dA by dL.

(Refer Slide Time: 20:37)



So, so this way you have the expression for the d epsilon naught by dL. Now, what we do is we define some material quantities and the material quantities which we define is, one is dimensionless strain hardening coefficient. Now, this is basically we defined as gamma and this will be 1 by sigma and dou sigma by dou epsilon. So, this is known as dimensionless strain hardening coefficient and similarly you we define this strain rate sensitivity.

Now, this strain rate sensitivity that is your m so, this we call it as m and this we know that this is sigma by epsilon. And then that so, dou of sigma by dou of ln epsilon naught and this is what the extended sensitivity is and this can be written as dot by sigma because this will be 1 by sigma. So, sigma will come down and then this epsilon dot will come up and then you have the dou of sigma by dou of epsilon dot. So, that is at a so, this is also at constant strain; so, this will be at constant strain. So, now, if you use these to you know equations from here to find.

Now, they can be further put in the earlier equations and what we get is we get these equations like dA by dL into sigma minus m sigma minus gamma sigma that comes as dA dot by dL and into m sigma A divided by A dot. So, this is what we get by substitute these values and from here if you do the final rearrangement you further do the rearrangement; what we get is we get 1 by A dot into dA dot by dL divided by 1 by A and dA by dL.

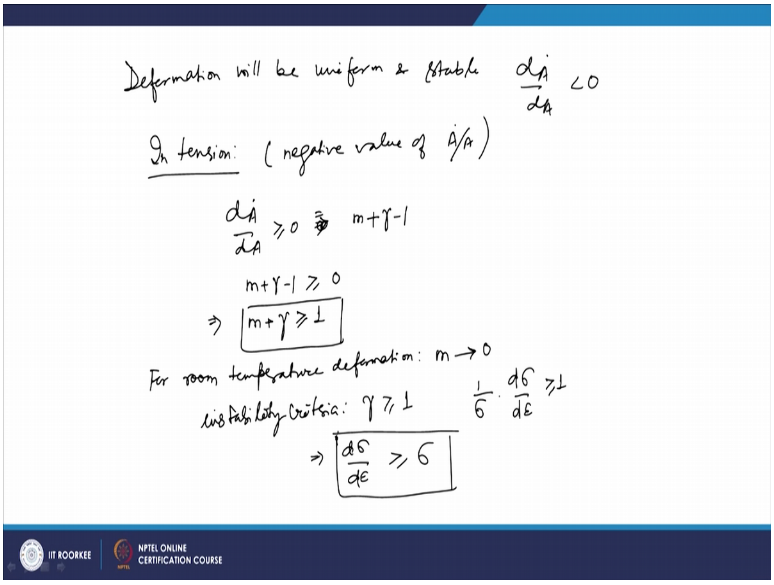
So, this will be equal to d of ln A dot by and by dL divided by d of ln A and then by dL and that can be taken as m plus gamma minus 1 divided by m. Now, what we see is that these A dot and this can be expressed in terms of these you know dimensionless values, these strain rate sensitivity value m you have the dimensionless strain hardening exponent. So, that way you get this expression. So, this expression basically this expression what we get this expression actually that is describing the rate of change of area that is dA dot you know and that is it will be correction for the you know onset of necking.

So, in those cases when the necking will be occurring what will be the correction required that can be you know seen from this expression. Now, for any specimen which is going to vary its length you know so, along its length actually you will have the variation in the across sectional area. And that may be because of many reasons you may have the taper, you may have the machining errors. So, where ever you go if you go along the length there may be the change in the area dA.

Now, in those cases there may be other reasons also like there maybe heterogeneities of the structure. Because of that also you may have at some point, you know you may have something like some impurities or some places where you had some shrink is cavities or source. Because of that at some localized position you may have the you know change in the cross-sectional area and because of that you will have the weaker section there and that will lead to the you know you know deformation starting there.

So, basically deformation becomes unstable there that place at those these you know smallest cross section area that will be shrinking faster than the rest of the things. So, that occurs so, for that to occur the condition is that this dA dot by dA and that has to be more than 0. So, for this condition what will happen your this specimen will shrink faster, now as long as this is less than 0.

(Refer Slide Time: 26:52)



So, for the condition which can be interpreted is that the deformation will be uniform and stable. So, as long as this dA by dA dA dot by dA and it has to be less than 0, but once you know if it is more in that case it will not be stable. So, now in when we talk in tension already what we know is that the dA dot will always be negative because the area is decreasing. So, the decrease from the final area to the so, the that difference between the final cross section to initial cross section will always be negative.

So, in the case of tension this value will be negative and so, it will be negative value negative value of A dot by A. So, so, in those cases the stable deformation in tension will occur when this dA dot by dA will be more than 0 and that is why so, dA dot by dA; as we talk about because in the case of tension your dA dot is anyway negative. So, for that to be positive now, in those cases that has to be more than 0. So, that is why it will lead to you know in the case of m plus gamma minus 1 already we have seen these values.

So, this will be equal to m plus gamma minus 1. So, m plus gamma minus 1 that has to be more than equal to 0 and that is why the condition for in for this tension case is that m plus gamma must be more than equal to 1. So, it shows that both these you know strain hardening strained hardening as well as these strain hardening both are suppressing the onset of necking. Now, this equation tells that both basically suppress the necking and when you are going for the room temperature deformation in that case so, for room temperature deformation. Now, for room temperature if deformation your m is basically turning towards 0.

So, that is why this instability criteria instability criteria will be you can that can be reduced to gamma more than equal to 1. And we know that this gamma is defined as so, so that is why this will be 1 by sigma into d sigma by d d epsilon that is more than equal to 1. So, this is giving you the further necking criteria that we know that is basically d sigma by d epsilon and this is basically more than equal to this sigma will go that side so, this is the necking criteria. So, what we see is that you have if you talk about these necking criteria this is the criteria which is coming for by taking into these when parameters like strain rate or strain rate sensitivity or so.

So, so this can be further you know analyzed, you can further see its on other interpretation when we talk about the Newtonian viscous fluid. We which where without strain hardening case you have when the gamma is 0 and you have m is more than equal to 1. So, that is for the Newtonian viscous flow that is opposite to its so, that is case for the instability in those cases.

So, that is how it is interpreted and we can use these concepts when we talk about the analysis of deforming processes in the coming lectures.

Thank you very much.