Principles of Metal Forming Technology
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Lecture – 25
Metallurgical considerations in metal forming

Welcome to the lecture on Metallurgical considerations in metal forming. So, we discussed about the different type of forming processes. We discussed about hot forming, cold forming, others. Now, we discuss about some other parameters, which have the effect on the, forming you know methods or the criteria's while selecting the, you know particular forming processes. So, in that first of all, let us have the, you know effect of the strain rates. We have already discussed somewhat about the effect of the strain rate.

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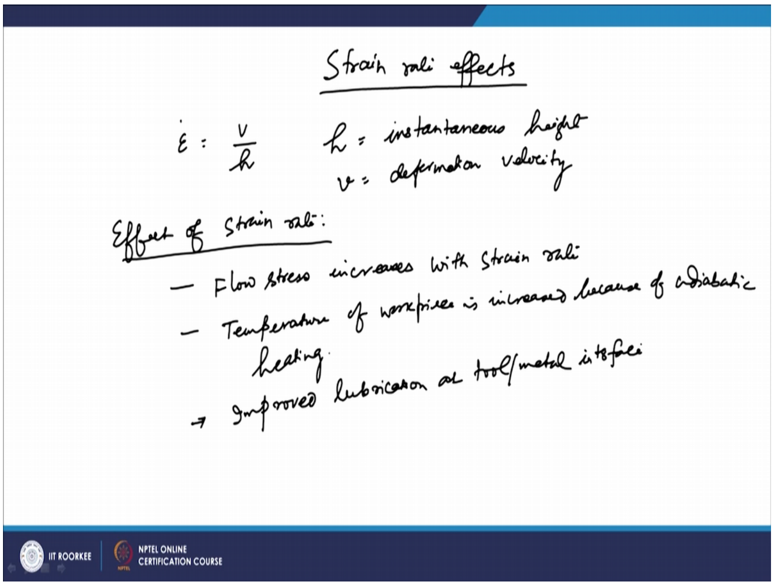

So, when we talk about the strain rate effects. Now, we know that how we define, this is strain rate and strain rate is nothing, but epsilon dot wise there. So, d epsilon by dt in that case, it was defined and normally, we define this is strain rate as v by h.

So, you have a, this wise our deformation velocity and this is, h is a instantaneous height. So, if you are trying to a compress a, cylinder or any specimen in that at any particular. So, this is basically, the true strain rate in that case. So, the true strain rate will be calculated using these methods. Now, depending upon the velocity the strain rate will be obtained and strain rate is normally expected to create certain effect, in that case that if you have the; so, in this case you have such h as the instantaneous height and b is, v is the deformation velocity. So, this is basically the definition for the true strain rate for up setting, a cylinder in compression. Now, many a times we must know that how these strain rates are going to effect the deformation processes.

So, the effect of the, the effect of these, strain rate; so, effect of you know strain rate is that, one thing is that the flow stress will be increasing with the increasing strain rate. So, now, first effect is that flow stress increases with strain rate. This is typically true for metals, because when you increase the strain rate, the flow stress required for doing the, you know plastic deformation that will be increasing. The second effect is that the temperature will be increasing.

So, temperature of work piece is increased, because of adiabatic heating and it is, third effect is the improvement in the lubrication at the interface. So, so there is improved lubrication at tool metal interface. So, as long as this lubricating films are maintained, it will be improving the lubrication at the tool metal interface. This is the, you know effect of these, strain rate, when we talk about the deformation of the materials in any case, especially in the, plastic deformation region.

Now, many times we also try to, because as you know that we have seen earlier when we analyze the metal working, what we say is that as you move in certain direction. So,, this h will be varying. So, when you have a converging die, the h will be varying as you move actually. So, in those cases, we try to define, these you know strain rate, as you know mean strain rate. So, that will be a function of the x. So,, in, in those cases when you know, when we use the converging dies, where h varies with axial distance.

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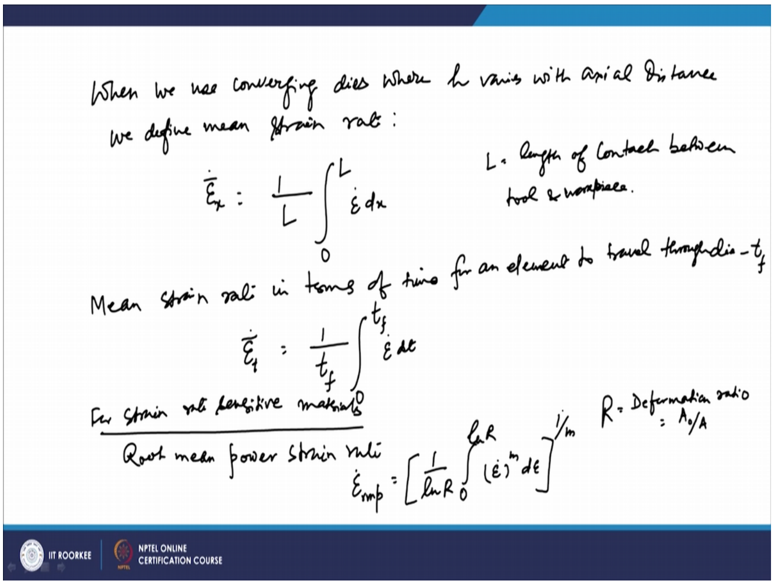

So, that is what we have. We had earlier seen in, in, in that case where we have the converging dies and as you move axially, that h will be varying. So, in those cases, we define, mean stream rate.

So, that will be basically in terms of, taking the parameter x into account. So, in that case we are going to define it as, this one epsilon x, you know bar dot and that will be basically; so, you have L. L is that, the length of contact. So, that will be contact between the tool and workpiece. So, we are dividing it and then we are getting the integrated value between 0 to L and that will be epsilon dot dx. So, this way we get the mean stream rate and where L is the length of contact between tool and work piece.

Similarly, many a times, we also try to define these strain rate in terms of you know, the time, during which it is, you know going under the deformation process. So, in those cases, we are taking that t and we must know that for how much time that, you know it is going to travel through the die. So, again, you know when we can have the mean strain rate in terms of time, for element, for an element to travel through die; so, suppose it is t f.

So, if t f is that time see if, if you take that time into account, in that case we again define this, as compared to, for this parameter t and in that case we define it as again. We define it, divide it, by this total time, you know this time for which it is going to travel that element through that die and that will be again, you know multiplied by this integral and that will be, epsilon dot dt and that will be 0 to t f.

So, this way you try to get the expression for the, you know mean stream rate in terms of time, further there has been, you know expression for this, you know, power strain rate in terms of root mean power strain rate. When we talk about the, you know strain rate, sensitive materials and for that; so, for strain rate sensitive materials. So, so we know that you have this parameter m. So, for that we will find again this root mean power strain rate.

So, there we defined as root mean power strain rate and this basically is defined by the expression and that expression is like epsilon dot RMP root mean power, that is strain rate and this will be basically 1 by l n R and then it will be 0 to l n R and it will be epsilon dot raised to the power m. So, that we know that m is the strain rate sensitivity and then you will have the d epsilon and since we have, taken this power m.

So, we are going to have this power has 1 by m. So, that is how you know, you have taken the integration from 0 to ln R. So, R is basically the deformation ratios, in this case the R is deformation ratio. So, that is A naught by A. So, that is known as the deformation ratio and here. So, that is what you know, when we define the strain that, this l n R will be true strain in that way. So, and then once you are giving this power m, that is strain rate sensitivity, then ultimately you are, giving the exponent 1 by m to neutralize that effects.

So, you are getting this, root mean power strain rate. So, this way, these strain rates are, coming into picture, when we talk about, if the, the effect of these strain rates. Now, the thing is that, these strain rates or, or the velocity, you know have, you know the crosshead velocity. So, you have, then you have the deformation velocity based on, that you have the strain rates. Now, this strain rates basically, vary from very small value to very large value. So, when we talk about certain processes like you have normal tension test, in those cases the strain case values are very-very small and that is normally in the range of 6 to 10 raised to the power minus 7 to, you know 6 into 10 raised to power minus 3.

So, that is the strain rate ah. So, that is velocity basically, you know, what we, encountered the velocity, in all the island based on that basically in what, you know, what is the zone, where the deformation is taking place, the strain rate will be determined so.

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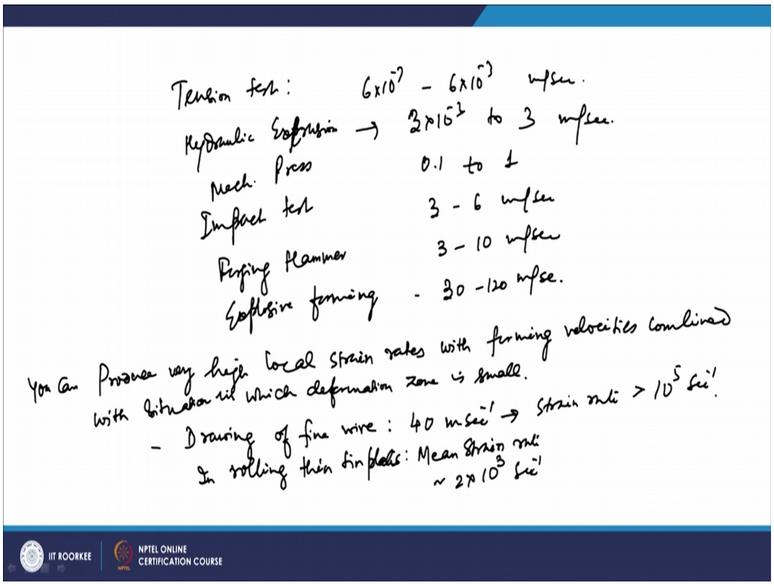

So, we have already seen that if you have normal tension test. The velocity which is encountered is minus 7 to 6 into 10 raised to power minus 3 meter per second. Similarly, if you have a hydraulic you know extrusion or that is through the press ah. So, in those cases you have 3 into 10 raised to power minus 3 to 3. So, that is the, range of velocity. Similarly, you if you have mechanical press in those cases, it is coming from 0.1 to 1. So, then, then if you do, do the impact test like Charpy impact test, in those cases what we get the velocity, it will be 3 to 6 meter, per second ah.

Similarly, if you have the forging hammer; now, forging hammer in those cases you get from 3 to 10 meter per second and, the maximum what you get is normally for the explosive forming. Now, in, in those cases, in the case of explosive forming, you get the range from 30 to 120 meter per second. So,, what we say that this deformation velocity, this is the deformation velocity for the different testing operations and this is normally, you know more than the you know crosshead velocity in most of the, you know, for most of the equipments. So, it will be, larger than the cross header velocity in the standard, tension test.

Now, when these velocities are combined with the zone, you know, if they are working on a smaller zone, in those cases, you can get very high local strain rates. What we have seen that you have strain rate is v by h. So, now, the thing is that, one thing is that, when the, there is deformation going on, there also you see that as the h will be changing your strain rate will be changing, but another point is that if this deformation, you know it is, I mean defined or it is confined in a very smaller zone. In those cases, the locally, the strain rates are going to be, you know attained to a very high value. So, you can have. So, you can produce, you can produce very high local strain rates with firming velocities, combined with situation in which deformation zone is small.

So, basically, whenever you, if you combine this, you know forming velocity is which those situations where the, this deformation zone is the small, in those cases, you can have the very-very high, localized strain rate, values, for example, when you draw a fine wires.

So, when we are going for drawing of fine wire now, in this case, if you have a deformation velocity of 40 meter per second. Now, that can basically, result in a, you know strain rate in the axis of; so, strain may go in the axis of 10 raised to the power 5 per second.

So,. So, that is how these you know, this velocity, you get this strain rate at the higher rate of, you know at the higher value of 10 raised to the power 5 per second. Similarly, you can get, you know in thin plates, in you know rolling thing plates, you get mean strain rate of around 2 into raised to the power 10 raised to the power 3, per second. So, so. So, that is what we, get these, you know a larger, you know local mean strain rates. So, that is more prominent way of having the, large local, you know, strain rate values rather than increasing the velocity. So, you can increase the velocity, all you can decrease the size of these deformation zones and in that case you can have the large value of these, strain rates.

Now, based on these strain rate values, you have the classification of different type of, advanced forming processes and as compared to the conventional 1, there are processes like high energy rate forming, you know processes. So, that is known as, that is in the category of HERF.

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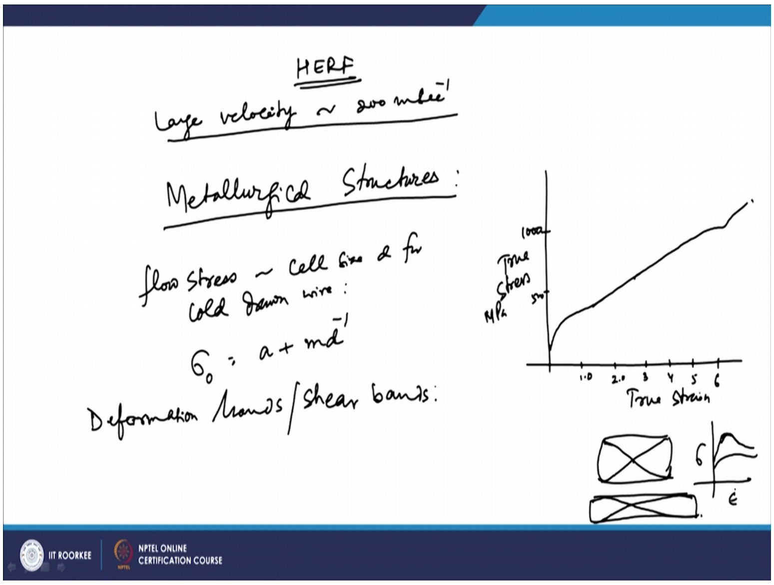

So,. So, in those cases you have, you know deformation velocity will be as high as about 200 meter per second and that gives to this. So, that will be imparting this energy at a very-very high rate. So, in those cases you have, large you know velocity and that will be of the order of about 200 meter per second. So, so there that will be used in normally in the case of forging or extrusion or; so, forming you can use and, they are normally coming under these category of HERF or high energy rate forming, because the energy of deformation will be delivered at a very-very fast weight as compared to the normal conventional, you know farming processes.

So, normally in these cases, you try to get, you know, what we do is, we use the explosives, where these deformation velocity very-very large velocities are achieved. We use the explosives or you know, explosive gases to create such high velocity and what happens that for many materials, you know, what happens that the, a longest into fracture will be, you know, you know that will increase, with strain rate beyond that usual metalworking you know range. So, that again depends upon the critical strain rate in a value.

So, and after that it will be, following also depending upon those cases in, in those cases. These explosive forming technologies are used and also that, that has also something you know, related to the, the, because when we do such kind of treatment that may also, you know affect the structure, you know structure of the material. So, that, that, that, that is also you know to be looked into and when we do that, in many cases that is not very much prominent, another extreme side will be with a very-very low strain rate values and as we know that when you have the, very high, you know standard sensitive materials and you, when you have very-very high, you know standard sensitive material.

So, they exhibit very much resistance to making. So, so that defines another set of materials that is you know the super plastic forming. So, that is normally you know promoted out that is normally prominent when you have very-very, fine grained structures and the temperature also is more than 0.4 tm, an strain rate is extremely small that is about 0.01, you know, per second. So, in those cases, you know there is little, you know chances of the, the necking. So, so there will be having the, they will have the higher resistance to the plastic stability and that is why they have the super plastic in many cases.

So, that basically will be again a function of the strain rate and then also the temperature at which you are doing that you know, this deformation and so. So this way, you can, you know many difficult to work alloys, they are basically, you know, can be word using these concepts or many a times, when you have to go for the fine, you know details and impression to be obtained, in certain material like in (Refer Time: 21:38) structures also in both cases. This concept is basically, utilized ah. Now, we will discuss about the metallurgical structures.

So,, as we know that, when we do the, plastic deformation, specially, when we do the cold working of the material. In that case, as you go on working the materials, the, the stress values is required.

The flow stress requirement will go on increasing and it is also,, because of the you know dislocations, which are you know (Refer Time: 22:21), which is increasing and that has also to, to do with the structures of these locations, which is basically reported to have certain kind of you know, certain kind of structure, which is formed during these workings.

So, what has been seen, that when you do the, cold working of these wires and when you do the, drawing of cold drawing of the iron wire then if you draw the stress strain curve the, the stress strain curve looks like this. So, what happens that if you, this is the true stress and, and, and this is the true strain and you are doing the cold working of these iron wire. Now, what has been seen that it, it, it goes and then, it will be moving like this.

So, so it will be moving like this now ah. Now, in this case true strain will be having the values like it is 1, then you have 2. So, 3, then 4 and 5 and 6 and all that. So, this way what we see and this side you have Mega Pascal. So, so you have here as 500, then you have here as 1000 Mega Pascal or. So, now, what is seen. So, this is for the 0.007 percent of carbon, steel ah. So, that iron is there.

Now, what we see that if you what we see here that even, if these you know, true strain value going above 6. These rate of strain hardening is not you know, decreasing, remarkably. So,, they are not diminishing, the significantly now, that can be, what happens that when the deformation goes on, you have, you know some structure is form several. Some structure which will be forming and you will have the tangles of dislocation structure, which is, you know seen and what has been for seen that when we when we talk about two types of materials normally, if you talk about iron, you may have the basis structure also you have the FCC structure and when we talk about the FCC structure they have, lower strain hardening.

You know as compared to the BCC structures and also the (Refer Time: 25:07) size is also important. So, you have the development of stable cell size in the case of BCC iron alloys and that will be you know continuously decreasing as the deformation goes on.

So, as you see that when you talk about the cold deformed materials you have the longitude grains and basically the, the deformation band will be appearing. So, you have the flow stress. So, the, the flow stress, which is, found and if you try to find the cell size d, cell size d for a cold drawn, wire. Now, it has been found that the sigma naught is basically. So, this is the flow stress and it is basically a plus m into d raised to the power minus 1

So, as the cell size, this will be decreasing, your flow stress requirement will go on increasing and, and in the case of these deep drawing, when you do or when you do the, you know why drawing operations are only in such cases. So, what has been seen that when you are going for cold working, you get equiest type of you know, self structures, which leads to you know and, because of that basically, you have these, increase in these you know, flow stress values. So, further you, as we discussed about the formation of this c r bands or deformation bands.

So, you have also, you must be, you know conversant with these terms like deformation bands or cr bands. Now, they are defined as you know, they are the reason of distortion, where portion of grains are basically, there is a, being basically rotated, towards another orientation to accommodate the apply, the strains. That way you have these deformation band and shear bands. They are found and if you try to, should look at these representation of these, bands.

So, what we see that when we increase the reduction. So, first of all you may have it is appearance like you know. So, this bands are developed like this and if you increase the, the reduction. So, as you increase the reduction, these deformation bands move like this. So, they have also, you know you can see that in the middle portion, you know, at these places the shear stresses at and that way this shear bands are formed shear band will be found like this and these shear bands, you know they are basically, moving and that basically is, basically the, you know, you know principle, based on which these deformation occurs, plastic deformation occurs.

When we apply the, the forces also typically, when you work the hot deformation of the material. In those cases what happens that some of these strengthening mechanism become unstable and then you may also end up with sometimes the, the, the, are usually if you have such kind of flow curve, after this deformation as the strengthening mechanism you know become unstable.

So, you get also such kind of you know change in this flow stress, you know curve. So, ah. So, this way that is further, being seen in the hot deformed materials, which has been you know observed another. You know thing which we must know is the, the deformation zone geometry.

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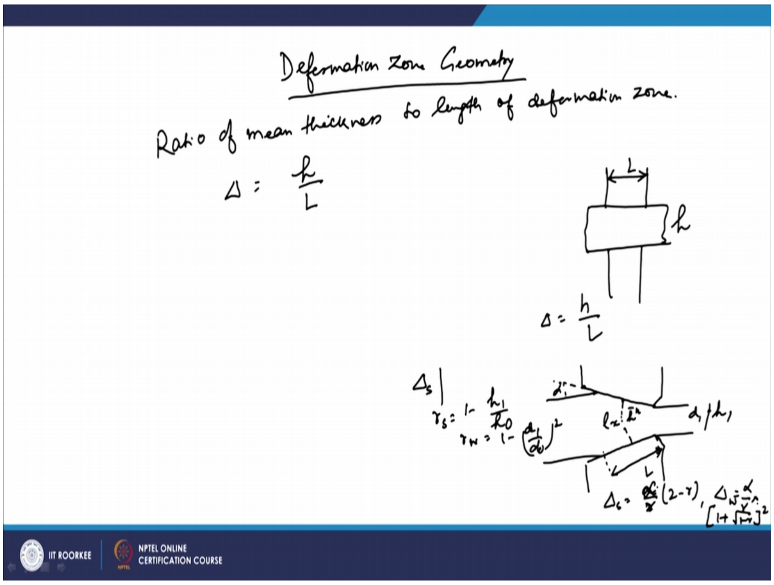

So, when we talk about. So, as we have discussed that deformation zone is very important and depending upon, you know it is, you know whether zone is small or larger, you can have the, you know presence of or the, you know production of, the larger value of strain rates or smaller value. So, when we talked about the deformation rates then there is you know, one particular parameter is important in those cases and here what we have, we have two things basically, you have the die and, in between the die you have a reason which is in contact with the die.

So, basically, you have a ratio of mean thickness to length of deformation zone. So,. So, you have two things; one is the one is the material, which has certain thickness and then, you have, the die which is in, in touch with that and that is why this ratio is defined as delta and this delta is normally defined as h by L. So, for very simple situations like you have, a such kind of situation, where this is your, this is your h and if this is your L.

In those cases, you can have this deformation as h by L, but now again, when we talk about you know, based on the plane strain reduction, in those cases, you know sometimes we define it. So, suppose you have one, another you know type of, you know tool, that is, that is where you have such kind of, you know.

So, this is a converging type of, you know die and in this case, this is here. So, here the, the material comes and this is your angle. So, this is your, semi die angle alpha and in those cases again what we see, that here it will come like this. So, it will be having either d 1 or h 1 can be you know, seen and depending upon d 1 or h 1. You can define, this delta and again here, you have this will be your L. So, this is the length. So, in this case these becomes the L and similarly, here you have, this will be your L.

So, this, this can taken as ah. So, this is ah. So, here this you have h and here it will be very. So, you have small L or h you know prime and in such cases. So, this will be average height. Now, in, in such cases what we do is, we can have the definition for the plane strain condition at, this is defined based on rs r s will be 1 minus h 1 by h naught or if you are doing for the wires.

So, in those cases you have r w and it will be 1 minus t 1 by d naught square and that way, you have the definition of delta s or delta w and delta s will be defined as a by r and into, you know 2 minus r.So, this is alpha by r. So, this is alpha by r into 2 minus r and similarly, delta w is defined. So, that will be again alpha by r into 1 plus under root 1 minus r and then whole square.

So, this way, you define this parameter for the deformation zone, you may have different types of you know zones. Different type of geometries and based on that, because that will be affecting what will be the deformation pressure required and deformation pressure, that way depending upon the value of h by L, you will have the calculation of deformation. You know pressure or deformation loads, which will be calculated so that we can see when we talk about the calculation load, calculations in those situations.

So, what we discussed in this lecture, about the different aspects or different parameters, which are required to define the deformation zones or, or the metallurgical structures, which are important while we, do the deformation in the case of plastic deformation of materials.

Thank you very much.