Principles of Metal Forming Technology
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Lecture - 24
Hot working and cold working

Welcome to the lecture on hot working and cold working. So, as we know that when we do the deformation, deformation may be done at lower temperature or at high temperature. So, in this lecture we are going to discuss about the hot working and cold working, traits of these processes what happens in these processes and then certainly when we are talking about the hot working and cold working. So, we are talking about basically the effect of temperature, how the temperature affects the processes.

Now, the thing is that when we talk about hot working; the hot working processes are the ones where you have the condition of temperature and strain rate are such that there is, you know, recovery taking place, where as in the case of cold working that recovery is not active. So, continuous with the deformation basically so, when we talk about the hot working if you talk about hot working.

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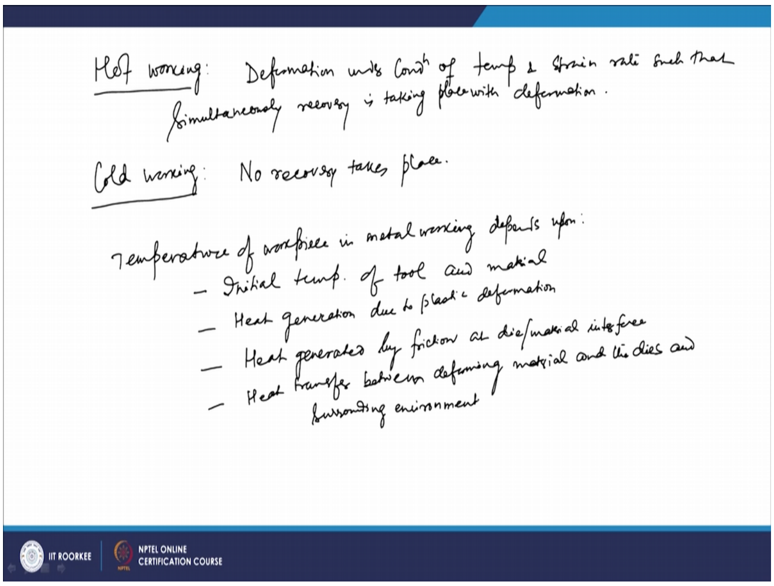

So, in that case as we know that we have discussed about the fact of temperature in strain rate. So, you have you have deformation under the action of under certain conditions of, you know, temperature and strain rate. And in this basically such that simultaneous recovery is taking place simultaneously recovery is taking place.

So, this is basically the difference between the hot working and cold working. In the case of hot working simultaneously the temperature is higher. So, the recovery is taking place you have 3, you know, basically, you know, things which happen recovery re-crystallization and grain growth. Now this recovery basically differentiates, this hot working and the cold working and so, in this case of hot working the recovery is actually simultaneously taking place with deformation so, that is with deformation. And in the case of cold working, you know, the difference is that the recovery is not taking place. So, the basically the material gets strain hardened as you go on deforming the material.

So, slowly and slowly the material gets harder and harder. And so, the load which is required the forming load or forming pressure which is required. Every time you deform the material in case of cold working, you see that the forming pressure requirement becomes higher. So, so that is the difference between the, you know, hot working and cold working, also when we talk about the hot working so, so in this case no recovery takes place.

Now in the case of hot working, basically you have the distorted grain structure also you have strain hardening that basically is rapidly eliminated because of the, you know, high temperature, so because of the re crystallization which is taking place at that high temperature. And that is why, you know, you can go for the larger degree of deformation in the case of hot working. Whereas, in the case of cold working as there is no recovery taking place there is strain hardening going on so, that is why the flow stress requirement or the stress required to remove to deform the material plastically that basically goes on increasing.

And basically you must that is why you have a degree of you have a limit up to which you can cold work the material. Because otherwise if you try to cold work the material beyond certain limit will be fracturing. So, there will be fracture so, that is how you try to also define the cold working that where you can up to what extent you can go so, that there is no fracture. You can increase the degree of cold work also when you try to give the any league in between. So, you do the some cold working then you further (Refer

Time: 05:15) the process and then again do the cold working. So, like that you have, you know, hot working and cold working.

Now, this hot working and cold working as we know that since there is a temperature which defines, the either it is hot working in the hot working range or in the cold working range, and it is normally a function of the Melton temperature of the material and many a times for the material with larger melting point certainly it is higher.

But for many low melting point (Refer Time: 05:48) even the room temperature working is considered as the hot working. So in fact, for tungsten like materials 1000-degree c is the cold working state, whereas, for tin the room temperature working is also the example of the hot working. Now coming to the generation of temperature, now what happens? That when we talk about the plastic deformation as we know, when the material is undergoing the plastic deformation there will be generation of temperature inside the work piece. So, so the temperature of the work piece so, temperature of work piece in metal working, it will be depending upon certain factors.

So, it will be depends it depends upon now first is that what is the initial temperature of the tool and the material. So, this is initial temperature of tool and material. Then the next is that because of the plastic deformation there will be heat generation, so heat generation due to plastic deformation. Apart from that as we know we have seen that when the die and the tool meet and at the interface you have large amount of friction. And because of this friction basically the heat will be generated and that heat goes into the work, work piece as well and that increases the, you know, temperature, so it is heat generated by friction at die or and material interface. And then you also have the heat transfer between the die material and the tool interface. So, you have heat transfer between the following material and the dies and surrounding environment.

So, these are the, you know, factors which are you now the ones which are basically responsible for seeing any change in the temperature of the body. Now the thing is that when we talk about a frictionless deformation process then in a frictionless deformation process.

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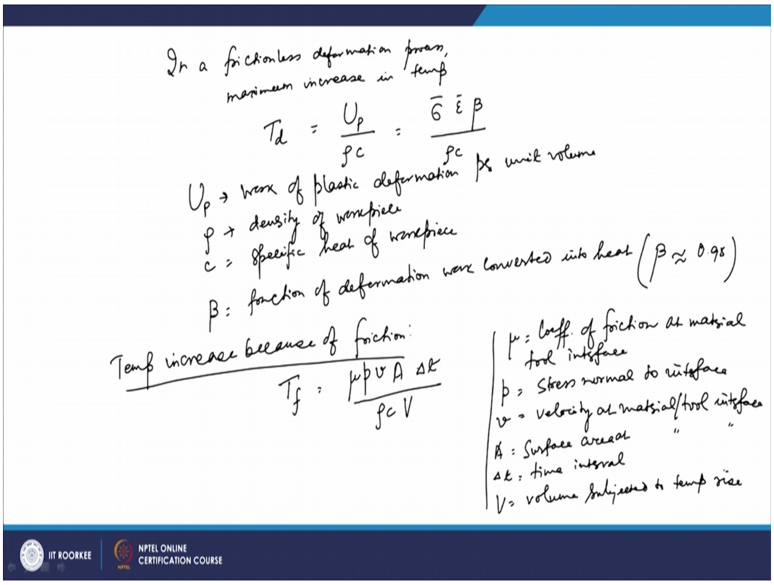

So, in those cases the maximum increase in the temperature. So, maximum increase in temperature so, that will be basically because of the work done on the material. So, that will be basically Td so, we call it as the temperature because of the deformation of the plastic deformation of the, you know, work piece. And so, this increase in temperature, and that will be divided by the, you know, specific heat of the material, and then you have the density of the work piece.

So, that will give you the, you know, work of plastic deformation per unit volume. So, so here this way so, this up which is nothing but it is the work of plastic deformation per unit volume, and it can be, you know, seen as the average value or mean value of the stress, then mean value of the strain that is what we have understood how to calculate. And then you have a factor because this factor will be how much is converted into heat, and then that will by rho c. So, if you look at these terminologies you have U p which is defined as the work of plastic deformation per unit volume. So, this is U p which is that work which is done, on this row is the density of the work piece, and c is the specific heat of the work piece. So, rho times the c and then delta t we know that you had been for the, you know, mass take into consideration you have mc delta t so, but it is per unit volume.

So, you have row and that is why you get this is the amount of plastic deformation, you know, work which is done for doing the plastic deformation. So, that is how and this is your mean stress mean strain and then beta is a conversion factor. So, beta is actually the fraction of deformation work which is converted into heat. So, when we work on the plastically work on the material so, what fraction is converted into heat, and normally beta is taken as I has highest normally closed to 0.95. So, rest is basically stored in the material as the defect structure that is stored in the material itself. Now we may have we may also find the change in the temperature, on increasing the temperature because of the friction. So, the temperature increase because of friction.

Now, see there is friction at the tool and die interface. So, this function will increase the temperature and this is basically denoted by tf temperature increase because of the friction f and it will be mu times. So, mu is basically the coefficient of friction which is applied at the material and tool interface, then you have the p. So, that is the normal stress which is acting so, to the interface, then you have v that is velocity which is there at the, you know, material to interface. And then you have the surface area which is there in the picture and then you have delta t. So, that is for how much time you are doing this deformation and divided by rho c and you have V. So, in this case you have like mu is coefficient of friction and certainly it is at the, you know, material and tool interface.

So, at material tool interface, similarly you have p as the stress normal to interface. Then you have v as the velocity at material tool interface. And then you have term as A, A is the surface area at again material tool interface. Then you have term as delta t so, delta t is the time duration during which you have to consider the temperature rise. So, this is basically the time interval for which we are going to consider the temperature rise. And v is the volume subjected to temperature rise.

So, you can just see from so, rho c v into then you have delta t that is this one, and then that will be equated to this coefficient of friction and then that we have the reaction normal forces. And then accordingly you have the time also. So, that way this is equated and you can get the value of t f from here and normally this temperature is highest at the tool and, you know, material interface where the friction will be generated. And then it will be falling off as you go inside the work piece, because it is maximum at this interface where the frictional force is generated, and many a times for simplicity we normally neglect this temperature gradient.

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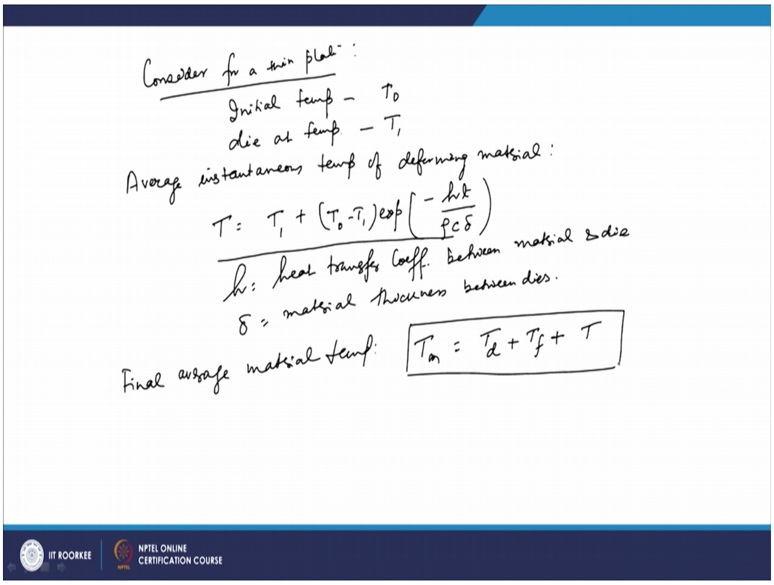

Now, if you consider for a thin plate. So, if you consider for a thin plate which is, you know, between, you know, to dies. And between so, and you will have it is initial temperature is T naught, and die is at temperature die at temperature is T 1.

So, in that case you have the average instantaneous temperature of the deforming material. So, average instantaneous temperature of the deforming material will be. So, that can be found there has been, you know, suggested by one (Refer Time: 16:25). And we has so far that it is computed as basically T will be T 1 plus T naught minus T 1. And then you have exponential minus of ht upon rho c delta. So, in that case h is the heat transfer coefficient between material and the dies. So, heat transfer coefficient between material and die.

And you have other things, you know, c is a specific heat, and delta is basically the material thickness between dies. So, what we see is that normal it will be discussing about. So, this material this equation basically this equation basically decides, you know, it talks about the average material temperature during the cooling of the material. So, normally for they very thin, you know, thing plate which is cooled between 2 dies surfaces for that this expression is; and if you talk about the final average material temperature.

So, final if you consider all the temperature rises which are taking place because of the friction or because of the plastic work which is carried over them; so final average material temperature. So, it will be basically it will be material temperature will be T d because of the deformation work which is increase then because of the frictional work which is friction with the increase in the temperature, and then this the average temperature and then this is the average temperature of the material. So, this way you can have the expression of the average material temperature at any instant. So, if you are given with certain conditions like if you are given any data for the for any material you are given the density or the specific heat, then certainly for a particular conditions you can find temperature raise, because of these conditions like may be because of the friction or because of the deformation work or so.

Now what we try to now see that when we talk about the temperature that is when we talk about the hot working temperature, now in these cases as we discussed that ; in these cases, your you have condition of temperature and strain rates that there is no recovery being taking place. So, essentially there is no hardenings so, in the hot working you do not have any strain hardening which is taking place.

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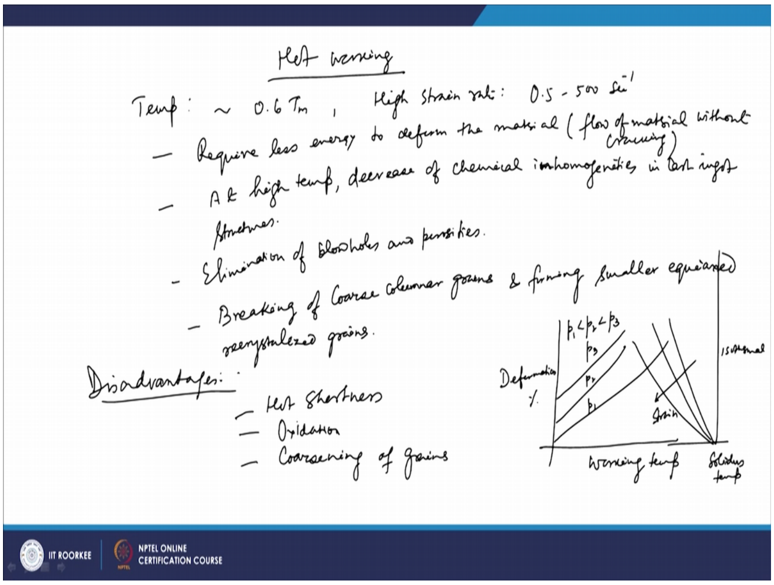

And, you know, in these cases the true stain values; which are achieved normally is quite high I mean it is it is there from 2 to 4 value is normally achieved. And normally hot forging or you have the hot extrusion or hot rolling is normally carried out, so that is what the advantage of the hot working is that you can go for the larger strain.

You know, large strains can be achieved with very much, you know, with not much of the increase in the flow stress requirement because once you go to the higher range. So, normally the temperature which demarcates these you know, hot working or cold working is normally point 6 times the temperature of the melting temperature of the material in Kelvin. And you have also a very hot high strain rates which are achieved in the in these cases, and this is normally in the range of 0.52 about 500 per second.

So, that type of, you know, conditions are there in the case of hot working. Now you also have other advantages of hot working not only that it is only giving less flow stress value for doing the deformation. Basically, so, certainly you the one advantage is that you require less energy to deform the material without cracking basically, to deform the material so, basically flow of material without cracking.

So, this is what ultimate requirement is that the materials must flow, and it is not crack. Also along with this process I mean along with this requirement being fulfilled that is the low value of the requirement of the floor stresses, there is another advantage that at that high temperature. you have the chances of decreasing the chemical inhomogeneities. So, at high temperature there will be decrease of chemical inhomogeneities, inhomogeneites in the casting that structures.

So, this is another example or another advantage of hot working. Further when we talk about the hot working, since we are doing at the high temperature, so, and we are deforming to a larger extent. So, the blow holes and the cavities they are basically welded they are eliminated. So, you have the elimination of blow holes and porosities. Then if you have the larger I have been columnar grain structure is there, now they are also broken when we deform the material at the high temperature, and then you get the equi x type of structures. So, basically we breaking of course columnar grains, and forming, you know, you get smaller (Refer Time: 23:49), you know, re-crystallized grains. So, because of these changes in the structure of the material what happens that when you hot work the material, basically the ductility and the toughness normally improves there are certainly some disadvantage of the, you know, hot working.

So, if you talk about certain disadvantages of the hot working. So, the main disadvantage is that since you are doing at higher temperature. And the maximum higher temperature limit is it can go up to the solidest temperature of the melting temperature of the material.

So, just if you take the difference of about 50-degree C below that, you can go up to that temperature and you can do the hot, you know, working of the material. Or the thing is that when you have certain phases you have low temperature you takes below that then maybe sometimes they have burning occurs below that temperature in the presence of the eutectic phases which have the low melting points, you know, as compared to solidities temperature.

So, in those cases you have hot shortness is or burning is many a times, you know, encountered. Another advantages another disadvantage which is encountered is the example of, you know, a scaling. So, basically oxidation at the surface occurs so, if you are doing the formation forming process in air then at high temperature especially for ferrous materials it has a chances to form scales or oxides. And then that will require larger tolerances on the, you know, dimension of the material.

And also another disadvantage with these scales is, that this scales may undergo we may go inside the deformation process itself and they can have the pits on the surface, you may have is there may be scale pits on the surface. So, that may basically jeopardize the machined surface the finish of the surface. So, these are basically the, you know, the disadvantages of the hot working processes it has many advantages, but these are the disadvantage for which you have to take care of you have to have wider tolerances. And you have to have also see that it should not go to, and also when we do the hot working. And we do the stages then in that case you have to see that where you have to finish, because if you are in the higher range you can go give for more deformation, but if you are at the more higher side then you may have coarsening of the grains.

So, there are chances that you may have the coursing of the grains, many a times when you are compressing the material you are giving the compressive stress at the material so, at the surface because being cooling fast. So, you have the final grains whereas, you will have the coarser grains towards the, you know, center part. And you will have because if the cooling is small rate is small then in that case you have the chances of the I mean formation of the coarse grains. So, what is series that when you are trying to see. So, there is a curve which can talk about the, you know, the working temperature it is the working temperature is increased. So, with increase of the temperature and if this is a deformation percent; so you have the flow curves curve goes like this. So, you have a this goes like this. And in this case you have this is as p 3 this is p 2 and p 1 so, you will have p 1 p 2 and p 3. So, basically when you have temperature increasing then in those cases what we see is that with the increase of temperature deformation basically increases you can go from larger and larger deformation of the materials.

Similarly, you may have the strain rate also graphs are there, and you can have the strain rates graphs are shown like your strain rate is increasing in this fashion. So, this way this is your isothermal curve. So, in that case this is your solidus temperature so, you cannot go beyond this temperature. And in this case, this is how the curve behaves for the, you know, hot working cases. If you go for the cold working; now in the case of cold working what happens that the material undergoes the strain hardening.

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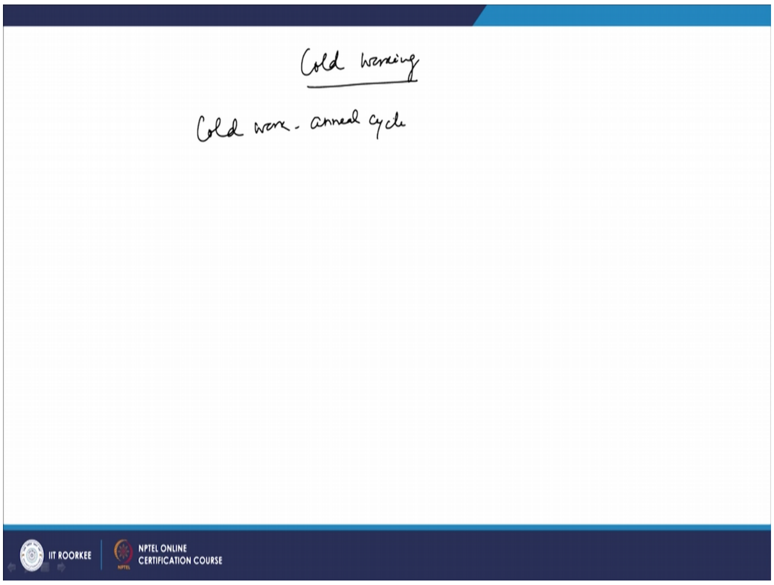

So, in the case of the strain hardening, basically material goes one getting harder and harder and your force as requirement as we have discussed that it goes on increasing. And in those cases you have the chances of cracking. So, what we normally do is, we are do the cold working stages you have a cold work anneal cycle.

Now, what we do is that depending upon the type of temper or type of hardness you require for the cord work of the materials, normally what we do you do the cold working then you go further annealing and then fed again you go for cold working. So, that way cold work anneal cycle is there, we know that when we do the cold working the (Refer Time: 29:46) will be increasing and your requestors requirement for further moving the dislocation or further the flow stress requirement will be more and more. So, this way there is a limit on the amount of cold work that can be done. Based on that based on the temperature also there is a warm working which is takes the difference advantage of both cold working and hot working. So, in the cold working you we know that there is no recovery taking place you have strain hardening that is there in the case of cold working. And then that way depending upon that you can analyze or the merits and demerits of the hot working and cold working processes.

Thank you very much.