Fundamentals of Materials Processing (Part-II)
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Lecture – 11
Cold, Warm and Hot Working

So we were discussing the effect of temperature and so for what we have seen let me summarize it in a bit we were looking at.

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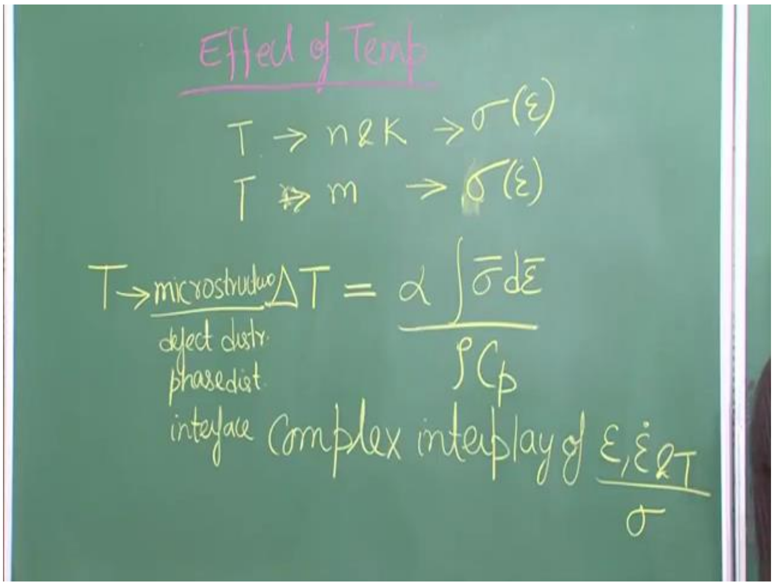

And we found that it is kind of very complex behaviour in the sense that temperature effects n and k in the (Refer Time: 00:41) equation and hence it effects the overall flow stress temperature also effects m which is the strain rate sensitivity and hence it all it effects strain rate sorry not the strain rate, but the effect of flow stress due to strain rate like in here it is stress flow stress because of strain, now the temperature effect on to stress and the strain is not one way. In fact, stress and strain can also influence temperature and if you put it like this total work done almost 99 percent of the work done when you are doing any deformation gets converted to heat energy and therefore, that heat energy is nothing, but temperature raise inside the material. So, if you were to look at. So, row C p times delta T would that the total work done or total utilization of work in terms of temperature and sigma bar times d epsilon bar integral is the total work done per unit volume and alpha is the proportionality constants showing how much heat is going into the material it could be part getting partition, some of it may be getting radiated away or it may be taken away by the tool or something like that.

So, alpha represents the amount heat or the fraction of heat that goes into the material and which will lead to temperaturized. So, now, we are see that temperature not only influences stress, the stress and a strain values intern also influence temperature and therefore, the relation between temperature stress strain rate are not linear to say the least. So, there is a complex interplay we can put it like that, strain, strain rate and temperature the three parameters which in turn will influence the flow stress behaviour. So, there is a complex interplay that we see now.

Now once we have seen the effect of temperature, we also talked about that there is origin for this and the origin is that temperature influences micro structure the structure add the micron level. So, things like your defects distribution, phase distribution interfaces these all get influenced by temperature and because of which we see all the different influence of temperature on the stress strain rate and so on. Now that we know that there is effect of temperature or and the stress strain effect temperature it is time to look into why we have the three domains, why actually we have already discuss the y part, but to look at it you can say to look at it in a little bit more detailed way, why we have the three different zones you remember the three different regimes?

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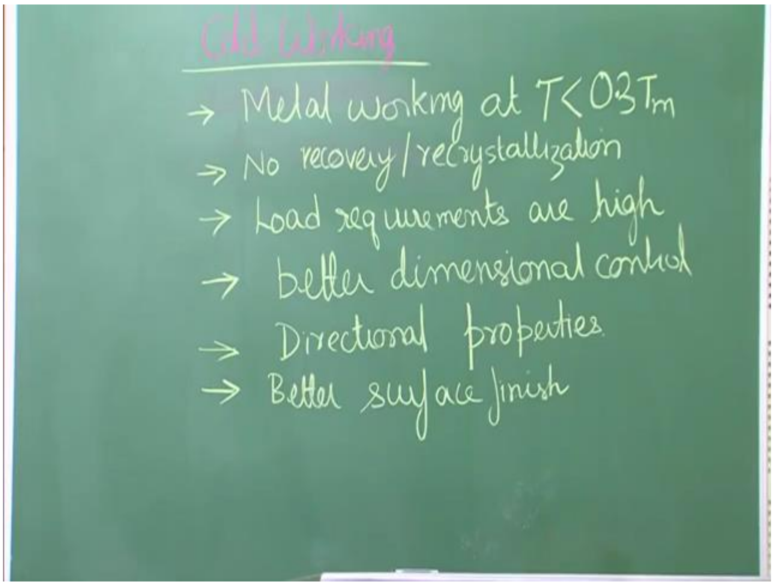

Cold work, warm working let be call it working, the hot working. So, the next part is we will look at each of these separately. So, let start with cold working; what is cold working? By now you would have realized cold working is nothing, but when you are doing the deformation are proud metal workings at temperature less than 0.3 T m, what is T m? It is the melting temperature expressed in Kelvin. So, there is a point. So, we are looking at it as a homologous temperature. So, when the homologous temperature is less than 0.3 then the work that we are doing is called cold work; there are some certain characteristics associated with cold work, now let us look at what are those characteristics since we are doing the cold work at a temperature less than 0.3 T m, where remember there is no recovery or recrystallization taking place in a micro structure. So, that is one characteristics of cold working that there will be no recovery and recrystallization that would mean if you are not recovering and there is no recrystallization, it means that when you are doing the deformation the material is getting work hard end and therefore, more and more stress is required.

So, the load requirements are high and it is related to the fact that no recovery or recrystallization is taking place; remember recrystallization is what in simple terms it is the creation of new strain free grains, if no new strain free grains are getting formed these are old strained work hardened grains and therefore, you need more and more or higher and higher stress to deform to a higher level to a higher strain value and therefore, load requirements for cold work is high.

On the other hand you have because you are doing it at a very low temperature therefore, the expansions are not there or basically you do not need to see how much the material will contract after you have cool down because you are already at a very low temperature, and hence you what you get is better dimensional control. Another aspect is again related to recrystallization fact that there is no recrystallization taking place when deform the material, and if you are doing the deformation in such a way that the material is getting deformed in one particular direction. So, at the micro structure level the structures which we call as grains will get directional structure, you can say there will be elongated in one particular direction and because of that you will have directional properties in the component formed by cold working.

So, these are some of the important characteristics that we know and there is by missed one of them which is better surface finish because we are not doing it at higher temperature as you would see that at higher temperature what happens is that some scaling forms, because the material is proven to oxidation, but in here hence your doing at room temperature or close to room temperature at least interns of the homologues temperature, you are at very low temperature and therefore, you get better surface finish. So, most of it that we have discussed here for the cold work or its advantages now let us also look at some of the negative points or the disadvantages when we are working with cold or when we are deforming the material to cold work and one of them actually I am have already listed out there and that is high load requirement. So, what is the drawback of high load requirement? It would imply that you will have to have equipments or much equipment with much higher loads.

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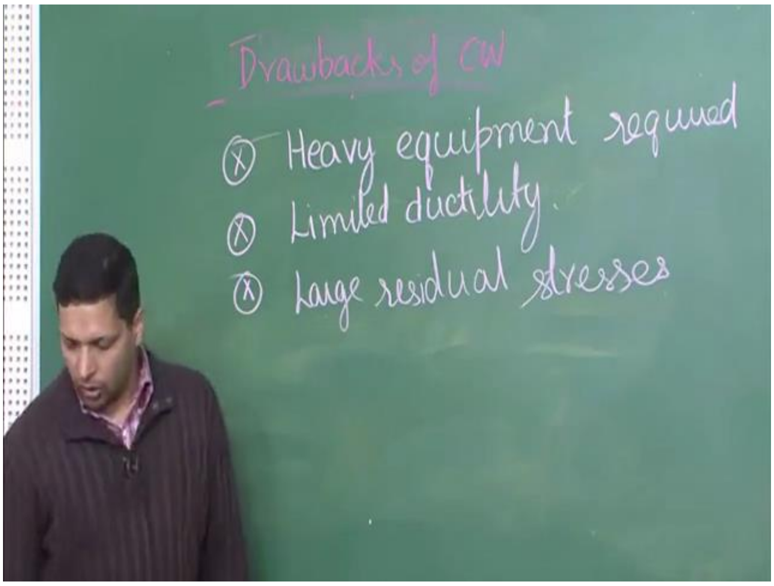

So, you will require heavy equipments in term of terms of cost it could mean larger capital intensive. So, heavy equipment required. So, now, we are looking at drawbacks of cold work.

So, you have need heavy equipment because the load requirements are high at for the cold work, no recrystalized ways a forming you have to keep increasing the load as the material gets defund for the rate further. Another thing is that again related to of course, all the properties have to be related with the micro structure. So, the micro structure since it is not getting recrystalized, it would mean that it is getting more and more deformed it is getting more and more and very soon it reaches the point that you cannot deform it further or it will start to create cracks or the material component will have defects at the component level, not at the micro structure level at the component level you may start to getting start getting defects and; that means, it has limited ductility.

And another important disadvantage of using cold work when we looked at the micro structure, we also saw that residual stresses do not get relived when we are doing or when we are at a temperature below 0.3 T m. So, large residuals stress: in most of the cases being residuals stresses are responsible for causing deteriorated property of the material. So, another important disadvantage is large residuals stresses and as I said earlier that when you have component manufactured using cold work and it has very large residuals stresses, what it implies is that those components can cause I can had generate defect very easily; particularly it may fail very quickly or at much lower frequency under fatigue stresses. So, thus kind of reduces limits the life cycle of a component. So, that is one very disadvantage when we are using cold work.

So now, having discussed cold work now let us move on to another or the other extreme which is hot working. So, right now we were dealing with temperature less than 0.3T m, but now it be move on to the hot working, we are in the temperature range about 0.5T m.

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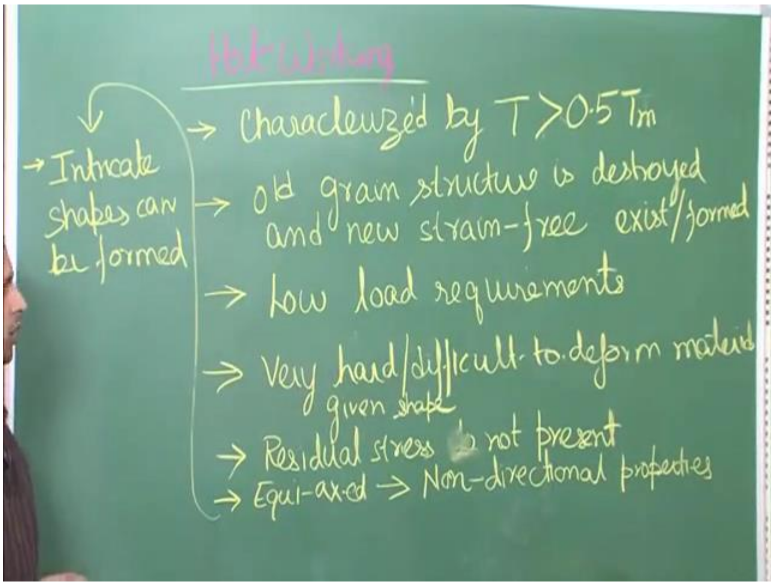

So, first thing is two understand that it is characterised by temperature greater than 0.5 T m and remember again I have to emphasises it again and again that we are talking when we are looking putting the temperature like this, the temperature is in Kelvin. So, here temperature must be used Kelvin and 0.5 of that when you are above that temperature in Kelvin is that we are talking about hot working. Other characteristics of hot working are that. So, if you are above 0.5 T m, it implies that old grain structure is distract is destroyed and new strain free grains exist it is as if these grains do not have any history of deformation. So, that is why is called strain free these are absolutely new grains, which are recrystalized, which have found inside the material exist or get are formed when we are doing the deformation at temperature above 0.5 T m.

Now, another thing we know for temperature when the temperature is very high we know that stress requirement will be high and therefore, low load requirements. So, this is the also an advantage. So, you can deform a material, so this fact that requirement of the load is lower, it implies that very hard a difficult to deform materials can such materials can also be formed given shape using hot working. So, that is possible only because our load requirements are much lower at higher stresses at sorry at higher temperature and the temperature we are looking at is point above 0.5 T m and at 0.5 if you remember from the micrograph brought that I do in the previous lecture, you would know that residual stresses are almost negligible.

So, residual stresses are not present when we are working at high temperature and since the grains are new in the cold working we saw what that that the grains will have directional structure, because they have deformation, there will be rolled in particular direction or their will be defund in a long one particular direction therefore, there will be have in advertently some directional nature, but here the grains are forming new that is new strain free grains are forming and therefore, when these new grains are getting formed, there will not know any particular direction and therefore, there will be what are called as Equi-axed grain and Equi-axed grain imply non directional properties of the component found by hot or hot working. So, in most cases this is a advantage that you have non directional properties in some cases, you may want to have directional properties and we will look at some example as an when we get to those things and another very important aspect hot working I will right it over here.

So, we have seen at high effect of high temperature we need low stresses, that has already been given here we also know because the effect of high temperature is higher strains are possible or higher ductility is possible. So, it means that integrate shapes which require much larger strains can be formed. So, these are the major advantages that we know for hot working of course, there will be quite a few more that you can come up with, but these are some of the most important advantages and these are most of the things that you can see here are related to the fact that you have recrystalized grains formed when we are dealing with hot working. So, the strain free grains up present there because of this the load requirements are lower and because of the same thing you are able to get much higher ductility and therefore, intricate shapes of a form and because of the same thing residual stresses are negligible or not present and then do have non directional nature or properties of the component data formed using hot rolling.

But there are of course, some disadvantages also related to hot working, it is not that if hot working word everything was good about hot working, then all the components would be formed using hot working, but we know that it is not true.

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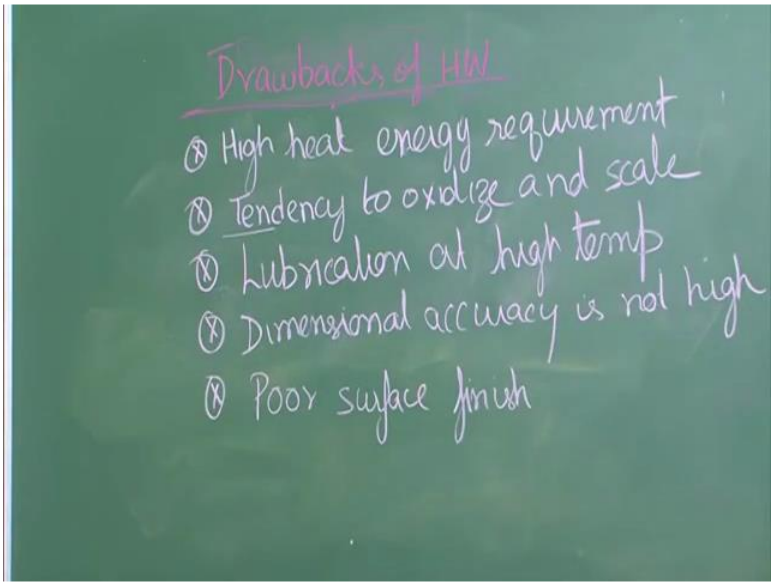

So, let us look at some of the advantage disadvantages of hot working. And one thing that you can quickly say is that since that we are doing that deformation at higher temperature, so high heat requirement; heat energy requirement which is a drawback because it in it in implies that heat energy what is you can translate in terms of industry as cost input. So, you have to provide so much if you have to heat a material for say one hour at 800 degree Celsius that implies so much of heat energy or so much of electrical energy will get invested into the materials. So, high heat energy requirement, which is a major drawback; that is not the only drawback, we also know that at higher temperature materials tent to get oxidized. So, there will be some scaling behaviour. So, tendency to oxidized and form scales.

What else can we look at as the drawback? At higher temperature another important drawback is that you may be using some die and in the die you try to give the shape, but the material and the die they do not have good you can a there may always exist some friction and for that we add lubricants, but at high temperature it becomes difficult to ascertain what kind of lubricant will work, because the temperature is very high the lubricant will either evaporate or it will get or it may be become inflammable. So, lubrication at high temperature becomes a problem and in the cold work we gave one of the advantages as good dimensional accuracy and that was possible because there was no change or that material need not have to come back to room temperature and therefore, you did not have to adjust for the change in the dimension, but that thing is not true over here, here if you form the component at a much higher temperature when it cools down their will be contraction and therefore, there will be some in accuracies in the dimensional. So, dimensional accuracy is not high.

And one of the other last one I will mention for that as a drawback of hot working, we know that there is a tendency to oxidize and a scale, which means that it will also have poor surface finish. See in effect what you will see is that hot working and cold working whatever advantages will yesterday in cold working, becomes a disadvantage in hot working and whatever disadvantages we mentioned in cold working becomes advantage in hot working and that is why in order to get compromise between these two, we have what we call as warm working of course, there is a origin to that micro structural origin we know that at this intermediate temperature which we call as hot working zone a phenomena called recovery takes place.

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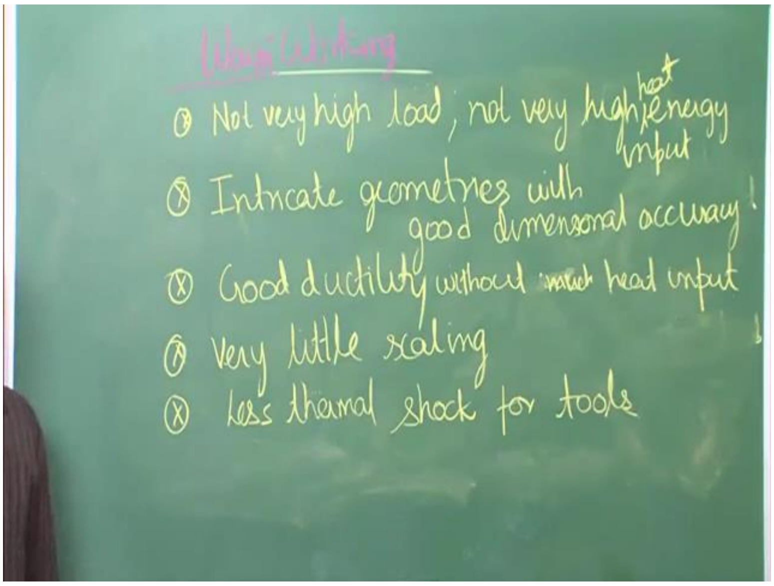

So, the compromise for hot working and cold working is warm working and what are the advantages of worm working? On one hand you do not require very high load not do you require very high temperature or high heat energy input to be precise let me put it as heat energy input. So, there will be of course, some amount additional heat energy required compare to cold working, but it is not as high has that required in warm hot working; similarly the load requirement is not very high, but it is still higher than what will be required for hot working.

So, it is if you are trying to get a compromise then you also make a compromise in terms of load requirement and heat energy requirement and the advantages that you get intricate geometries as almost as good as you would get in hot working with good dimensional accuracy. So, now, you see we are getting best of both the worlds. Good dimensional accuracy is not related with hot working and intricate geometry is not related with cold working, but if you go for a high little bit higher temperature which is our zone of warm working, then we are able to get both we are able to get intricate geometries with good dimensional accuracy. We are able to get good ductility without much heat energy, without heat input. In cold working there was limitation because the grains do not the grains keep accumulating, the default the dislocations or defects and eventually it will break.

But when you are doing the deformation at warm working, what happens is that the material is able to relax, you can say to put in codes to certain extent and why is that because the dislocation form cell was their able to minimize the energy in the micro structure by forming cells and cell was and therefore, you can say that the material has is in a better position to accommodate more strain and therefore, you are able to get a little bit higher ductility than you would get in cold working. Very little scaling: so although we are using high temperature relatively high temperature and since we are using a little less high temperature, less thermals shock to the tools, remember if you are working at high temperature even you are tools get expose to those temperature and that is if you start from a cold temperature to hot temperature and then again bring it down to low temperature it is called thermal shock.

So, less thermal shocks of those kind for tool materials. So, it is a good compromise between the two, but it is still not that this is best or this is the only option available to you for example, in some cases you may still have to go with cold working in some cases you may still have to go with hot working in depending upon the requirement that you have.

So, these are just take the three, as three different zones of temperature at which working is done to get different kinds properties and for different kinds materials for example, let us say if you are working with aluminium, which as very low melting point then why do you need to go to the very high temperature? Even the room temperature is sufficiently high for that and therefore, you can in fact, all the window frames that you see where made out of a aluminium they are extruded at room temperature; on the other hand if you are if you want to work with a hard material like titanium then and you want to do some extrusion for titanium then you will have to deal with or you will have at work at higher temperature in that case hot working will becomes a necessity. So, there is no hard and fast role that this is the temperature you must use, it depends on combination of several factors including in the properties of the material of the component that you require, the properties of the material that you are exposing toward that you are trying to deform and show on.

So, now just take a small example here to understand what is exactly cold working hot working; let us take a material like.

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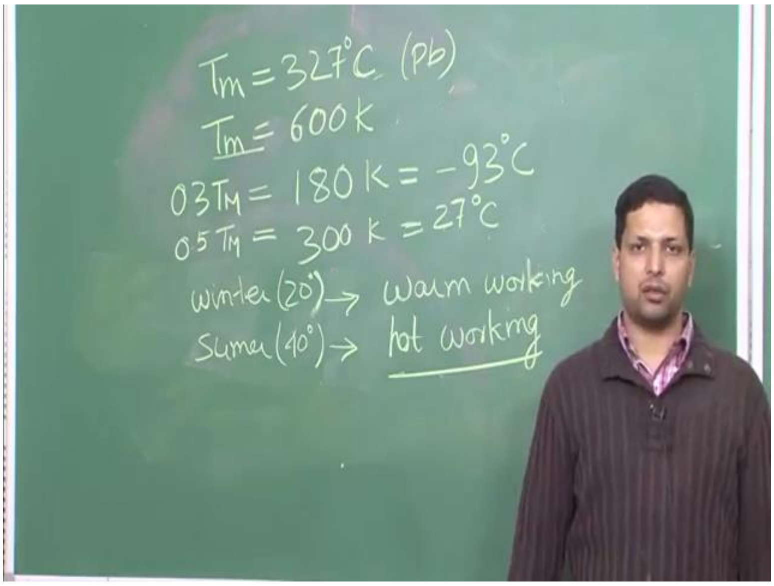

Led which has a melting point of 327 Celsius. So, this is temperature melting point temperature of led; now if you want to put it in first thing we need to do is put it in Kelvin. So, this is 327 plus 273 equal to 600 Kelvin, now what is the 0.3 T m for this? 0.3T m for this will come out to 180 K, which is Celsius it will minus 93 degree Celsius data 0.5 T m for this led will come out to 300 K, which is equal to 27 degree Celsius. So, you see if 0.5 T m for this is actually what it a room temperature for us. So, one thing is important is to understand that when we say hot working does not mean you have to elevate the temperature, it is related to the melting point of the material. Now let us say you were doing the rolling of this in winter when the temperature is 20 degree Celsius.

So, you are working at 20 degree Celsius and the 0.5 T m is 27. So, you are you are actually in the warm working zone or you are deforming the material like a worm working. If you are doing a same experiment in summer when the temperature is let say 40 degrees in your lab, so this is higher than the 0.5 T m and therefore, what you are doing is actually hot working. So, this is the simple example that we have.

So, we will leave it at this point over here and will come back in the next class and we will talk about the mechanics of deformation. So, we have dealt with all the basic parameters for deformation like strain, strain rate and temperature in different ways possible, now it is time to move on to the next step, which is tool understand the mechanics. So, will meet in the next class and discuss mechanics.

Thank you.