Theory of Production Processes

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Lecture - 30
Temperature in metalworking: Hot and cold working

Welcome to the lecture on temperatures in metalworking. So, in this lecture, we are going to discuss about the effect of temperature in metalworking. And typically we will be talking about hot and cold working, or hot and cold forming. So, we discussed about the metalworking processes. And now as we discussed that the temperature has a role, because once you increase the temperature, the flow stress required basically is decreased. Now, the thing is that this is the advantage in case of increase in temperature, but then there are associated disadvantages also with the hot working. So, hot and cold working when we talk about basically hot and cold means certainly it will refer to one standard temperature and that temperature is basically the recrystallization temperature.

So, when we do the working of the metal at large temperature, so that is known as hot working. And when we do at the smaller temperature then it is known as cold working. Now, there is no you know you cannot say what is high and what is low value of working temperature, so that depends upon basically the melting temperature of the material. Now, the melting temperature of certain metal may be very small like tin or lead or so, and for some metals it is quite high let us say for steel or you can say for tungsten or so, so it is quite high. So, basically for certain metals, the hot working of others may be the cold working in such cases like if you take the 1100 degree centigrade temperature it is hot working for a steels, but it is cold work condition for the tungsten.

Similarly, if you take the tin or lead or so, such alloys, when the room temperature is the I mean you can say at that that is itself a case of hot working temperature. So, basically normally 5.5 to 6 times the melting temperature in Kelvin is defined as the recrystallization temperature.

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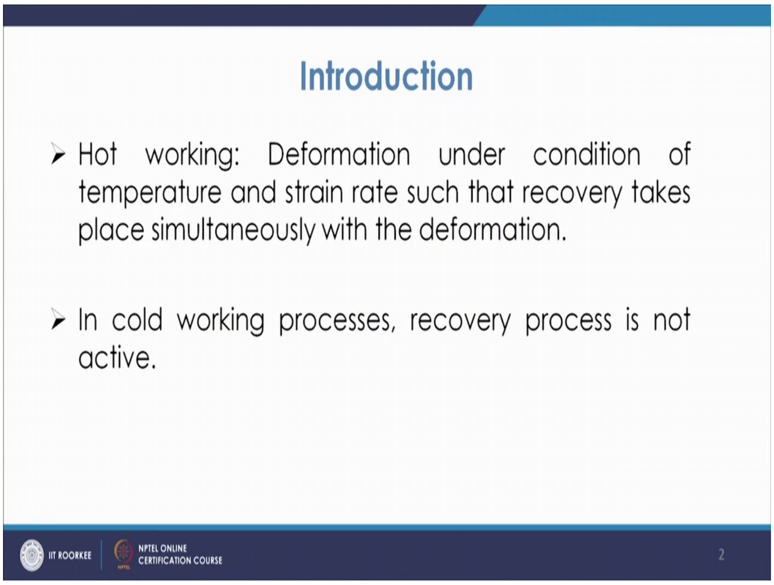

So, what is the hot working process. So, by definition it is defined as the deformation under the condition of temperature and strain rate such that recovery takes place simultaneously with the deformation. So, what happens that as we know when we apply the stresses on the body, then because of the when the yield strength value I mean when the stresses which are basically generated inside, and when that basically is increased above the yield strength of the material, then there is plastic deformation of the material.

So, how that is how the plastic deformation starts. Now, this stress which is required to deform it plastically that is known as the flow stress. And we have already discussed about the flow curves, then the stress true stress and true strain terms which are used with such analysis. Now, in the case of hot working as it tells that recovery takes place, so what happens when we apply the pressure then the grains are strained, because the grains which are there they will be under the action of the stresses and then they will be deformed. So, strains are or these will be strain fields generated, but then because of the high temperature, the recovery takes place in that and there is no strain field remaining, so that is what the difference between these two.

So, in this process, basically in the case of cold working that does not take place. The recovery is not taking place the grain which is strained when we apply the grain is deformed and the strain energy which is stored so that is there. So, basically it is under so lot of energy is going into the material and that is not and in that case that is relieved whatever though in the strain field is there so that is basically relieved so, but in this case that is not relieved. So, that is why in the case of cold working when we do the cold working of the material, the grains are quite elongated they get distorted you have the, and in that case basically you are putting that, so strain hardening is taking place and because of this strain hardening and the strength basically is increased.

So, in the case of cold working, the strength will increase, but then the ductility will decrease. Whereas, in the case of hot working what happens that since it is at higher temperatures, after once it is deformed then at that particular height temperature there will be recrystallization of grains, a small stress free grains basically recrystallize. So, normally what happens because of that and since the temperature is high, so that way the recovery process is active in those cases so that is the main basic difference between hot working and cold working.

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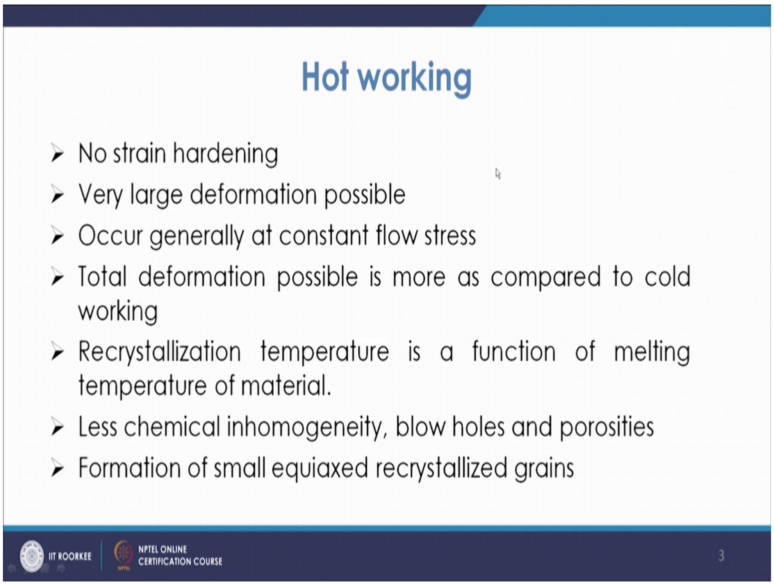

Now, we will discuss about the traits of hot working. Now, in the case of hot working as we see the point is that there is no strain hardening. So, what happens that because the it is high temperature and grains are distorted, and then again rapidly there is formation of new grains. So, because of this high temperature, this strain hardening does not take place. So, because of the recrystallization process or because of the formation of new grains, you have always a formation of new grains, so that way you do not have the strain hardening taking place.

Second trait of this hot working processes that you can allow for large deformations. So, because the recovery process is active, you do not have the condition where the flow stress basically is increasing with time. So, basically flow stress is normally constant which is the third point occurs generally at constant flow stress. So, because of this constant flow stress value, because the temperature is higher, so because of that you can go for larger degree of reduction. So, large deformation is possible and flow stress is normally constant because we are doing at a temperature or a higher value of temperature.

So, normally you have the constant value of flow stress and the value of flow stress is normally quite smaller as compared to that in the case of cold working because in the cold working as we do the straining, so the flow stress goes on increasing. So, as we go on doing the reduction, so with the degree of reduction more and more this flow stress value will be more and more, so that way that is the difference between hot working and the cold working.

So, again recrystallization temperature is a function of melting temperature of materials, so that we have already discussed that. It is basically a function of the melting temperature of material; normally 0.5 to 0.6 times the melting temperature and the maximum temperature can be the temperature of melting. So, normally is kept below 50 degree c so that will be the higher range and there will be lower range certainly defined I mean that will be defined by this process of recrystallization, so that way we define the lower limit of the recrystallization.

Now, so again the working temperature for hot working as we discussed earlier that it depends upon material to material. So, many material, if they are deformed when at room temperature it is a condition of hot working basically, so because the melting temperature is quite slow, so tin and lead come into that varieties. Whereas, for certain materials, even a very high temperature, where I mean like even steels are considered to be in hot working range at 1100 degree centigrade, and that is the cold working range for a materials like tungsten. So, that again depends upon the type of or different melting point of the material which is being basically you know hot worked.

Now, basically what happens that when you do the metalworking, then there will be temperature which will be generated in the workpiece, and this temperature generated basically will be depending upon the initial temperature of tool and material. Then you have there will be heat generated because of the plastic deformation. You have basically heat transfer will be there between material and the dies and the surrounding environment, so there will be heat transfer that also occurring. So, depending upon that also you will have the increase in temperature in that case.

And also you have the friction of the at the material and die metal interface. So, because of that also there may be change in the temperature of during that process of deformation. So, I mean it is seen that when you do the plastic deformation, there will be increase in the temperature. And maximum increase in the temperature during the deformation that can be found out, so basically that can be found out by formula like you have rho c into delta t. So, that will be the heat you know what is going for increasing the temperature. So, that way you have rho as the density of the material, c will be specific heat of the material that is workpiece, and delta t will be the change in. So, that should be equal to what work plastic deformation what work it does. So, basically that will be mean value of a stress into mean value of strain, and then that can be multiplied by with you know one fraction so that fraction basically will tell about the how much of work will be converted into heat. So, this way you can say that what will be the increase in the temperature during the plastic deformation.

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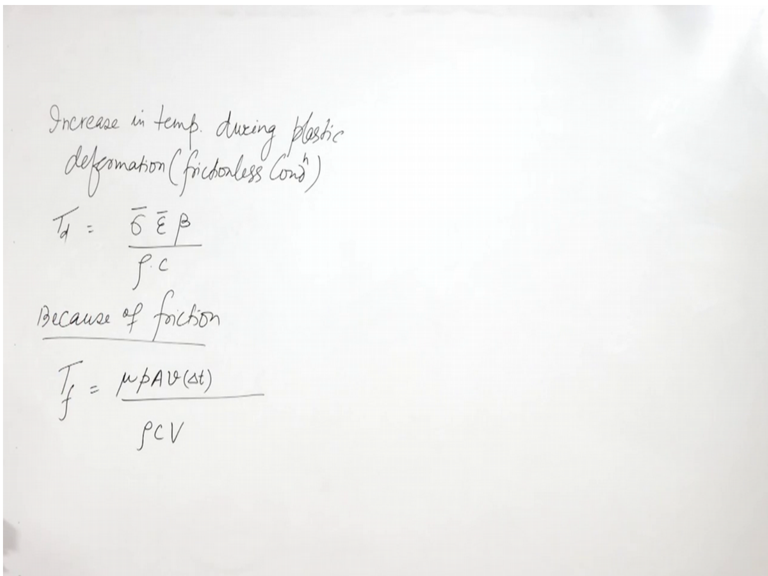

So, basically it is seen that if you say the increase in temperature during plastic deformation, and you take frictionless condition. So, basically you are doing the work, so that is why if you take the increase during the deformation T d. So, this will be increased that will be basically taken as sigma mean value of a stress mean value of a strain, and then there is a parameter that is beta which basically talks about what percentage of the work will be converted to heat.

And then you will have to convert it multiply this with rho and c. So, basically this is you know equivalent rho is a density of the work piece, c is the specific heat of the work piece, this is a temperature rise, this is the mean flow value of flow stress mean value of strain. And this beta is the factor which talks about that how much part of the work is converted into heat. So, this way you can say that how much will be converted So, normally this value is taken as 0.95 or so. So, this has been given like that.

Similarly, you will have also that temperature increase because of friction. So, this is when you do not take the friction into case, so it is case of frictionless deformation. Now, if you take the frictionless deformation in that case again similar you know expression will come. So, in that case, it will be again like rho c into v and then you are going to multiply that with t f so that it will be increase in the temperature because of the friction, and that will further be you know equal to mu times you know p into a, so that will be force. And then further you have into multiplied by velocity and then multiplied by again time interval of consideration so that will be equated. So, that is why if you look at T f that increase in temperature, it will be mu into p a into V again in to delta t divided by rho c into v that is volume. So, this way you can find these values.

So, because of friction, you will have T f as so T f will be multiplied with rho c and v and then at the top you will have. So, rho is again the density, c is the you know specific heat, v is the volume. And then here you will have mu pressure then you have multiplied by area then you have multiplied by velocity. So, this will be force then velocity and so that will talk about this force, here then you have velocity, and then you have the time duration for which it is working. So, this is how you can find the increase in temperatures when you go for deformation you need to know some of the things that basically is quite you know simple.

So, p will be basically the stress normal to the interface, so p is that. And then further you have a as surface area or the interface. So, this way you have these terminologies which are very much common. And v will be the volume of the material which is subjected to temperature rise, so that is why you have a this is v. So, this will be mass into c or so. So, you see this expression will talk about the increase in temperature because of the friction, so that is how you calculate it.

Now, again coming to the different aspects of hot working what you see is that as we discussed that because of the rapid diffusion, so you know in the case of this hot working, so that basically aids into decreasing the chemical in homogeneity. This point this is chemical in homogeneity. So, what happens that since the hot working is done at higher temperature, so there is diffusion at a higher rate at that temperatures, because diffusion will increase rate of diffusion will be more at higher temperatures. So, in that case, the chemical in homogeneity which is there inside the material that is basically minimized. So, the material will be more and more homogeneous chemically.

Another thing is that because of the deformation whatever you have the blowholes and porosities they are basically welded up. So, blowholes and porosities they are minimized. So, this is another advantage of the hot working processes. So, you have when you cast the ingot, basically you have larger chances of larger probability of having these you know defects like blowholes or you know segregation and also the porosities. So, basically once you go for hot forming initially, and you require to go for that and then during that process basically this is minimized.

Another advantage is that you have the formation of small equiaxed recrystallized grains. So, what happens that you know because of the pressure you know these you have the growth of the normally in the cost structure, you have the growth of columnar grains. Now, when you plastically deform these columnar grains are broken. And because of the recrystallization, you have the formation of new grains; and at that time, the formation of the grains or the shape of the grains will be normally be equiaxed. So, you will have a small fine equiaxed grains.

So, basically the structure which will be changed from the columnar to equiaxed and that basically enhances the property of the material, so that gives you more ductility and more toughness over the caster state. Because in the caster state, you will have the you know columnar structure that is we have already discussed in the lectures of casting that in the normal case you will have initially the formation of equiaxed grains, but then later on you will have the columnar grains because of the growth. So, that basically breaks up and you will have a refined structure fine equiaxed structure which is giving you a better property. So, this is about this is the advantages associated with this hot working processes.

Now, let us discuss something even some disadvantages of also the hot working processes. What are the typical disadvantages? The disadvantages that you have the probability of surface reaction between metal and furnace atmosphere. So, furnace has atmosphere and then you have metal, so you may have the reaction, and that may lead to you know the undesirable you know products. So, you have surface reaction, so reaction products will be or the surface, so that is undesirable.

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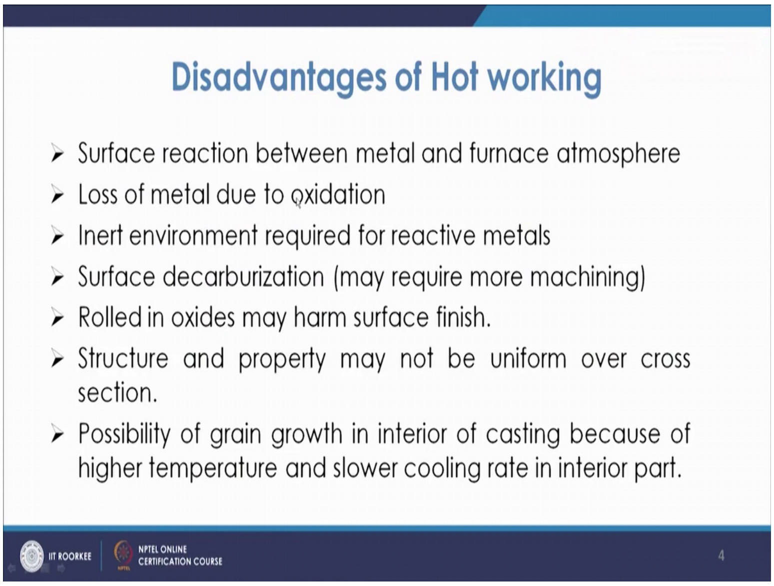

Further, you have loss of metal due to oxidation. So, because you have air normally in the furnace, if the furnace is not completely you know free of this air or so, or you do not have that medium like vacuum or so. The normal cases in normal circumstances the furnace has air and the oxygen reacts and the reactive metals react with the oxygen and make oxides, so that is how you lose metal up to certain extent. So, you have loss of oxides, loss of the metal in terms of oxides. So, many a times especially for reactive metals and many highly reactive metals, you require the inert environment because otherwise there will be loss of the metal to a larger extent and that will affect the productivity of the process. So, this is the one thing which has to be kept in mind in the case of hot working. These are the challenges that you will have to you know pass.

So, basically then next is the surface decarburization. So, there may be the cases of surface decarburization. And in that case, you may have to remove certain layers from the top, so that you get adequate you know surface of requisite quality, so that basically enhances the further you know operating cost for the making it you know and the machine to work satisfactorily for the intended purposes.

Again, the next point is the rolled in oxides may harm surface finish. So, as we discussed that if the control atmosphere is not there, then there may be formation of oxides. Now, these oxides need to be removed if they are formed and if you are going for rolling in subsequent passes, because you are there it is not the rolling is done in only one go and you get the desired shape or size, you have to go in many and you know stages that is known as passes. So, when the material is under one case set of rolls or rolling you can say forming or working. So, when it is going for one pass in that case, in the second pass where it is going you have to ensure that if there has been surface reactions or there has been formation of oxides. Then these oxides must be removed.

Otherwise, these oxides which are there at the surface they may be rolled in they may go into in between the die and the metal itself or the surface of the metal itself and then that may dent that may have a dent mark on the surface of the material, so that may decrease the surface finish of the material. So, this way it harms the surface finish. And you require to have a better surface for that you have to again further machine. So, again you have to increase the machining allowances and tolerances and all that. So, that is the one of the point which needs to be taken care.

Then you have a structure and property may not be uniform over the cross section. So, what does it mean, it means that what happens that at the surface, you have larger heat extraction rate; whereas in the interior you will have the slower cooling rate higher temperature sources, you will have lower temperature at the surface. So, when they come, the die and metal surface come into contact you have larger heat extraction rate. Whereas in the inside because the heat which is generated which goes inside, so that is another factor then the more heat content is inside. So, because of that the cooling rate in inside is basically smaller, temperature is higher.

Now, what happens because of that that on the surface you will have the larger heat transfer inside the surface and inside the core portion you will have slower cool heat transfer. So, basically that leads to the grain growth maybe inside. So, basically you will have the change in structure over the cross section of the whole you know product which is basically metal work. So, that is why you see that you have the possibility of grain growth in the interior of the casting because of higher temperature and slower cooling rate in the interior part.

Now, few things which are to be kept in mind when we go for hot working is that you must be basically careful about what should be the lower limit of the hot working. So, it should not go below that, below that recrystallization temperature, because then it will be coming under the cold working cases. So, you will have to work in that zone. And then you should not go also too high and approach towards the melting temperature. So, what happens in that reason if there are basically the you know low temperature melting point phases that in that case also there may be problems like hot shortness. So, they may you know fail or you know they may collapse or sort. So, that basically is the condition of hot shortness of burning. So, you will have to have a proper control of the working temperature range.

Another important consideration which has to be kept in mind that these operations are not the operation used only in one go you are getting the final shape, so you have many intermediate passes. Now, intermediate passes are normally done at a higher temperature. So, when you do at higher temperature, certainly flow stress requirement is less. So, you require less forces to do the deformation, but if you leave from there in that case the chances of grain growth will be more. So, you will have the may coarse grain structures or so which is not desirable. So, what is the normal practice is that in those cases when you go for final pass after which the material will be simply going to the dispatch section or it will be told as formed material, in that case the temperature at which it should be worked it is should be very close to the workable range.

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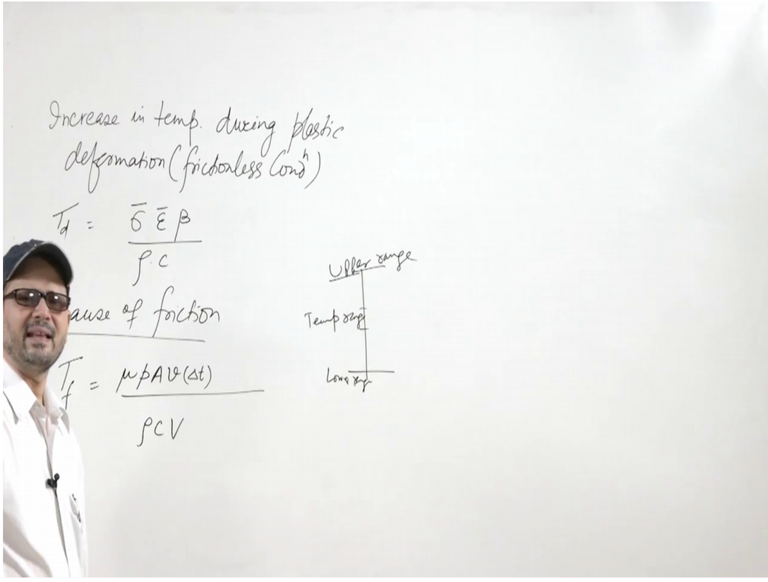

You should not have, so if suppose you have a temperature range like this and this, this is a temperature range. And then this is a lower temperature lower range and this is the upper range. So, normally what we do is normally we do in this temperature ranges. And then the final pass should be done not in the towards this side, but towards this side. So, certainly above this, but in this range because at that time finally, it has to go out, so the chances of this grain growth will not be there, so that kind of you know I mean care you will have to have in the case of hot working.

Also the curves are their processing maps are there which talk that how you know and the pressure will vary I mean what will be the maximum degree of reduction you know at any temperature. So, with certain pressure what should be that or similarly you know the strain rate, if you change how the pressure will change or how the degree of reduction is affected. So, there may be the maps, so these processing maps will talk about it.

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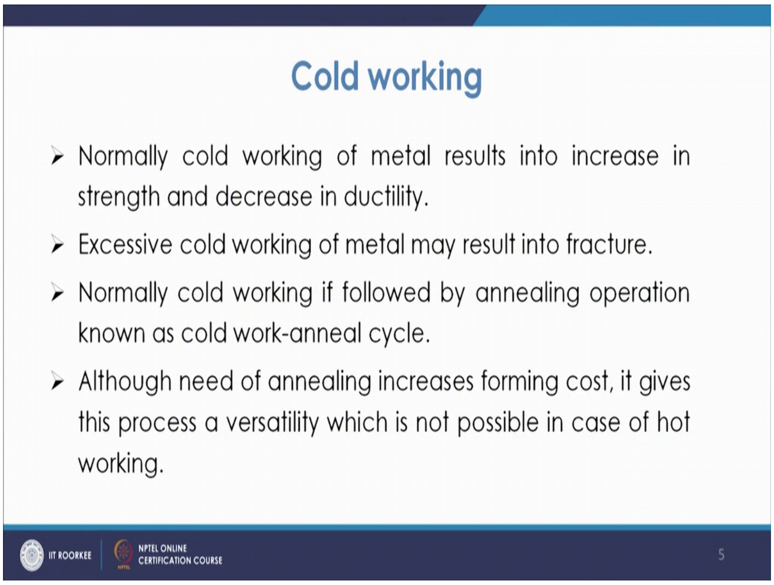

Then we come to cold working. Now, cold working as we know that the cold working is again the condition of deformation and under the pressure and strain rate in such a way that your recovery is not active in that case. So, that is why it results into increase in the strength and decrease in ductility in case of cold working. So, what happens that many a times if you do the excessive cold working, it results into the fracture before it reaches the final shape. So, normally the cold working is done in such a way that it is followed by annealing operation. So, there also you have multiple passes. And you do the cold working and then you go for annealing operation.

The advantage of cold working is that in the case of hot working we saw that because of high temperature you have the chances of oxide formation reaction these problems are not there in case of cold working. But certainly in the annealing so what we saw is that you have a cold work anneal cycle. So, normally because when you go for cold working as you go on deforming because of strain hardening, the flow stress requirement goes on increasing.

So, basically if you try to deform more in that case there may be a situation, where you know that the material that inside the stress generator is more than the yield strength, so their material may fail or it may fracture. So, for avoiding that we do the annealing operation in between. So, although it is increasing the forming cost, but it increases also the versatility of the process. In the sense that you can have a degree of reduction, also you can see that degree of a strain hardening possible. And normally the result the practices that I mean you can control the hardness of the material you know in this cold work and anneal cycle.

So, what we do is that whatever type of hardness you have to have depending upon that normally you see that this annealing if you want to have a hardness to be high then the this cold working should be the last operation. Or, if you want the material to be in soft state, then the annealing, it has to be ended with annealing. So, this way you can control the hardness of softness of the materials.

Similarly, in the case of wire drawing or. So, you can control the temper. So, based on based on this cold work annealed cycle, you can have the different kinds of hardness or the you know properties of the wire itself like you know spring temper or how much hard, water hard, half hard or so, so this is all based on this cold work annealed cycle. So, this is how we see that the temperature is how much important in the cases of working. And we will study about a different processes and then see that how and you have based on these temperature itself you have the cold working and hot working.

Apart from that, also you have warm working process. So, if you see warm working process, it is basically in between it is take the advantage of both cold working as well as hot working. So, it goes below the workable range that in which the recrystallization the hot working and then comes up to room temperature. So, it has the advantage of both hot and cold. So, sometimes less load or and less chances of you know more I mean this one's less load then less wastage because of the oxidation or so, so this takes the advantage of both cold working as well as hot working and it is in between that temperatures. So, this is about these temperature effects in the case of metal working.

Thank you very much.