Mathematical Modeling of Manufacturing Processes
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Lecture - 33
Heat Treatment

Hello everybody. Now I will look into the next module of this mathematical modeling of manufacturing process course. So next module means it is a heat treatment process. So basically, here we will not be discussing about the details and content in the heat treatment rather we will try to look into the basic principle of the heating treatment process and practically in manufacturing processes when you handling the different kind of materials how this heat treatment process actually influences the properties and structure of a particular material.

And mostly, steel, most of the cases it is; it will; our analysis will be focused on the steel components. So heat treatment process we have gone through this heat genuine process from the, from basic principle so first thing is that what do we understand the heat treatment process. In general, we say that it is a control heating and cooling process to; for the purpose of altering the properties. Properties mean most of the cases we generally perform of the heat treatment process after manufacturing; apply any kind of manufacturing process.

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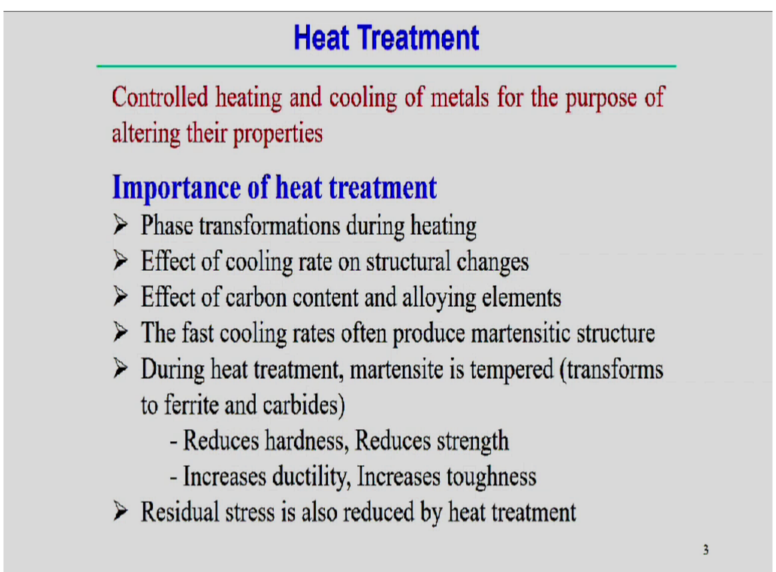

For example, in general in after oiling process most of the cases we try to follow some kind of the heating treatment process such that the certain specific properties material properties can be improved and mostly the mechanical properties, micro structural properties can be improved by the application of the heat treatment process. And of course having some importance of the heat treatment process and which may be most of the cases followed by any kind of manufacturing process.

So in that extent we just get the overview of the different heat treatment processes. So, first importance of heat treatment process; so importance of heat treatment process, if you look into point wise first is the Phase transformation during heating. So you have to give some idea about what phase transformation happens during the heating phase, during the heating and cooling and most of the cases we normally get all this information from equilibrium phase diagram.

And; but in this cases we would look into the; assuming that some idea about the equilibrium phase diagram or maybe iron-carbon equilibrium diagram, and we try to analyze look into the different types of the phases exists at different composition and depend temperature. But assuming that all these phase transformation happens normally happens at a constant pressure. Now then what are the effect of the cooling rate on the structural changes because most of the structural changes happens normally most of the we handle the alloy system.

So diffusion dependent system the rate of heating and rate of cooling is important. We normally follow and structural; structure changes accordingly during the manufacturing process. So therefore, the importance of the effect of the cooling rate is important when you look into the application of the particular heat treatment process and of course effect of the carbon content and allowing elements specifically in the alloy system.

What is the carbon percentage, because the phase transformation is entirely depends on the composition of the two components and therefore, mostly still the carbon percent is important there and we try to represent in the iron-carbon equilibrium as a function of carbon percent? Therefore, at different carbon percentage what type of the heat treatment process we normally follow to improve the properties of a manufactured component.

Of course this information also important when you try to analyze the heat treatment process that is the fast cooling rate. If it is possible to follow particular situation if you; very cooling rate this becomes very high most of the cases is produced the martensitic structure and of course this martensitic structure is almost diffusion the structure. So therefore having some important and this martensitic is normally very hard so therefore, if we improve the hardness we want to increase the hardness of a particular component maybe we can follow a very high cooling rate.

So therefore, this is one aspect. Then of course if we follow the; if we high cooling rate and then martensitic structure is followed but practically, we cannot use this thing until and unless we do the; we follow some kind of a tempering of the martensitic structure. And after tempering then only can use that structure in practically; so, therefore during heat treatment that is also under the heat treatment process whatever we follow the tempering process and we bought different cooling rate different heating rate a particular component and up to which temperature we can raise particular temperature.

All are actually included or explained in general the heat treatment process of a particular component. So therefore, heat treatment process martensitic is tempered then martensitic is transformed into the ferrite and the carbide structure in general and then when you distransformation happens it actually imparts that kind of properties if you reduce the hardness, reduce the strength but increase the ductility and increases the toughness that is another property or may be that bring the uniformity in particular properties if we do the heat treatment process of the martensitic structure.

So therefore residual stress is also reduced by the following the proper heat treatment process. So, therefore each heat treatment process having very much important if we look in the perspective of both materials and manufacturing processes. So that is why we look into that different aspect of heat treatment or different types of the heat treatment process here.

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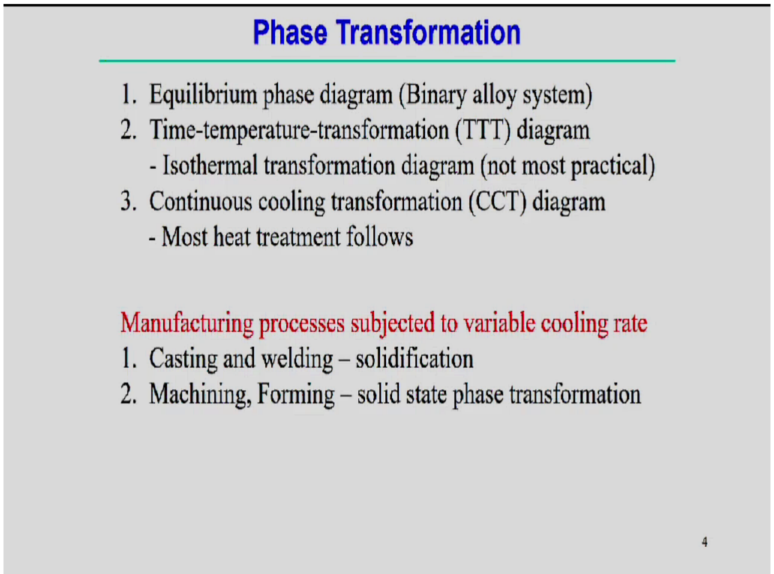

Before doing that some idea about the Phase transformation is required in these cases. So normally if we analyze the phase transformation we know these three different types of the curve normally follow. One is the Equilibrium phase diagram, and most of the cases it is easy to understand if we follow some Binary alloy system. So binary alloy system means it is when you try to make the solid solution or the particular solution by combining the two only, two components then that can be represented as a function of the composition or as a function of temperature.

The total different phases exist in the; and that all information we can get from the binary phase diagram. And then that is also important but of course this equilibrium phase diagram we assume that equilibrium condition is achieved that means in practical when you try to form the equilibrium phase diagram to different phases that actually forms under equilibrium condition means that we are allowing the transformation of one phase to another phase sufficient time.

So mathematical you can say the rate of this transformation may be tends to infinity, so in that case or taking the very high time, long time that actually the typical characteristic of the equilibrium phase diagram or to reach the equilibrium condition to transfer from one phase to another phase. And of course this is an important equivalent phase diagram but actual processes there may be some variation of the rate of the cooling rate; yet it may not happen at constant temperature.

So therefore, in that cases time dependent or time temperature transformation also important. So time temperature transformation or we can say that TTT diagram and this TTT diagram the typical characteristic is that. In this TTT diagram we represents the transformation diagram an isothermal condition so that we can define it is a particular temperature keeping temperature as a constant work with the transformation from one phase to another phase or happens; that information we can get from the TTT diagram.

But that is; practically the transformation or it is very difficult to follow any kind of any manufacturing processes to as it allowing the transformation at a constant temperature. So most of the cases temperature varies in actual process then this TTT diagram may not be feasible for practical use but till some much more information we can get from the TTT diagram. Apart from that we can look into more practical that is called the CCT diagram that is Continuous cooling transformation diagram.

So in continuous cooling transformation diagram we can get the information if a transformation happens; if we follow a particular cooling rate, rate of the cooling rate, rate of the cooling so in that cases what kind of phase transformation what kind of structure we can expect that represented as a function of rate of the cooling and that is most in practical information we can get brought from the CCT diagram.

So therefore, most of the heat treatment follows the information from the CCT diagram of a particular material and all this information we can say mostly the binary assuming the binary alloys system. So that is why I am not going into that how to construct the TTT diagram and then CCT diagram that is not the objective of this course rather just to overlook assuming that it is a equilibrium phase diagram, TTT diagram, CCT diagram is well-defined.

And in this case we get the information from this diagram such that we will be able to explain the different heat treatment process. So therefore, if you look into the different manufacturing processes that mostly subjected to variable cooling rate, and variable cooling that if you see that casting and oiling process if you see is never followed. Everything is happening as a constant temperature but during solidification also rate of the cooling not as a constant also then practically it is the rate of the cooling also even cooling rate also varies at the different position.

And it is associated with other manufacturing processes also if we see the machining and the forming processes. There also solid state phase transformation happens, but in this in that case change of temperature or maybe we can say the rate of heat cooling may not constant all these process. So therefore, but till we get the information the; at constant cooling rate the different phase happens that information is may be useful to explain the different manufacturing processes or expected microstructure.

And at the same time this; we can modify or alter this microstructure to that information we can get from CCT diagram and accordingly we can apply the different types of the heat treatment processes to get the feeling of the changes it is happening during the; during manufacturing process or if you want to change the structure what should be the heat treatment process we should follow.

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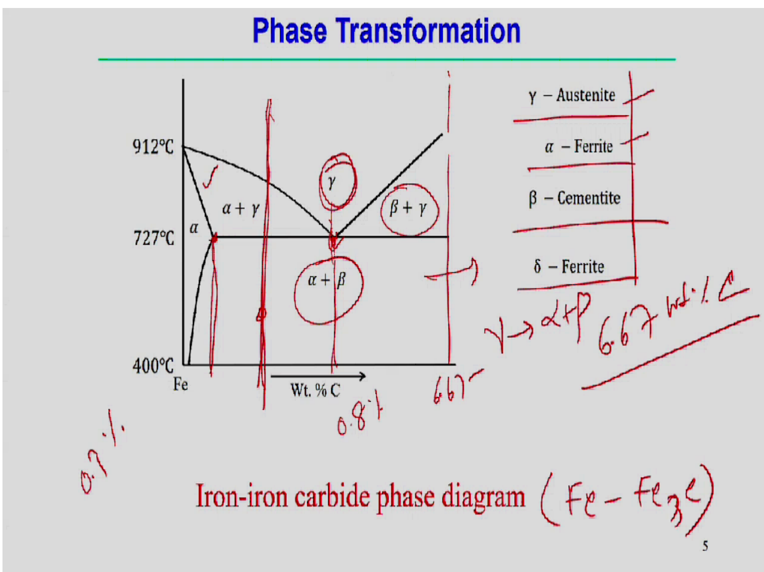

Here some basic phase diagram of Iron-carbon diagram or we can say that Iron-iron carbide phase diagram, say you can say that Fe and Fe3c phase diagram. And that if you look into that phase diagram with this phase schematically you can see here there are different kind of phases exist at different temperature range and maybe different composition range. So Austenite if you see; this phase indicates the gamma is basically the austenitic phase. So, if you see this diagram that weight percentage of carbon and this x-axis represent and y-axis represents the temperature.

So in this case over a wide range of the weight percentage of carbon it exists in a single phase structure; and that single phase structure is up to 727 degree centigrade. So, that is we can say that this is called austenitic phase. Similarly, alpha ferrite structure, this alpha ferrite structure we can see that it is also range over 912 degree centigrade and you get to around 400 degree centigrade in between that range. But solubility of this alpha or carbon up to certain extent mostly 0.02 weight percent of the carbon so it is very small and that exist it is called alpha ferrite.

So alpha ferrite we can say almost, almost pure iron in that kind of structure and the single phase structure. Similarly, we can get the Cementite structure, cementite structure is mostly 6.67 weight percentage of carbon and that from the cementite structure and that is beta phase and we can see that right hand axis; oh, if we present that can be in; that can be that 6.67 weight and that represents the cemented structure. And the cemented structure also exists over a range.

But the solubility maximum solubility of carbon in symmetry structure is 6.67 weight percentage of carbon. So therefore, in certain zone we can get the mixture of the two phases. So here you can see this zone represents that mixture of the alpha ferrite and austenite phase. Now if there certain carbon percentage is forms it is around 0.8 to 8% of carbon; this percentage and that actually clears some kind pearlite structure.

Now this beyond that 0 beyond 0.8 percent of the weight percentage of carbon it is a mixture of beta plus gamma that means it is a mixture of Austenite plus Cementite phase. So that two-phase mixture phases coexistence and all this phase, two different phases coexistence and but in a solid state basically. And we can say the mixture of the two phases and both the phases are in the solid state or overall mixture of this it is also in solid state.

Now in this phase we can get it is the mixture of two different phases; it is the alpha phase and beta phase cement ferrite plus cementite. So, any structure at in between these weight percentage of the carbonate if it forms; if we follow this weight percentage of carbon less than 0.8 percent for example if we take 0.3% of carbon. So 0.38% carbon it creates the final structure which is consist of the mixture of the ferrite plus cementite.

And the morphology can be different in these cases. For example, exactly at 0.8% of carbon this; and it is a below at 727 degree centigrade the austenitic phase decompose into make in the two different structure, so gamma phase is consist of the alpha plus beta phase and that mixture of the alpha plus beta phase form certain morphology and it depends on the; this morphology represents the what is the microstructure for this particular composition of the carbon. So in this case it is a 0.8% of the carbon.

So therefore below 727 degree centigrade that structure exists and of course all the equilibrium condition is a mixture of ferrite plus cementite but above 727 degree centigrade but carbon weight percentage is 0.8 in this case, the structure exists in the form of the single phase austenite structure. So phase transformation normally happens and at particular temperature and that information we can get from this equilibrium phase diagram.

And of course from here also we can get the information at what may be the effective weight percentage of the carbon and such that it transform one phase to another phase or may be one phase to two different phases and mixture of the different phases. So therefore, all this information and here you can get when you are telling that alpha phase exists up to this point so this indicates that what is the maximum solubility of the carbon such that it creates the single phase structure.

So all this information from here we can say but overall you can see the 4 single phase normally exist if we look into the binary phase diagram of our iron and iron carbide. So here one phases is the austenite phase, alpha ferrite which is normally exists in relatively low temperature, beta is the cementite phase and delta ferrite also exists in narrow range and small percentage of the carbon, but this normally exist over relatively at high temperature, so that is why we can get all this 4 single phase structure from this phase diagram.

So using this information and information means what way the transformation or what composition we can we can follow we can develop the different heat treatment processes.

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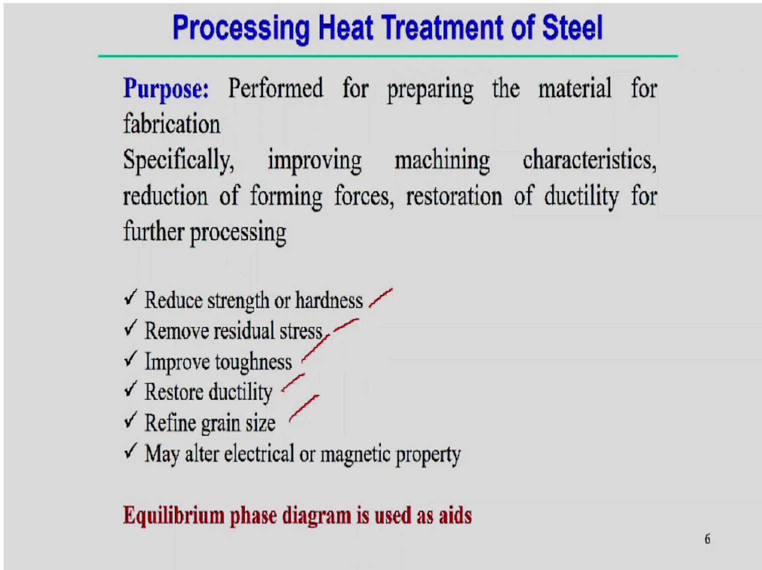

So first we look into that processing heat treatment of steel. So because steel is the most widely used material and we can explain the; what are the different heat treatment process normally fall in case of steel. So what is the purpose of the processing heat treatment? Perform for preparing the material for fabrication. So sometimes before fabrication before using that particular material to follow any kind of manufacturing process we can process it by following certain kind of the heat treatment process that is called the processing heat treatment of Steel.

in these cases, the purpose is to improve the machining properties machining characteristics or a particular component and the such that it will be it will be easy to do machining process or for example in case of forming process first the reduction of the forming process so that before applying a particular forming process of a particular material we just prepare we follow some kind of the heat treatment process to the particular metal.

So that it will be easy to do the forming is in the sense that material can be processed at the lower forming forces. Similarly, some cases restoration of the ductility for further processing so you can restore the ductility or you can improve the ductility for a particular metal, such that the formability of the particular component can be improved. See in that sense we can follow the different kind with the processing heat treatment.

So what is the purpose in general, first is the reduction of the strength or hardness, removal of the residual stress, improve toughness we can restore the ductility also that means again and of course by heat treatment process it is possible to refine the grain size also. And of course in certain cases it is a possible to change the electrical or magnetic property through the processing heat treatment of steel.

But processing to understand the, what heat treatment process we need to follow then we need we can take the help of the equilibrium phase diagram as an aid to explain the different heat treatment processes.

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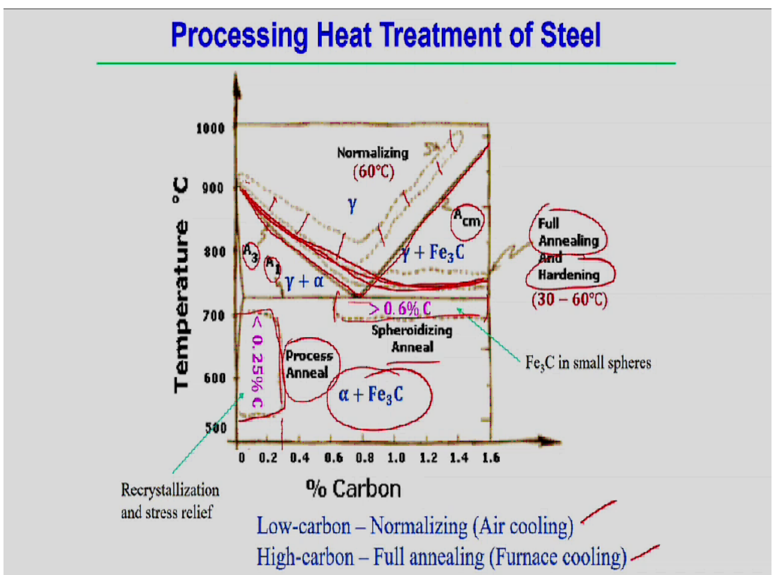

So if you look into graphically here, if you see that here this graphically you are trying to replace in the equilibrium phase diagram of Iron-iron carbide actually and this represents the weight percentage of the carbon. So first we look into that normalizing process, one kind of the heat treatment process. So what happens normalizing process, so we know this is the line these two lines here which represents that you can put at the transformation line A3.

And of course it A3 line which is characterized by the particular temperature and composition. Similarly, A1 line this is the line were this line is represented a1 is A3 and this is A cm all these three transformation lines we can define from the in the equilibrium phase diagram. Now if we follow some normalizing process. For example, normalizing process this is the normalizing process about the range that means the common process is that; particular component raised to that particular temperature.

If you know the composition raised above this thing and particular temperature above 60 degree centigrade that means above A3 or A cm line and plus adding another 60 degree centigrade and this process and give sufficient time such that all this component is transforms to this that phase because if you raise the steel component at this temperature range, we keep you for a sufficient time then it will transform to the austenitic phase, because; and why it is austenitic phase because how this is austenitic phase for some of the phases that information we can get from the equilibrium phase diagram.

So once it is transformed into the austenitic phase then we follow certain rate of the cooling and that rate of the cooling is also important to get particular microstructure or particular grain size. So normally in normalizing process for low carbon steel we normally follow the air cooling process. Similarly, if you full annealing process, of course this is full annealing process.

So full annealing process the range is from here to here so this range indicates that around above this A3 and A1 depending upon the what carbon percentage we are using particular composition above that temperature more above the temperature 3 to 60 degree centigrade mode we can raise the temperature of a particular component. Then we follow the cooling. And in case of the full annealing process we normally follow the furnace cooling.

This is furnace cooling is actually very controlled cooling process we can follow or normally cooling rate is very low in this furnace cooling, so that we can achieve certain properties, if we follow certain cooling process. We will discuss in details the different processes. So here we are trying to explain that what way we can take the help from the equilibrium phase diagram to define different kind of the heat treatment processes.

Similarly, if we follow the hardening process almost the same temperature range we can raise within this zone, say full annealing zone and normally 3 to 60 degree mode temperature we can add to that particular composition above A3 or A1 temperature and then normally hardening process we can follow the very rapid cooling such that we can import the hardness bring hardness to the component.

Similarly, we can see the process annealing process annealing normally followed in the less than 0.25 weight percentage of carbon. So this is the zone we define. So this is zone indicates that this process annealing is followed the composition having less than 0.25 weight percentage of the carbon. So in that cases we follow the process anneal and of course the temperature is below the critical temperature that critical temperature we define for example by temperature line A1 in this case.

So therefore, re-crystallization happens and some seriously normally happen and process annealing. And mostly process annealing is normally followed when you try to perform the metal forming maybe the drawing process which is one kind of metal forming processes. So here to restore the re-crystallization to relieve the stress and the in process we can follow the process annealing.

Similarly, the spheroidizing process that is also can be followed but this temperature we can raise the temperature below the one critical temperature below the A3 the below that around 727 degree centigrade, that means in this zone and this range of the carbon partition normally; relatively higher carbon partition greater than 0.6 weight percent of carbon; for that particular component.

We normally follow the spheroidizing annealing process and below the A1 temperature such that, the Fe3C the carbide forms in this cases iron carbide can brings produce the small spherical particles and certain properties can be improved by this processes. So finally, we can get this zone that we are getting the mixture of the two phase structure is the alpha ferrite, is the mixer or cementite or we can say the iron carbide mixer of iron carbon, alpha ferrite structure.

We can expect between this zone and that we see that over a range of carbon percentage 0 to 1.6 we can follow the different heat treatment processes, different zone different temperature and if there is a restriction of the percentage of the carbon if we know that what is the weight percent of the carbon accordingly we can follow that kind of the heat treatment process and of course some other purposes also maybe in some cases process annealing can also be followed if in; which is attached to a particular manufacturing process.

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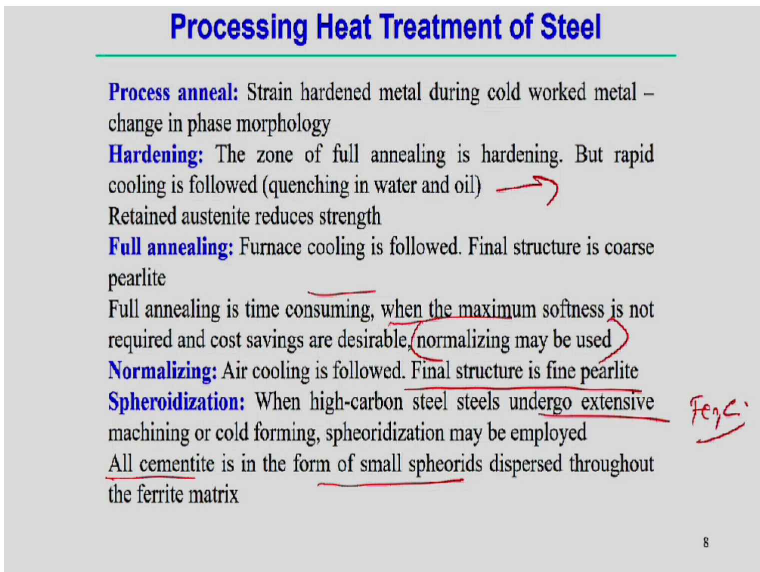

Now in details we can see the process anneal is basically the strain hardened metal. So normally in cold work forming process, cold work metal, cold work metal in that cases to release some kind of residual stress generation to allow some recrystallization process then we can apply the process annealing treatment in this cases such that we can change up the phase morphology can be changed in this case.

Similarly, in hardening process also the zone of the full annealing we can follow the hardening process also but in this cases we need to follow the very rapid cooling or quenching in water or oil that means heating or particular temperature, keep sufficient time then we put the medium either water in the oil and if you choose the different medium in that cases the rate of the cooling will be different, so in this cases if we put the medium as a water normally the cooling rate is very high so we can say this is the quenching process as well also.

So retained austenite but in these cases we can you can get kind of martensitic structure and that imparts the hardness, but of course if during this heat treatment process retained austenite remains in this case probably in that will reduce the strength of a particular components, so therefore, we have to look into that what is the return austenite and what is the martensitic transformation happens during the hardening process.

Similarly, full annealing process, in this cases hardness cooling is very controlled cooling is follow such that it takes sufficient time because cooling rate is very low and final structure is basically core structure because if we follow the very low cooling rate and sufficient time for the grain growth normally happens in this cases so that we can expect the pearlite structure in these cases and pearlite is coming because of the carbon percentage here.

And full annealing is time consuming but in practically it is very time consuming or because of very slow cooling rate they are therefore. And but at the same time it can impart the maximum softness to the component. So therefore if there is not a requirement of the maximum softness or time restriction is there and because time restriction is there so may be in other way we want to save the cost, in that cases' normalizing is most preferable as compared to the full annealing process because normalizing little bit first process.

And in this cases because air cooling is followed, so air cooling is the; in case of air cooling the rate of the cooling is faster as compared to the furnace cooling. So therefore, final but since little bit faster in the normalizing process cooling the decision faster takes less time or you can save the cost also but the expected structure is the fine structure for fine pearlite structure in case of steel. Spheriodization when high carbon steels may be goes under extensive machining or cold forming processes.

Excessive machining on cold forming product in that cases we normally follow and product, but if the carbon percentage is very high in that particular composition then we can; spheroidization can be employed in this process. So basically, in this cases simply allowed to all cementite. So high carbon percentage maybe Fe3C percentage is more, so in these cases Fe3 all cementite can be from into the small spheroid throughout the matrix and that is the most purpose of the spheroidization, so that can be followed in case of the in metal forming.

Heavy machining or very high cold deform process we can follow the spheroidization process. And of course spheroidization process but when the carbon percent is a little bit more. But if carbon percent is little bit less maybe we can follow the process annealing in that case.

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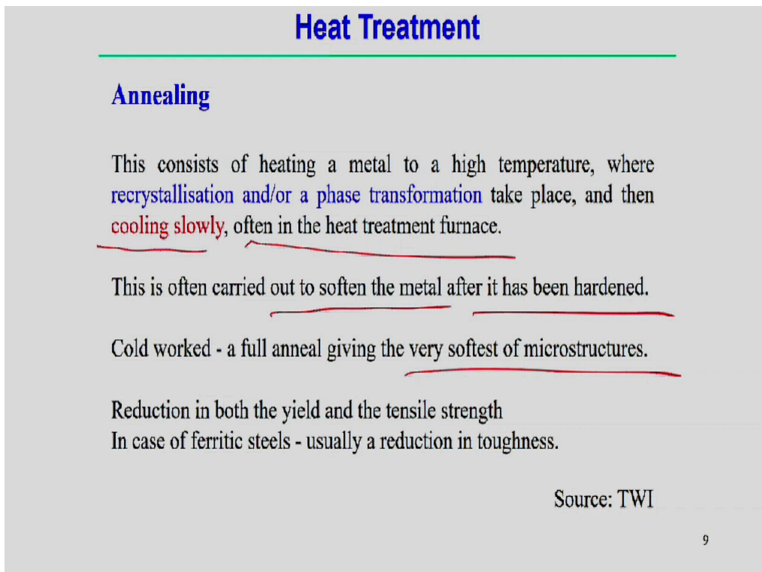

So annealing also in general you can say the heat treatment is the; in general, the annealing process heat treatment process. It is consist of the heating of a particular metal at a very high temperature we have already discussed. And of course in these cases the where recrystallization or phase transformation may takes place during the annealing process but in these cases the slow cooling is followed and of course often in the heat treatment from the furnace.

So therefore, this is normally occur this when we want to soften the material after the after being the harden it has been hardened after we harden if you want to solve we want to restore the ductility brings the ductility probably in that cases we can follow the annealing process. Cold worked a full annealing giving the very soft and microstructure, softest microstructure and if we follow that full annealing heat in your process of the cold worked material.

In these cases, both reduction and the tensile strength is there but at the same time it also improve the toughness. But in case of ferrite normally improve the toughness in this heat treatment process. But if carbon percentage is very lower side there was almost pure iron in that cases usually reduction is toughness also happens by following the annealing process, annealing treatment.

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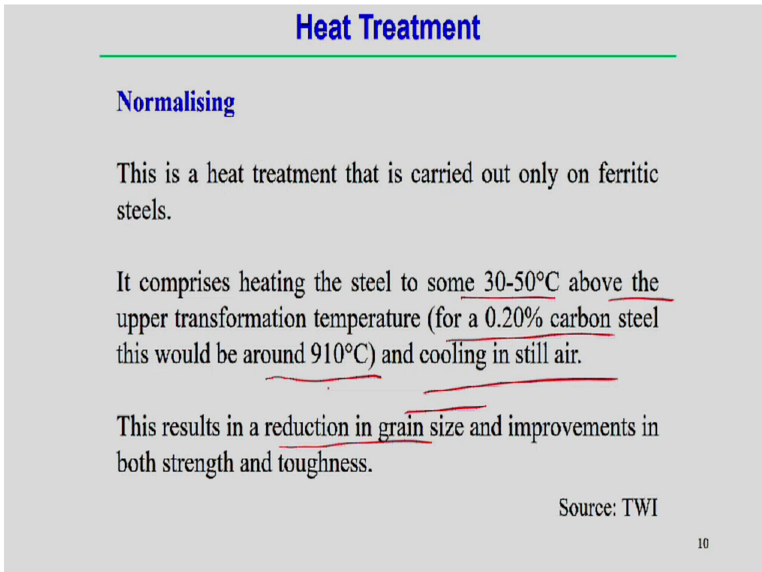

Similarly, normalizing in normally heat treatment process only on the ferritic steel, in that cases normalizing; but normally it happens ferritic steel and it comprises the heating of the steel to some 30 to 50 degree centigrade. Actually I am trying to explain the normalizing process here in the perspective of the different oiling process. So here 30 to 50 degree above the upper transformation temperature that transformation temperature I already mentioned we use and there is a normally 0.2 weight percent of the carbon steel that would be around 910 degree.

If we is use 0.2 weight percent of carbon this transformation temperature is around 910 degree centigrade and that information will be getting from the equilibrium phase diagram and then after reaching that temperature we normally follow the cooling in the still air, because normalizing we follow the cooling in the normal ear. So therefore, this results in the reduction in the grain size.

So definitely you can find pearlite structure normally follow; we get from not following the normalizing process fine structure so therefore, reaction in grain size is possible using these things and at the same time improvements in the both strength and toughness is possible by following the normalizing process.

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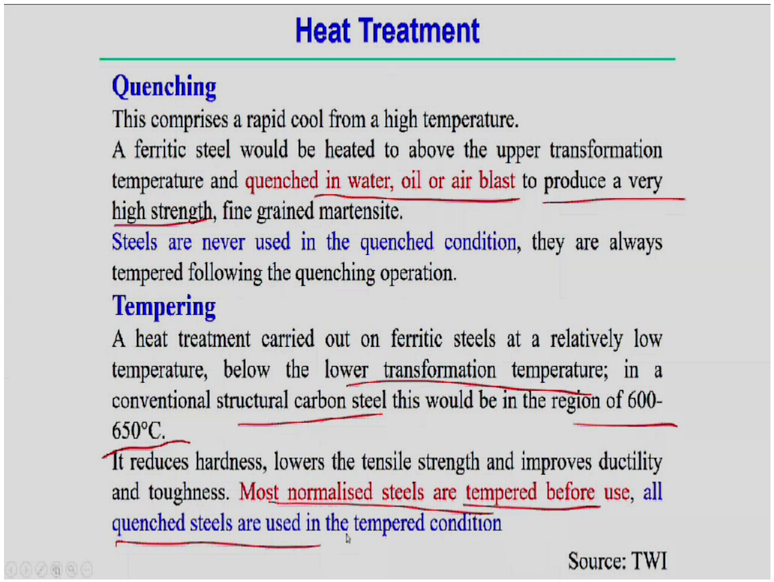

Similarly, quenching is basically it is consists of the very rapid cooling of a particular component and where this rapid cooling normally happens when you start from the very high-temperature. So ferritic steel would be heated to above the upper transformation temperature in that cases and maybe quench if you that quenching process normally we see the quenching is normally done in using the water oil or the air blast because water and oil they impart the normally very high cooling rate.

And of course in these cases it produce the very high strength material and fine grained microstructure, in this case quenching process. But of course steels following the quenching we directly it seems it follow the martensite structure it is not we normally do not use this structure after quench condition. Further processing; normally following the tempering process normally following a quench product.

So we can say that if you follow the quenching process in a particular composition of steel then we cannot directly use after the quench we get the structure after quenching. Normally after quenching we normally follow kind of tempering process. So then tempering is the heat treatment process. This is also another kind of heat treatment process but normally carried out with the ferritic steel but this ferritic steel carried out in these cases particularly in this perspective of the oil/air structure but at a relatively low temperature.

So tempering normally done at low temperature and below the lower temperature and below the lower transformation temperature in case of the steel in a conventional structural carbon steel this would in a region of 600 to 650 degree centigrade. Actually the tempering is performed around 600 to 650 degree centigrade. Basically, tempering is also performed after quenching that component has raised a temperature around 6 to 650 degree centigrade for particular steel.

Then once you raise these things it then we can follow the tempering process such that it imparts reduces the hardness, lowers the sensations strength and improves the ductility and toughness. But most normalized steels also are tempered before use. So even normalized components we are not directly used so after normalizing still, we normally follow the tempering process then we can use the component.

So all quenched steel similarly tempered steel as well as the quenched steel share also used in the tempered condition so that is why tempering is one very important heat treatment processes and that normally happens at the raise the component of the temperature towards the lower temperature 6 to 650 degree centigrade.

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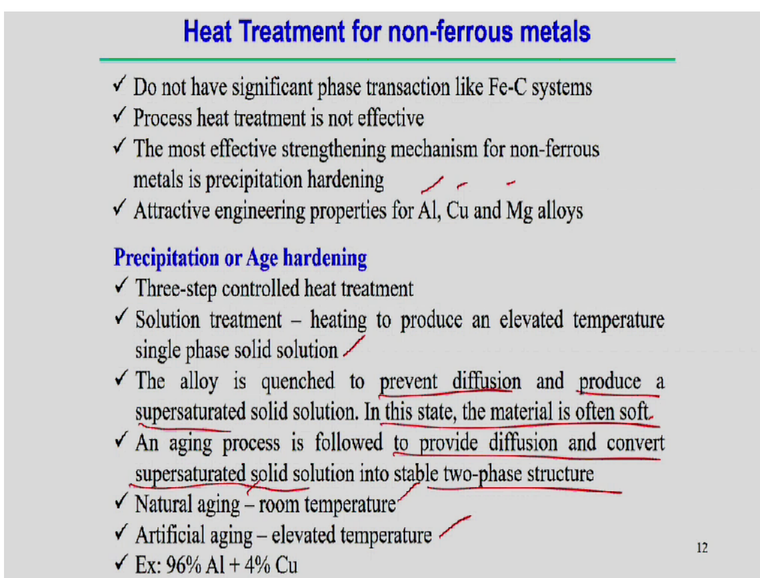

Now apart from this heat treatment of the ferrous material there may heat treatment for non-ferrous metals also. So non-ferrous metals if we are not having the significant phase transition like iron-carbon system; iron-carbon system, we can see there are the different type of the phase transformation from one phase to another set and that numerous phase numerous structural morphology we can observe in case of iron-carbon.

But that kind of several phase transform may not very obvious in case of non-ferrous materials, so therefore, they may not having just like several phase transformation like iron-carbon system. So therefore, in these cases the process in heating treatment may not sufficient or may not effective, so therefore, most of the effective strengthening metal for non-ferrous metals mainly the precipitation hardening.

So if we allow the small particles to precipitate out during the heat treatment process then that imparts the strength to the structure, so that is normally most usable in case of the non-ferrous metals. So in this cases active engineering properties or attractive engineering properties can also be possible to this kind of non-ferrous metals such as aluminum, copper and magnesium alloy. What do you understand precipitation hardening; it is a basically three step process control heat.

This heated treatment process so therefore, control heating and cooling process also in this case. But first step in precipitation hardening is that solution treatment is follow. Solution treatment means heating to produce heating is applied to produce the elevated temperature and such that it brings to the single phase structure or it brings to the single phase solid solution phase. So therefore, the alloy is after that the alloy is quenched to prevent the diffusion quickly quenching means very rapid cooling if you follow.

So therefore, such that rapid cooling is followed to such that the diffusion is prevented so therefore, it produce kind of the supersaturated solid solution structure and in this state actually the metal becomes soft which is completely different from the ferrous metal because in ferrous metals we; if we follow if we see that if we follow the very rapid cooling in the ferrous metal heat normally follow the martensitic structure and martensitic is normally hard but in this cases the structure is different if we follow it can create some very soft structure in case of the non-ferrous metals.

So therefore after that and aging process is followed, aging process followed to provide the diffusion and convert the supersaturated solid solution into the stable two-phase structure. So if we follow the; if we raise; in this case if you raise particular single phase solution at a very high temperature after that if we follow very rapid cooling then we try to retain the similar kind of the structure, single phase structure as well.

But that is; since that gives this kind of supersaturated solid solution so therefore, further processing is also required to brings the two-phase stable structure. So supersaturated single phase solid solution normally it follows. So then two phase structure if you want to bring that then we follow the aging process that aging is either natural aging it is a simply what cooling process room temperature it following or artificial aging.

In these cases, the elevated temperature controlled cooling normally we follow. So then example is that 96 percent aluminum and 4 percent copper. If we look into the phase diagram 96 percent aluminum, 4 percent copper. So in that cases we raise first to the single phase solid solution structure then rapid quenching will followed after that we follow some kind of the; at different temperature some cooling we can follow. So that is called the precipitation age hardening.

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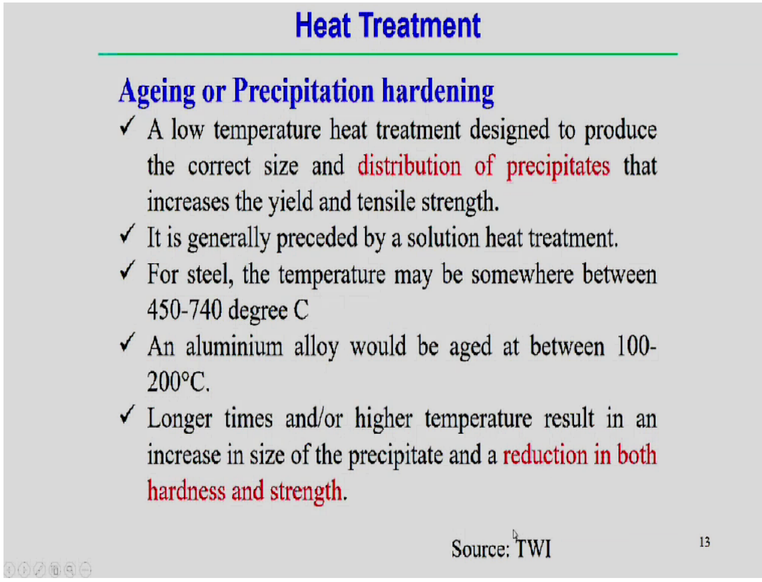

In general, we can say the precipitation hardening also here the; we can say the low temperature heat treatment process to produce the correct size and distribution of the precipitates because here the purpose is to brings the precipitates. So in this cases if it is possible to from the precipitous but this distribution of the precipitous and size of the precipitates also important and that imparts the different kind of the strength and of course that decides that what is the yield strength and the tensile strength of a non-ferrous material.

So it is generally preceded by the solution heat treatment process that we already discussed, first we do the solution heat treatment that means to bring the single phase structure particular temperature even it is; for steel also temperature may be in between 450 and 740 degree centigrade, for aluminum alloy it can be aged in between 100 to 200 degree centigrade. So we see that natural aging or artificial aging we can follow but natural aging can be done a room temperature but artificial aging can be done at little bit higher temperature.

So therefore longer times or higher temperature results in the increase in the size of the precipitate and reduce in the both hardness and strength. So therefore, this; whether we can decide follow the natural aging or artificial aging so it depending on the whole time and the temperature at what temperature we can follow in the aging process accordingly the precipitate size and reduction changes and of course finally it influence now what is the strength and the hardness of a particular non-ferrous material.

So therefore, that information whether we could call this low temperature or high temper at what temperature that of course we need to follow that particular phase diagram of this particular composition.

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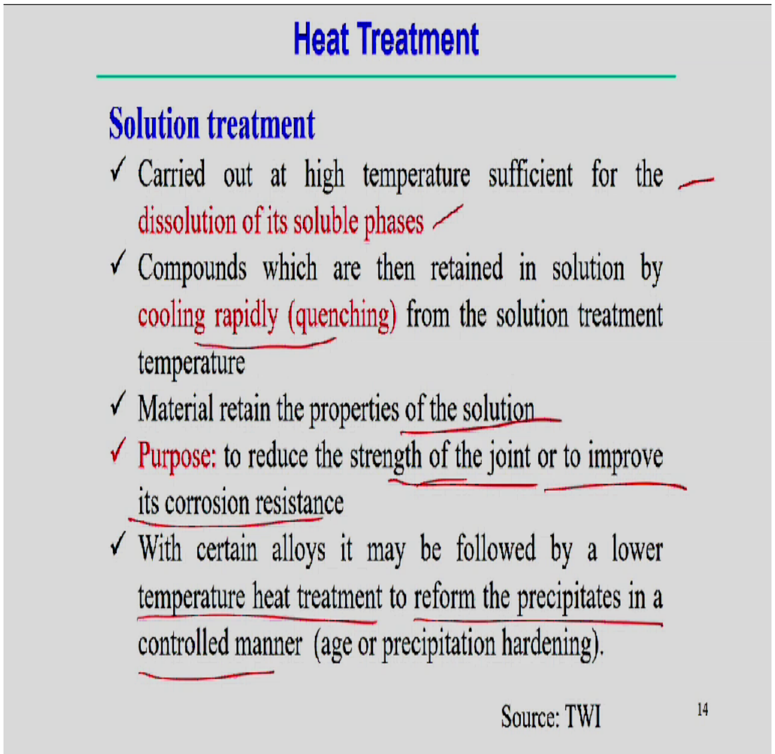

Now solution treatment we already discussed the solution treatment but we can look into that. It can be carried out at very high temperature and sufficient for the dissolution of its soluble phases, so it is purpose is to bring the single phase solution structure and compounds then we can follow the rapid cooling quenching from the solution treatment temperature. And then material retains the properties of the solution that means if you follow a rapid quenching.

If you follow the quenching or rapid cooling process so in that cases the material retained that kind of properties what was in the solution at very high temperature. So here purpose is to reduce the strength of the joint or to improve the; its corrosion resistance sometimes we can do the solution treatment of a particular composition to reduce the strength of the joint or to improve the corrosion resistance properties.

So therefore, certain alloy it may be followed by a lower temperature heat treatment process to reform the precipitates in a controlled manner. So that is why in case of non-ferrous metals we can follow certain aging process such that we can impart the some kind of the control size of the precipitates and that the properties depend accordingly.

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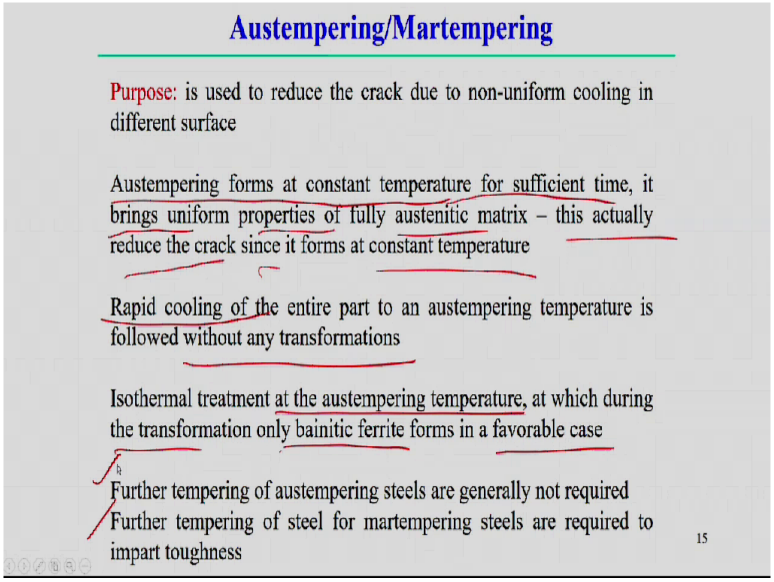

There are other heat treatment process so that is Austempering or Martempering processes. The purpose is used to reduce the crack due to non-uniform cooling in the different surfaces. So normally Austempering and Martempering other type of heat treatment process when big size of component and big size of the component during the heat treatment process or any other processes if it is follow the different cooling rate and the top surface and the interior part.

Then the different difference in this cooling rate brings some create some kind of the crack at the particular component. So in that cases we can follow the austempering or mastempering process such that to avoid the non-uniform cooling during the; at the different surfaces or different parts of a component. And what we can control we can define the austempering or mastempering process.

So austempering forms at constant temperature definitely and for sufficient time so is just try to bring the austenitic phase and at this particular temperature and for a sufficient time. Then, such that it brings the uniform properties of the full austenitic matrix. So if you follow brings the all the components as a particular temperature as a constant temperature in a whole for a sufficient time so it brings the uniform properties or uniform structure throughout, and this actually reduced the crack since it forms a constant temperature, that is the purpose.

And then after that rapid cooling of the entire part of the austem, at an austem temperature is followed. So rapid cooling is followed but during this rapid cooling is followed the purpose is to follow the rapid cooling such that no transformation happens during this process. So therefore, that is normally happens. So therefore, rapid cooling is followed such that without any transformation normally happens during this rapid cooling process.

Then after that we follow some Isothermal heat treatment at the austempering temperature at which the transformation the; it is transformation happens only bainitic ferrite forms in a favorable case. Most favorably it produces the bainitic structure from austenitic structure. But this transformation happens this transformation should follow at particular temperature and that transformation we normally promote at the isothermal transformation such that it creates the; in favorably the bainitic structure in case of steel.

But austenite; austempering is fall in such way such that further tempering of the structure is not required generally not required in this case, but similar but if we follow the martempering structure, martempering process in this cases after martempering we need to follow some kind of the tempering process of steel. So that is the difference between the austempering and martempering. Now we look into the martempering process also.

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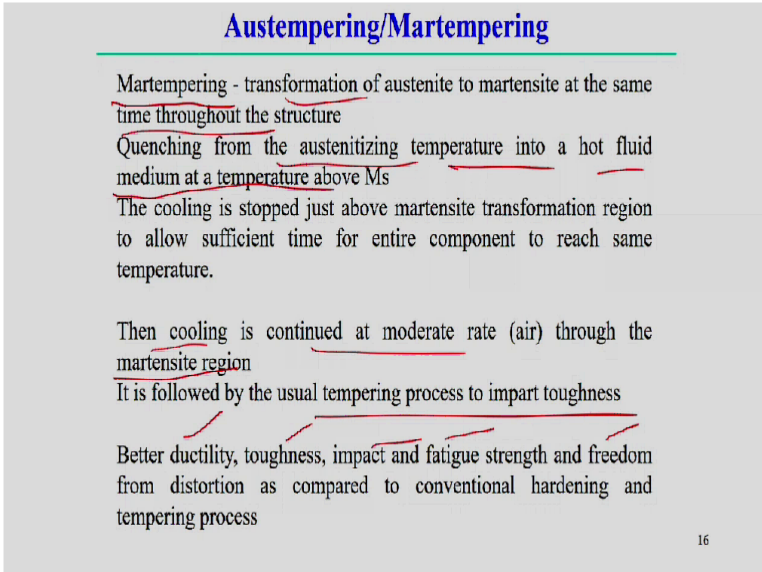

In martempering, you see the transformation of the austenite to the martensitic structure at the same time throughout the structure we just at the same throughout the structure just to avoid the same purpose that means to avoid the different rate of the cooling at the different component of a different single component at the different part.

So therefore, at the same time throughout the structure that is also purpose of the martempering but in this cases quenching the follow, the quenching from the austenitizing temperature same thing into a hot fluid medium and that quenching is followed up to the particular temperature that martensitic started just above the martensitic start temperature quenching is followed, so that the structure can be retained here. The same structure can be retained what was in; was above the austenitic temperature.

So now once we reach above the martensitic temperature then cooling is followed or cooling is stopped just above the martensitic transformation region to allow the sufficient time for the entire component to reach the same temperature. So therefore in this cases the; we bring the rapid quenching of a particular temperature so that at that particular temperature then allow to sufficient time such that it can be transformed to the same temperature we can reach the same temperature throughout the structure.

Then once the sufficient after sufficient time keep the sufficient time then we allow the cooling then cooling is a continual moderate rate, normally our cooling is followed through the martensitic region. So temperature region is the through the martensitic region normal cooling is followed, such that it can follow the brings the uniform structure such that uniform structure. And of course after forming that there is a necessary to follow some kind of the tempering process to brings the, to impart the stiffness of this component.

So therefore, martempering and austempering we normally follow kind of heat treatment process and that is brings the in general improves the better ductility, toughness, impact, impact and fatigue strength is improved, freedom from distortion as compared to the conventional hardening and tempering process and compared to conventional hardening tempering process the ausstempering and martempering is more useful when the size of the component is very big.

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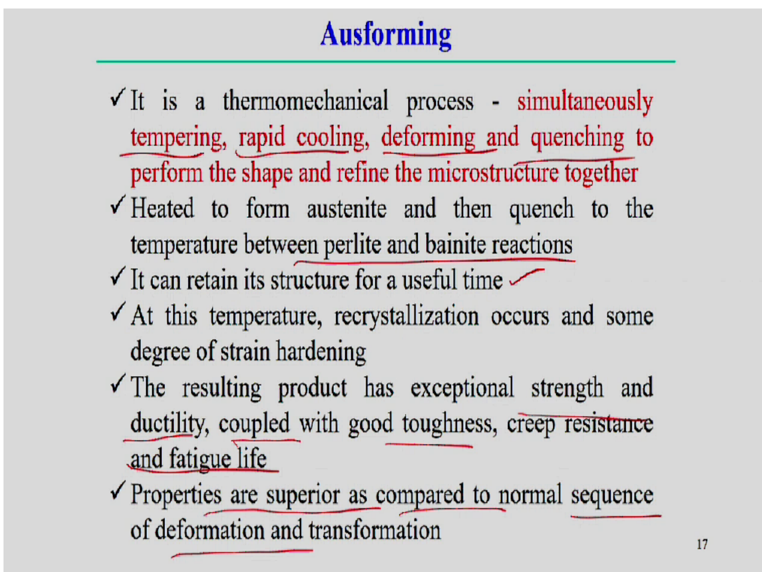

There is another heat treatment process that is called the ausforming process also. So ausforming process here you can see it is a combination of the; if we look into other heat treatment process if we say that is a thermal process also but it is a combine of the thermomechanical process. So thermal-mechanical process in the sense that simultaneously application of the tempering process then a rapid cooling process and also some mechanical process we apply here.

So in the form of the deformation and the deformation that is the mechanical process introduced here and after that quenching. To refine to perform the shape change as well as the refinement of the microstructure together, so that is the purpose of the thermomechanical process which is called heat treatment which is also under the heat treatment that is called the ausforming process. So here heated to the heated to form the austenitic first same we bring the austenitic phase heated the sample to that temperature and then quench to the temperature below de between the pearlite and bainite reaction in between that temperature we bring it by quenching process, so once in between these things.

Then it can retain its structure useful time that means between the pearlite and bainite a mixture of the pearlite and bainite structure in case of the steel and at this time if we follow some kind of the deformation deform the component then recrystallization happens at this temperature occurs. And of course when recrystallization happens it imparts and maybe degree of strain hardening can be imparted during this process.

So therefore, the resulting product as the exceptional strength and the ductility combining of the strength and ductility coupled with good toughness, creep resistance properties and fatigue life all can be improved by following the ausforming process. And of course these properties are superior properties of the company is superior if we follow the ausforming process as compared to the normal sequence of the deformation and transformation.

So if you follow the normal sequence of deformation and transformation that means deform and then we follow heat treatment process rather the combined effect can be imparted in the ausforming process simultaneously performing the thermal process as well as the mechanical process to improve specific properties of a component as compared to the other heat treatment processes.

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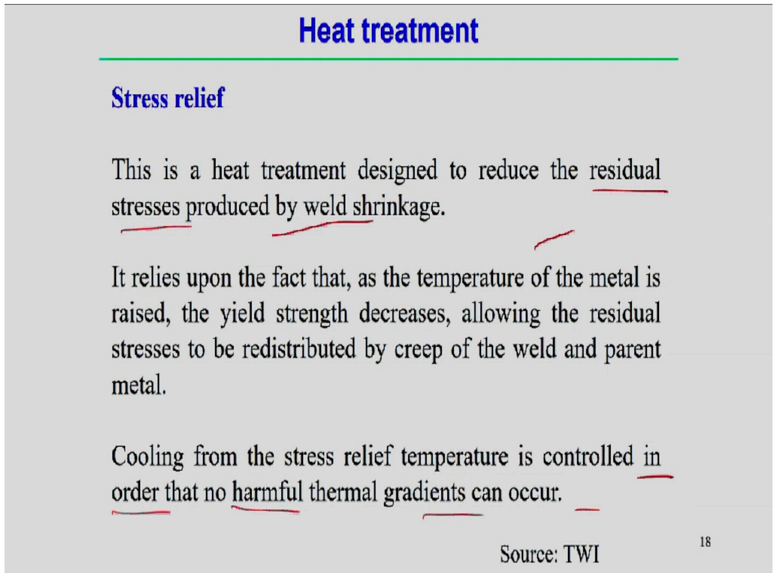

But other type of the heating process we can observe that is simple called the Stress relief process and this is normally followed in case of a late structure. This is the heat treatment designed to reduce the residual stress produced by the well weld shrinkage and in this case it depends upon the fact that temperature of the metal is raised the instant decreases that means along the residual stress to be redistribute during this process, by redistribute by the creep of the weld and parent metal.

So redistribution of the residual stress is the main fact of the stress relief and may be maximum peak values of the stress is reduced and redistributed and this is done by the forming of the creep of the oil components. So cooling from the stress relief temperature is controlled in order that no harmful thermal gradient can occur.

That means, we just try to reduce the temperature gradient in the cooling process just by the simply heat treatment the basically following the heating of the sample in case of the in a weld structure when this normally use the residual stress by the shrinkage of the component. Similarly, post heating only treatment can also be done in a welding structure also.

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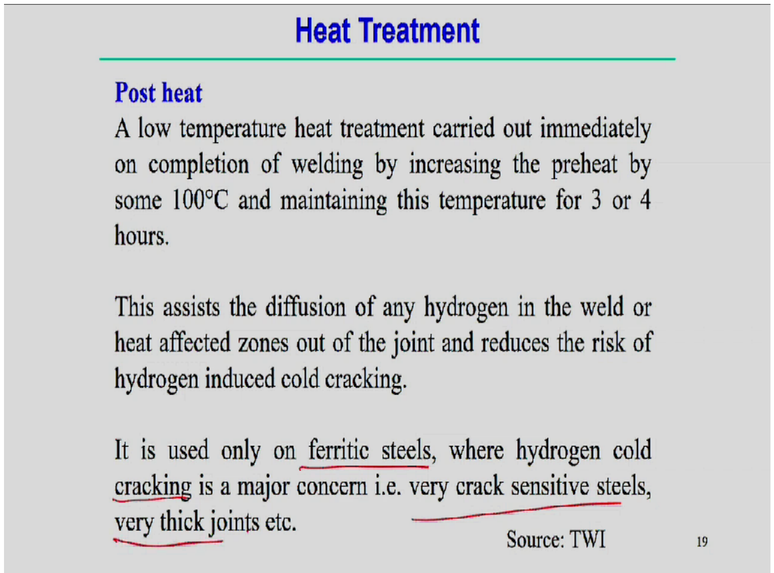

In this case, low temperature heat treatment process immediately just immediately after completion of the welding process. And by increasing the; preheat to some 100 degree centigrade. So therefore just completion of the heat treatment process we just preheat the sample and maintaining this temperature for a 3 to 4 hours for a longer time. Such that diffusion of the hydrogen in the weld or the heat affected zones is depletion out from of the joint or it is actually reduces the risk of the hydrogen cracking or hydrogen induced cold cracking process.

So that is the purpose of the simply heating the component in say controlled way controller in the sense for sufficient time and not much heating of the sample but just 100 degree centigrade. So if you follow this thing process it is possible to reduce the hydrogen cracking hydrogen induced cold cracking process in welded structure. It is normally used in case of the ferritic steels or hydrogen cold cracking is the major concern in that cases.

And of course in case of the very crack sensitive materials or if very thick section of the oil metal in that cases we normally follow the post heating of a weld component.

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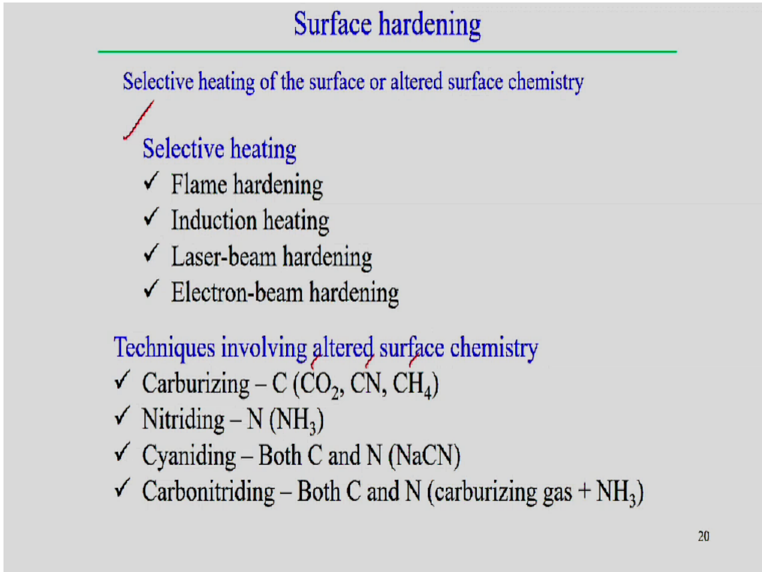

Now apart from that all these heat treatment processes we need as a throughout the structure or throughout the volume or we can say that in principle the throughout the volume of the component we follow the different heat treatment process. But of course the treatment process can also be done in the; to impart on the surface also that is called the surface hardening processes. So this surface hardening process can be in various localized way certain depth we can impart the hardness of a surface to improve the surface properties also.

By doing the selective heating of the surface or without altering the surface chemistry also in the; or it is possible to alter the surface chemistry or to impart certain mechanical properties on the surface, so that is called the surface hardening processes. So selective hardening processes we can see that there are four category of the selective hardening process more or less may be these are the Flame hardening, Induction heating, Laser-beam hardening and Electron-beam hardening.

So flame hardening means we just simply heat the surface the surface and that impart some kind of the hardening of the surface. And of course induction heating can also be done on the surface simply using the laser-beam or using the electron-beam also but of course we will not allow in this cases using the laser or electron beam to below the low temperature. So in this cases may be some phase transformation may happen of a particular temperature up to certain depth up to certain, so that it imparts it brings the hardness to a particular component.

This is a very usual and a common process and very easy to; easy process to impart the hardness of a particular surface. But if you want to change this surface chemistry and want to impart the hardness of a surface then it is possible to this techniques can also be involved for the surface hardening. One is the Carburizing. Carburizing process we just simply induce the carbon on the surface and this carbon normally forms; if it is a steel component is forms the carbide on the surface.

So what the process is like that surface is exposed to a medium for example we can use some gas medium liquid CO2 gas medium if we expose the surface and it is possible some liquid medium also and of course some gaseous mixture also we can use. So CO2 cyanide and then methane can also be used, that all brings with the impact of a air on the surface. And then with the reaction we decompose the carbon such that carbon can be absorbed on the surface and that imparts the hardness to the surface, that is the usual procedure of the; that is in general that is called the carburizing process.

Similarly, nitriding process also we can use the introduce the nitrogen to the surface and it is basically from the nitrites there and simple common example of importance is in in the available ammonia gas in that ammonia is the source of the nitrogen here. And of course you need to dig the reaction in such a way we can follow the some oxidation process also such that nitrogen can be absorbed by the surface and or we can say the from the ammonia the nitrogen is imparted to the surface to bring the surface hardness in case of the nitriding process.

Similarly, in case of cyaniding also we can impart the combining of the supply of the both carbon and nitrogen, so we can for example you can use the sodium cyanide. So then this in this if we allow the sodium cyanide then both carbon and nitrogen can be imparted on the surface and both carbide and nitrate it forms that both carbon and nitrogen distribute on the surface and it brings the change the hardness of the surface.

So, but this if we use the cyanide which may be health hazard or may not be available commonly available so the alternating is the carbonitriding. In these cases, also both carbon and nitrogen can be introduced on the surface. And here the combining of the carbonizing gas what we use the CO_2 and methane and plus ammonia.

So carbonizing is the source of carbon here and ammonia is the source of the nitrogen here, make the reaction in such a way carbon and nitrogen both can be used in this carbonitriding process. So you see the surface hardening process in the selective hardening we just use the simple the heat source to just heating on the surface and follow certain cooling rate also and then most of the cases we can follow the normal cooling rate and that imparts the hardness on the surface.

Similarly, if we want to change the surface chemistry just by introducing in the carbon and nitrogen in that cases also it is possible to change the hardness of the surface or brings as compared to the interior part of a component, so that is why surface hardening is also another important treatment process we normally follow, some time most of the cases we can finished product also it is possible to follow this surface hardening.

So in this module I have tried to express the different basic components of different heat treatment processes. And of course the heat treatment processes is normally associated with the manufacturing processes. So next module we try to look into or try to discuss that different micro structural change what type of microstructure normally we follow, if we follow the different kind of the heat treatment processes. So thank you very much for your kind attention.