Welding Metallurgy

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Lecture - 16
Introduction to Heat Treatment Processes in Welding

Welcome to the lecture on Introduction to Heat Treatment Processes in Welding. So we know that heat treatment processes are employed to optimize the properties in the materials and for that we are subjecting the material to thermal cycle. We are heating and cooling you know in different ways for different heat treatment processes to achieve the combination of properties, we want. So this is also required for the welding products also.

Like when we do the welding especially in the fusion welding processes, then in that case the material is subjected to the thermal shock, basically you have a heat affected zone and also because of the value of stresses which are developed the material may have large amount of stresses inside it, many a times because of that there is distortion or there may be even cracks and also the properties, which are lost you may have to recover those properties or you may have to change the properties.

So for that you know, so similar to the cast materials you have also the heat treatment processes required in the case of welding. So we will have the you know basic understanding about some of the heat treatment processes, which are widely used for welding parts.

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So as we know that depending upon the composition of parent material welding processes and the associated welding conditions involve various heat treatment processes to achieve desired properties in end-product. So as we know that you may have the different type of parent materials, whose compositions are different maybe ferrous or non-ferrous and then in ferrous also we know that there is large variety of ferrous-based alloys.

Similarly, there is large variety amount in non-ferrous alloys. So varying from cast iron to steel and in steel also you will have different types of steel low alloy, high alloy steels, you will have austenitic steels or you know that way. So now you need to have the understanding about the heat treatment processes and the associated you know effect of the heat treatment on the desired properties. So some of the you know heat treatment process, which are more popular and which are used you know normally for when we weld the material.

So in those cases some of these typical heat treatment processes are like annealing, normalizing, hardening, tempering you know austempering, martempering, precipitation hardening, many others are there. So we will have you know the idea about you know in a nutshell, we will have the idea about these processes. So coming to the first process suppose say the annealing.

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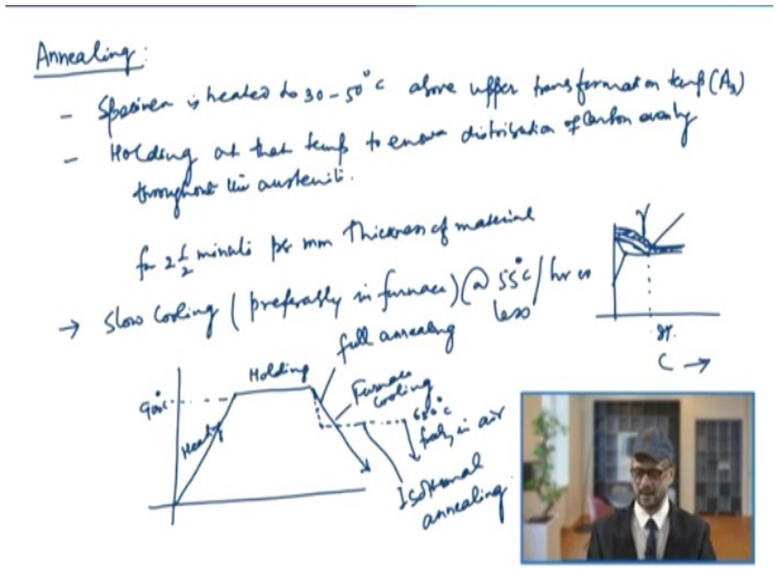

So as we know that you know annealing is the heat treatment process, which refers to the process where the cooling rate is very, very slow. So in that case its main purpose will be to get the material rid of the stresses which are developed while welding. So during any phase transformation process, especially when you have, you are giving the thermal treatment you are heating and further cooling in a fast way, at a fast rate or so.

So the temperature gradients are set up that results into the formation of stresses or so. So you need to have the material basically you know free of stresses then many a times because of the very fast cooling, you also develop very hard surfaces and many a times it becomes difficult to machine. So you need to have also the increase in the machinability. So that is one thing. Then similarly many a times if you have to increase the toughness, at the cost of hardness.

So that way also you have to basically go to a particular temperature and reduce the temperature at a very slow rate. So basically we must know that it at what temperature we should go and from there how we should cool, so that you know the benefit of annealing is achieved. So first is annealing and when we talk about annealing, then normally we refer you know this term as a full annealing. So for that what we do?

Also the heating rate or cooling rate normally, especially the cooling rate, it will also depend upon the thickness, that is some thickness of the specimen, weld specimen or cast specimen or specimen which is there. So in that case you have some guidelines like if you go for full annealing in that case the specimen is heated, so specimen heated to 30-50 °C above upper transformation temperature.

So if we are talking about steel basically and normally if you may have hypereutectoid steels right to the eutectoid point or you may have hypoeutectoid steels, which is left to the eutectoid point, that is may have carbon less than 0.8% or it will be many more than 0.8%. So for the hypoeutectoid steels normally you are heating to 30-50 °C above the upper you know transformation temperature, that is A_3.

And then you know again 30-50 or some value will be depending upon what is the you know carbon content of the steel. So accordingly you will be going and then it will be held at that temperature. So you will be holding at that temperature for some time. So basically that you ensure because you know the carbon which is there in the form of ferrite and pearlite in normal case. Now you are going into that temperature zone.

So if you talk about normal case, so this is how it goes. So this is your 0.8% and this will be over 727 or 730 °C, this line lower critical temperature and this is your upper critical temperature this line. So this line so at this zone is the gamma zone. So you have to go somewhere in this zone. So you have to go on this zone basically. So for this you know composition you have to go you know in this zone.

Now we are talking about the hypoeutectoid steels. So we are going 30-50 °C above this line and then we are holding for you know some time. So that you know carbon basically distribute itself evenly throughout the austenite. So to ensure distribution of carbon evenly throughout the austenite, so if the temperature is high in that zone and you are allowing that that temperature to hold for some time, in that case the diffusion will take place.

And then carbon as you know that it is you know carbon in the FCC iron and earlier you have the ferrite which is carbon in BCC iron. So it will come out and then it will fit into that you know FCC places. Accordingly, so for that you need to have the holding at that temperature and then so if you normally do the holding, for holding also there are certain rules and I mean some guidelines and it is hold at and at the rate of about 2 - ½ minute/mm thickness.

So depending upon the thickness of the material, you have to hold it you know roughly at the rate of 2 - ½ minute/mm thickness of the material and then you are slowly cooling. So normally the cooling is done in the furnace. So preferably in furnace you may control the furnace temperature, so you may nowadays you have the controllable furnaces and you can have this cooling rate you know defined or you can bury it inside the lime or you know you can have under the hot acids or so.

So that way also you can cool it and this slow cooling is normally at the rate of 55 °C/h or even less. So your cooling rate should be either 55 °C/h. So in a one hour, you have to have the decrease of the temperature at 55 °C. So if you say, if you cool it you can have the estimate that up to what temperature or how long you have to have the and that cooling, so that you come to the near the room temperature.

So normally this is how you know, we are doing this annealing or full annealing treatment. So as you see this will be about 20 °C and then this side it will be 30-50 °C depending upon the you know carbon content. This is your A_1 line and this is A_3 line. So if you draw the curve showing that how this you know full annealing process works, so you will have heating first you know and then ultimately you will have holding for some time.

And then you are going for the furnace cooling, so you are holding for you know so this is your holding period. This is your heating period. So heating can be even a little faster and then you are cooling very slowly. So this will be a furnace cooling. So many a times you know because the full annealing you have to hold and you have to cool in the furnace at a very, very slow rate. So many a times what we do is, to avoid that time or to reduce the time which is spent in very slow cooling, we also cool isothermally.

So that is known as isothermal annealing and in isothermal annealing what we do is, you know we heat and you know after that for cooling we are holding in a salt bath. So a salt bath is there, so this salt bath will be maintained at certain temperature and this will be going you know close to about more than 900 °C. So this will be 900 °C. Now a salt bath will be maintained at some temperature, which will be close to 650 °C.

We hold at this for sufficient number of time, sufficient amount of time. So that is basically because we are keeping at this temperature this salt bath, which is you know close to 650 °C somewhere. Now this is to ensure that there is complete transformation of austenite to pearlite, if you are holding at this temperature because this is below that critical temperature. According to the eutectoid reaction you will have austenite transform to ferrite, to pearlite.

So this is this bath is maintained at 650 °C, you are quickly dipping that in this temperature then holding for some time and then cooling fast. So cooling to the you know cooling freely in the air. So you can cool freely in air. So this cycle is, the upper cycle is for the full annealing whereas the same advantage you can have you know, I mean disadvantage is the time. So for that you can go for another type of annealing, that is known as isothermal annealing.

So this is you know the another kind of annealing process. Now there is another variety of annealing and that is known as subcritical annealing.

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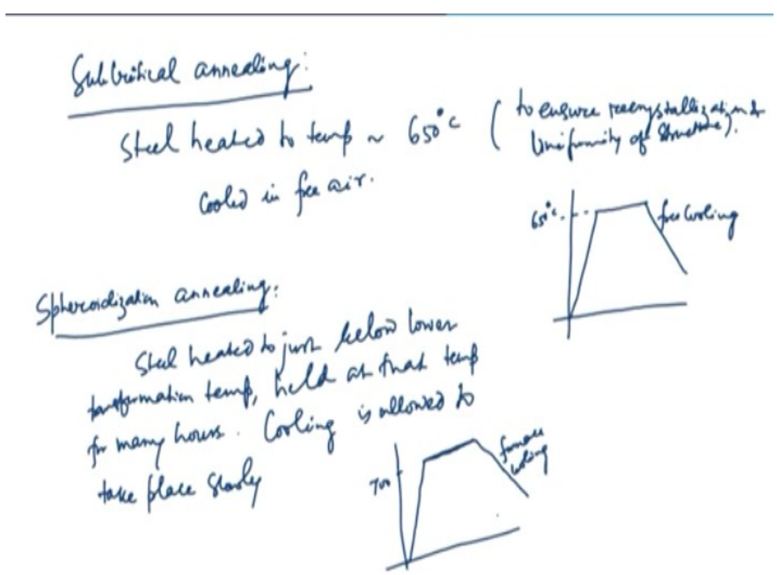

Now this subcritical annealing as the name indicates, this subcritical annealing is annealing at a temperature, which is below the critical temperature, below the lower critical temperature in fact. So in this process what happens the steel will be heated to a temperature. So in this steel will be heated into a temperature lower than the lower critical temperature. So heated to a temperature of about 650 °C.

So at this temperature if it is heated, then it will ensure you know the recrystallization and uniformity of the structure to ensure recrystallization and uniformity of structure. Typically, the uniformity of the structure and once you heat then you are cooling in free air. So you know normally what happens that this treatment, so in this you know the purpose will be to basically the cementite lamellae, which is there for you know for the hypoeutectoid steels. So they will be contracting and later on they will be rounded or for hypereutectoid steels basically there will be the cementite will be changed to the spherical you know shape.

So you know the process which is used is normally you go to heating and then further you are free cooling so close to you know 650 °C you are heating, holding and then further you are free cooling. Now what we do is similar you know to this, you will have another typical process that is you know is spheroidization annealing. So in that as the name indicates this is for you know the steel, which has more than 0.4% carbon.

In these cases, for making these cementite phases you know, they are made round or spherical and basically typically to improve its machining properties, this spheroidization annealing you know treatment is given. So steel will be heated to just below this lower critical temperature to lower transformation temperature and it will be held at that temperature for many hours. So in this process what happens that the cementite that will be changing to a spherical size.

That is why it is known as the spheroidization annealing process and so you will have the farad matrix left throughout and that improves you know the machining properties of the material and you know in this case cooling will be allowed to have slowly. So cooling is allowed to take place slowly. So you know throughout the upper part of the cooling range. So you will have the slow cooling in this case.

So normally what we do is just to understand that you have, this is your 700 °C. So just above so 730, so just above that you have this as the holding. So you are heating and then you are holding to this temperature for you know quite long time and then you are furnace cooling or you may go from here and then you can go also for the free cooling. So you may have some faster variants to it.

You can increase your temperature, come to a salt bath maintained at somewhat lower temperature, keep for some time and then you can go even for you know the fast cooling also. So to just you know reduce the time, so that way, but the thing is that when you know you are doing this process then especially for the more carbon percentage is more than 0.4% or so in that case it is used where because in otherwise the formation of the cementite will make it very hard and your machining becomes very, very you know hard.

Machining becomes very, very difficult. So in those cases, what we do is we normally adopt you know these methods and increase the machining behavior of the you know material. Now the next type of you know heat treatment process will be your you know tempering. So before that we will also discuss about the hardening and also the normalizing. So you know if you talk about the normalizing:

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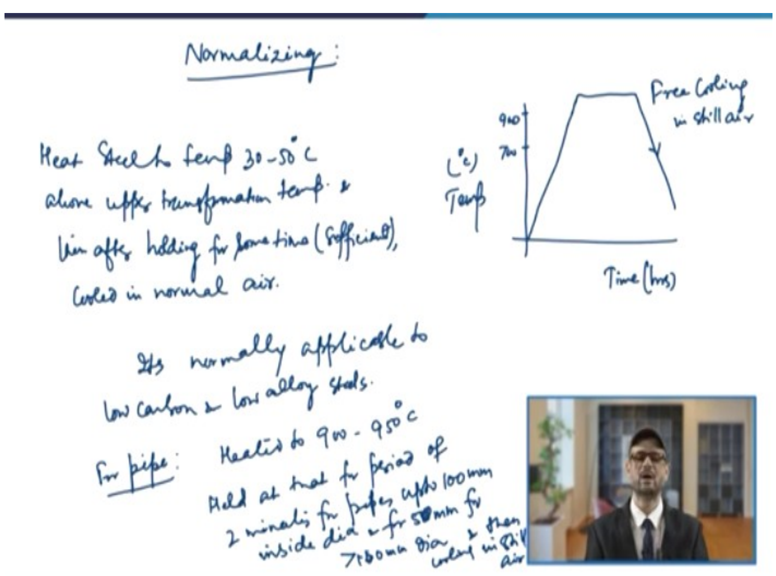

In normalizing normally as the name indicates, again we are going to the temperature above the upper critical temperature and then from there we are holding for some time and then we are cooling in freely in the air. So that is the normalizing process. So here the cooling rate will be faster than that is achieved in the case of annealing and you have a refined structure as compared to what we achieve in case of you know annealing.

So normally you have the heating rate and this is your you know temperature, which is this is 700 and this is your about 900 or so we go more than a 900 °C and then we are holding for some time and then we are going for the free cooling. So that way this is your free cooling in still air. So we are cooling to room temperature in this case. So this basically refines the grain structure.

So what we do is heat steel to temperature 30 to 50 °C above upper transformation temperature and then you know and then after holding for some time that is sufficient basically you have sufficient time cooled in normal air. So that way you know you have the fine grain structure as compared to the annealed structure in this case because the cooling rate. So here the cooling rate when we are you know cooling in the you know normal air, in that case your cooling rate is faster.

In case of furnace cooling, this line goes like this. So you will have a slow cooling whereas if the line is following this way the slope in that case this cooling rate is fast because for the same temperature drop, it takes less time. So you will have you know more you know smaller grains formed and you will have fine grained ferrite plus pearlite structure formation. So it is basically faster than full annealing and you know often it is used in the welding industry to refine the coarse grain structure.

You know it will also at the same time, it will be reducing the stresses because you are heating and then you are cooling, which is not very fast as compared to quenching, which we will discuss, but it will reduce also the stresses, it will refine the grains, which is you know if you have a coarse grain structure at certain point in the welding specimen. So it will also remove the hard zones that way. So it is normally useful.

So it is normally suitable for the low carbon and low alloy steel. So normally applicable to low carbon and low alloy steels. So you know we also do for normally when we make the welding of pipes, so you know for the mild steel pipes, we do the normalization process and normally a rough data tells that you know for pipe, when we do this normalization process then it will be heated to 900 to, so it will be heated to 900-950 °C and it will be held at that period.

So held at you know at that period you know of so at that for period of, so depending upon the you know dia, so for a period of 2 minutes for pipes up to 100 mm inside dia and you know for 5 mm, for more than 50 mm you know, 100 mm dia and then you are and then cooling in air. So that way you know what we do is you have the data normally for the different type of materials depending upon the thickness, section thickness or so.

So that process will be known as the you know normalization process. Now we will have the you know introduction about the quenching process or the you know quench hardening process. So now when we talk about quenching or hardening, in that case we are concerned with the cooling at a very fast rate. So you have to immerse the heated specimen into a liquid, which is at room temperature or even at lesser temperature.

And depending upon the liquid of different properties, how it can extract the heat from the specimen, you will have different types or different level of cooling rate achieved in the specimen and accordingly you will have the different properties being achieved. So the next you know the process is hardening.

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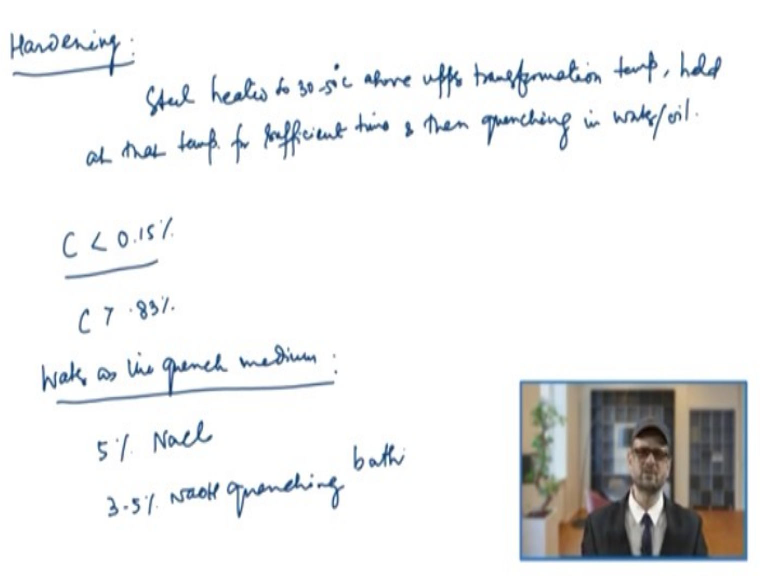

Now when we talk about hardening as we said, so again here also we are heating you know to a temperature, which is again 30-50 °C above the upper you know transformation temperature and then you will be holding at that temperature for enough time and then further we are cooling at a very fast rate. So you will have steel heated to 30-50 °C above upper transformation temperature held at that temperature for sufficient time.

So it will be you know ensuring that it is completely converted to the austenitic you know in a form and then you know you are quenching it to you know and then quenching in water or oil okay or some other cooling media. So you know it will be transforming. So at that very high temperature, the austenite is completely converted to martensite. So you will have a martensitic structure the product of these hardening processes.

So if you go for the slower cooling, then you will have the pearlitic structure and if you have the higher cooling, then you will have the martensitic structure. We have studied the TTT diagrams which shows that how if you go for the slower cooling, then you are in the pearlitic zone and if you are increasing the you know cooling rate, so if you are your cooling rate is higher, if it will pass the nose of the C curve towards the left of the C curve nose and if you are going at a fast rate, in that case you are likely to have this you know formation of martensite.

So in that case, so the quenching basically or the hardening process means that you will have the heating to the temperature above the transfer for upper transformation temperature, helding at that temperature and then you know cooling at a very fast rate. Now the thing is that you know the properties, which will be achieved it will be depending upon the percentage of carbon of the steel and you know the temperature to which you have heated.

And you have hold you know holding is done for how much time and what will be the cooling rate under which the material is subjected to. So on all these parameters the property of the material will be depending upon. So if you know now the thing is that it also defines the hardenability of the material as you know that when we talk about hardening, so similar so that will be also defining the term hardenability.

And hardenability we will be talking about the condition which tells that how easily you can confirm you know we can transform the austenite to martensite. So if by cooling, you get to martensite easily, it is easily hardenable or vice versa. So and carbon is a very important element for that, because you need some whatever you know amount of, appreciable amount of you know or significant amount of carbon, because that will only be responsible for making the martensitic phase.

If the carbon is less than certain value, then the chances of having martensite will be less. So you know it is normally if you have the carbon and if the carbon is less than 0.15%, in that case you know, you will have no effect of quenching. So quenching you cannot have much effect, but you know also if the carbon content is you know more than 0.83% percent. So in that case you know you are not trying also you know you to convert you know the free cementite to austenite.

You know because you know, this will be already quite hard and it will be producing a coarse structure. So the hardening capacity of the steel will increase with the you know carbon content increasing and it will be increasing up to you know 0.6%. So you will have also you know there are data which tells that up to 0.6% you know the hardening capacity of the steel will increase with the carbon content.

Now when you may have the use of different types of the coolant medium, you can have water, you can have brine solution as the quench medium. So when we use the water as the quenching medium, so now you can have the use of water as the quench medium and in the case of water we normally what we do is, we try to keep that medium agitated. So that there is enough you know heat transfer taking place and otherwise we can also use the 5% sodium chloride that is brine solution.

So you know that also gives quite a good satisfactory result. We can also have the 3-5% any wet solution quenching bath. So that is also another quench medium which is used. You know oil quenching is also a very good practice and it is normally for the thinner you know sections of carbon steel and high carbon steel high alloy steels, because that avoids the danger of cracking.

So this way depending upon the you know different you know properties to be achieved you can have the different quench medium for the application. So we will talk about other you know heat treatment processes in our coming lectures. Thank you very much.