Theory of Production Processes
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Lecture - 45
Heat Treatment Processes in Welding

Welcome to the lecture on heat treatment processes in welding so, we discussed about the heat affected zones in welding and as it was clear that because of the thermal cycling there is micro structural change in the weld specimen there are zones which are basically affected because of this thermal cycling and so, many a times we need to do certain treatment to the welded specimen. So, that the properties are restored or the undesirable property which we get because of the heat treatment cycle I mean because of the thermal treatment cycle due to the welding or the you know temperature effects in welding, now that is basically that should not be in such a way that it affects the mechanical properties.

So, for that the heat treatment processes are implied in the weld bent so, that you get the desired structure desired mechanical properties, especially what we see is that because of the you know uneven heating and cooling cycle you try to see normally that there are residual stresses developed many a times. The brittleness is increasing, large amount of stresses are developed inside then there may be chances of the formation of some phases which are very extremely brittle.

So, many a times you will have to see that you have to see that the phases which are very brittle you know that brittleness should be removed little bit so, you go for some treatment for that. Then we will also try to see that what are the other heat treatment processes in other materials or basically we are going to also discuss about the heat treatment processes and alight processes in certain materials like if we talk about certain materials like aluminium copper alloys or so, which are very much used for engineering applications.

So, in those cases the strengthening is because of the aging treatment or precipitation hardening treatment so, we will discuss a little bit about those processes in this lecture. Now, coming to the heat treatment processes in welding when we talk about the heat treatment process, then normally we know we have discussed in the last class that there is basic difference between the heat treatment process and the welding process. So, in

welding also you have the heating and then for the cooling so, in heat treatment also what we do is we heat and then we cool. The only thing is that how we heat, how we cool and then how long we are basically retaining it so, there are three things in heat treatment one is heating, one is retaining another is cooling.

Now, heating is up to what temperature and at what rate so, that is also important for that we do not go much into detail because heating does not if we have certain heating rate then after maybe if it is too rapid maybe it may have somehow many undesirable effect, but otherwise we heat you know to certain temperature and then holding at them that temperature is important how much to hold. Now, holding basically depends upon the section thickness of the material, now holding is important because there are that temperature we feel that everything should be dissolved.

So, that you have homogeneous you know a phase mixture which is obtained at that particular temperature and then we are basically cooling it. Now, cooling medium may be different, we may cool in air once we cool in air then we call it as normalizing and if we cool in the furnace itself at a very slow rate then we call it as annealing.

Now, in the case of annealing also you have different type of you know classification for annealing based on what way we cool, how much we hold. So, that we will see that what are the different processes of annealing and then you have other processes as we discussed that you have the process of stress reliving, where the purpose will be to relieve the weld bent of these stresses. So, that is known as stress relieving I mean processes then you have other related you know operations that we will discuss. Now coming to the different heat treatment process which is employed in welding process.

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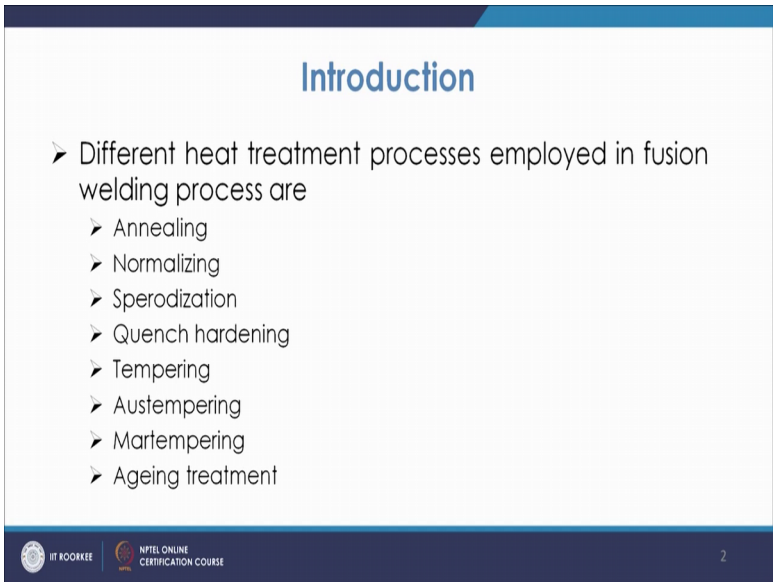

So, the first is the annealing process so, as the name annealing comes up, annealing means very slow cooling. So, we are heating to a temperature and normally that temperature which is you know maintained is basically above the upper critical temperature.

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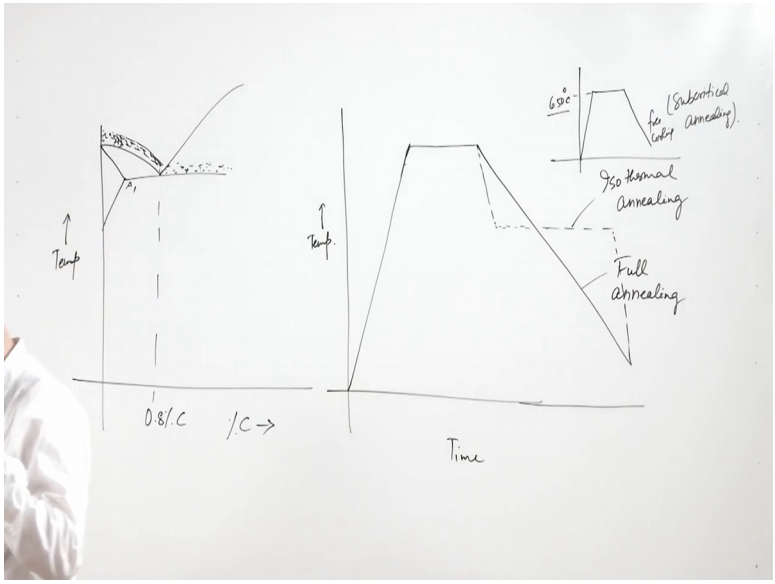

So, what we have this is are the iron carbon diagram so, here this is the you know, this is the lower critical temperature of 723 degree centigrade and this is your upper critical temperature that is a three line. So, this is your A 1 line and this is your A 3 line now

whenever we have to heat treat, we go a little bit above the upper critical temperature. So, normally what we do is this annealing is normally done in this temperature range so, we go to this temperature range.

So, this is the zone where we go for the annealing purpose and once we so, this is your 0.8 percent of carbon and then we take only up to so, once we have to do the annealing of these hyper eutectoid steels we go in this zone. So, this is your 0.8 percent carbon and this is your temperature so, what we do is we are going to this temperature we are heating to this temperature and then after that we are holding there. Now, holding time will be normally depending upon the section thickness of the material and then after holding we are cooling slowly in the furnace.

So, depending upon that you will have the different type of annealing purpose now the holding time is 2 and half minute, you know per mm thickness of the you know plate so, once you have a plate which you are welding then depending upon the thickness of the plate you will have about 2 and half mm, 2 and a half minute per mm section thickness you are holding. So, what you do is you first go and heat up to a temperature of more than about 900 degree centigrade and then you are holding there and then you, if you are cooling slowly in the furnace itself to the room temperature then it is known as full annealing.

So, if you are suppose heating to this temperature and then this is 900 degree centigrade about and then further you are holding it so, this holding time is about 2 and half minute per mm of section thickness and then further if you are cooling in the furnace slowly so, this is your temperature and this is time.

So, this is the holding time and this holding time in normally from 1 hour to 2 hours depending upon the section thickness and normally have on average we call it as about 2 and a half mm per section thickness. So, you know depending upon the suppose you have some centimetre thickness so, you have to convert it to meters and multiply it with 2 and half so, that much that many minutes will be your holding time Now, if you are you know cooling it in the furnace up to the room temperature then it is a case of full annealing. So, in this case the basically this is the process which is known as full annealing and you know this way you have the grains of pearlite and ferrite is formed and you will have because normally annealing is done to relieve the material of stresses,

to impart more ductility to the specimen certainly at the expense of its strength and hardness.

Now, that is another annealing treatment another way we give the annealing that is you know isothermal annealing so, isothermal annealing what we do is after we are doing the heating and holding then you have a bath maintained at certain temperature, you have salt bath which is maintained at that temperature and then you are just dipping this into a bath which is maintained at certain temperature here and then you are holding this for a large time.

So, that is basically this transformation will take place at a constant temperature and then once you go here from then after that you are cooling it fast to the room temperature. So, basically the transformation which will be taking place is at this constant temperature so, this is known as isothermal annealing. Now, as you know that you have in this case a salt bath is maintained at that temperature and you have the further because here you are allowing it to cool freely in the air.

So, that is from there you have so, there is a fast cooling from that side, you have slow cooling in the case of full annealing and here you will have the fast cooling that leads to finer type of structure. So, in that case you will have since you are cooling at a very slow rate you will have coarse type of pearlite where as in this case you will have the fine pearlite structure which is obtained.

Now, there is another variety of annealing and that is known as subcritical annealing so, the subcritical annealing in that basically you are heating to a temperature which is below the lower critical temperature so, you are heating to about 650 degree centigrade and then further you are holding it for some time and then you are free cooling it to room temperature and that is known as you know subcritical annealing and that is also formally we it was known to be as the process annealing.

So, that is subcritical annealing in the case of subcritical annealing if you look at you are heating to something like say 650 degree centigrade and then you are going for free cooling so, this is about 650 degree centigrade and that gives you the process of subcritical annealing and you have many a times you have the carbides, I mean dispersion will be fine in that case of subcritical annealing so, there will be free cooling this is subcritical annealing. Now, after annealing you have other you know processes of

heat treatment which is normally important in the case of welded specimen and one of the important is you know spheroidization. So, we have already discussed about the spheroidization treatment now in the case of spheroidization as we discussed that in this case the cementite particles they are transforming to a spherical type of structure. So, the treatment which we give in this case is that we are heating to just above the near this lower critical temperature.

So, we heat to about 700 or 720 degree centigrade then we are holding for some time and further we are coming down and then we are holding it at a lower temperature for again sometime and then we are going for different type of cooling mechanism. So, this way the spheroidization treatment is employed and in that basically the cementite which is in the lamellar structure that basically so, once you have you know good amount of time available you are holding it for some time. In that time basically you are getting the spherical type of cementite particles so, that we have already discussed while discussing the heat affected zone in the earlier lectures. Now, coming to normalizing now in the case of normalizing what we do is we are heating to the again the temperature which is above the upper critical temperature and then after that we are cooling in the air.

So, in that case you have fine structure obtained in the case of normalizing so, in the case of normalizing as we discuss that you will have will be going in this range and then further you are going and then you are going for cooling in the air. So, that gives you the you know fine structure of fine grain structure is obtained in the case of normalizing. After normalizing you have another is quench hardening now in the case of quench hardening once you go to this temperature then what you do is you are basically dipping that specimen into a oil bath or the water bath which is maintained at room temperature.

So, that is known as quenching so, this quenching basically provides a large value of hardness and strength and certainly at the expense of its ductility. So, in this case normally depending upon the cooling rate you will have the presence of different structures and martensitic structures are quite common when we go for the quench hardening of the material. So, this way you do the quenching.

Now, in this case the strength is also increased what ductility since it is decreased so, many times the since we get the martensitic structure which is quite hard extremely brittle. So, we need to go for the tempering treatment so, the tempering treatment

basically in induce certain softness and it decreases that brittleness which we achieve in the case of quench hardening.

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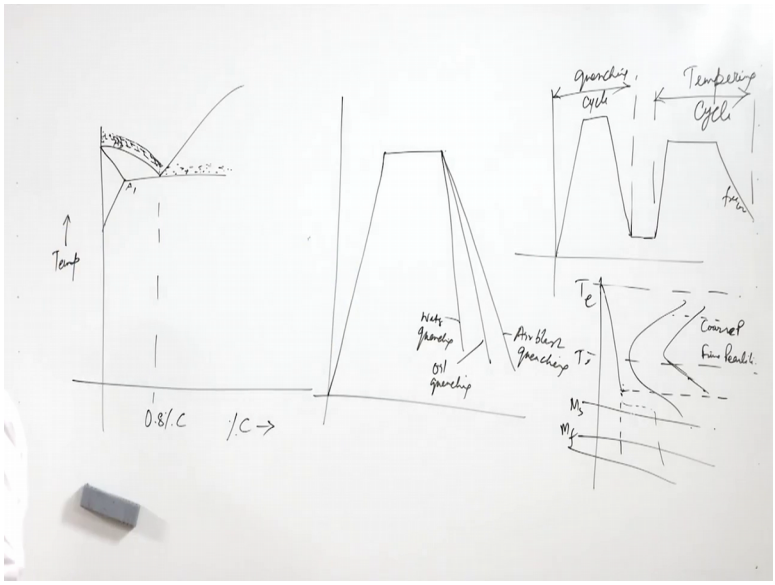

Now, as we discussed so, in the case of quench hardening you again go to this temperature and then further you are holding for some time, you may cool in different medium, you may quench it in different medium and this medium may be either water or brine solution or it may be you know air cooled at very high speed. So, this way you may have the different medium air blast cooling or so, maybe you know adopted. So, you may have water quenching or oil quenching so, the this will be very fast so, you will have water quenching then you have this as oil quenching and this may be by the air blast.

So, that when we talk about normalizing then basically it is done in the free air, we do not have the force application of air, but once we have the force application of air then it is known as quenching again. So, here because the heat extraction rate will be quite high so, that is normally done in the case of quenching. Now, in the case of quenching one thing is to be understood is that what happens that when the carbon percentage is less than certain value like 0.5-15 percent or so, there is no much effect of quench hardening. Well, also it is not advisable when the carbon percentage goes above 0.8 percent so, up to you know its effect is seen from this range to this range.

So, that way this quench hardening is seen to be more effective and up to about 60 percent of, I mean 0.6 percent of carbon it is seen that it will be increasing and the

hardness of the steel. Now, again the water which is used as the quenching medium normally the water will be maintained at about 25 degree c and also it is agitated. So, that the you know it is not stagnant because there may be a formation of blanket around the specimen and that may reduce the heat transfer process.

So, that is why this is agitated so, that the water fresh water is in contact with the specimen and proper cooling takes place and proper hardness is also obtained. You may also use the 5 percent sodium chloride brine solution for very satisfactory results so, it has been seen that if you use that 5 percent NaCl solution then it is quite effective. Now, coming to the next process that is tempering now what we see that when we do the quenching.

Now, in the case of quenching you have the formation of martensitic phases which is really very brittle so, the formation of marten site and that leads to very high value of strength and so, high that its becomes brittle. So, sometimes it is not usable for services or for applications so, to reduce this hardness now tempering treatment is required to be given. So, that the brittle meant to the phase which is there which is achieved because of the quench hardening because many a times when we do the welding we put it in the water quickly so, that leads to that type of phase.

Now, if we get the marten site then marten site which obtained in this case situation that is extremely brittle. So, that needs to be softened and for that we do the tempering treatment and the tempering treatment is done by heating that into a lower temperature own zone so, that temperature zone may be from 200 to about 650 degree centigrade.

So, you are heating that in that temperature zone either towards the higher side or towards the lower side and then you are holding it for quite a large time and then you know depending upon the properties required you have to hold it and then further you are allowing it to cool in the air. So, that is the normal tempering treatment which we do to improve so, by tempering the ductility and the toughness property is improved so, and the extremely high brittleness is basically undergone.

Now, many a times we also do the tempering in the temperature range of about 260 to 310 degree centigrade and that basically shows a loss of toughness. So, if you do that in that lower temperature zone then many a times we get to see that the toughness is

decreased so, that is known as brittle tempering range that temperature zone is known as the brittle tempering range.

Now, in so, what we do is normally in the industries once you go for the quenching so, in the quenching you go heat and then hold for some time and quickly quench it to a quenching medium then further it is followed by the tempering treatment. So, again you are heating to lower temperature and then further heating holding for some time and then further you are free cooling in the air to give you the tempering stages and that is known as quench temper cycle. So, quenching and tempering cycle if you look at so, you will have this as the quenching and then further you are further heating and then slowly cooling free cooling. So, this will be your quenching cycle and further this will be your tempering cycle.

So, this is the practice in the case of industries where we depending upon the kind of properties you require you go for tempering treatment, you adjust the temperature at which the tempering is to be carried out. Now, there are other tempering treatments like you know not that in treatment that is a heat treatment process, one of that process which is very important is the Austempering treatment. Now, what happens that you know when the in this case as we discuss about the heat treatment process in that case if we talk about the transformation product which is obtained.

So, what we see is that you have a type of this curve and you have this m s and m f temperature so, you will have this as the equilibrium temperature. Now, in that case as we know that this is this is nose of the c curve and as we know that this is the zone of so, you will have this kind of c curve. Now, in this case what we see is that in this zone you get coarse pearlite and this is a fine pearlite similarly, you have in this size use case you have. So, as you cross this line you are bound to get the pearlitic structure, many a times what we do is you are initially cooling to a very fast to a solution which is maintained at this temperature, you do not go to the past of this c curve and then you are holding it for some time.

So, in that case you are getting a different morphology of pearlite and that is a type of structure that is known as so, here the cementite which is embedded into that ferrite matrix that has different morphology. So, it is a in a very needle type of structure so, you have coarse structure this side and fine structure towards the lower side and that structure

is known as benaite so, it is having a very good toughness property. So, that treatment where you are basically tempering you are basically coming to this temperature and then you are holding it to a temperature due to the temperature and you are getting the benaitic type of structure this treatment is known as the austempering treatment. So, in the case of austempering treatment you get a magnetic structure in that case and quite a good hardness and toughness is obtained in the case of this austempering treatment.

So, that is what it is and that is how this one is one of the very important heat treatment process which is used for whenever we need to have the magnetic type of structure then you go for this treatment of treatment where we you have the austenitic structure which is tempered. So, austenite it is tempered so, that is why it is known as austempering and that is how you get the magnetic type of structure then you also get another type of treatment that is known as martempering. Now, martempering is again here is you what you do is in this case you go to a temperature where basically it is the tempering of the marten site.

So, what you do is before that once see once you pass this if you go to had you gone like this you could have got the marten site which is extremely hard in that sense. Now, what you do in the case of martempering that once you pass that zone then once you come to this lower side you go little bit and then you pass this zone.

So, basically what happens you get tempered marten site the marten site which you could have got in earlier case could have high brittleness, but in this case you get not that much of high brittleness and this term treatment is known as the martempering treatment. So, this is also one of the special heat treatment process which is given to have a good mechanic combination of mechanical properties for the welded specimen. Apart from that you have the main purpose which is used main heat treatment which is used for the welded specimen is the stress relieving. Now, stress relieving is normally done at the temperature which is normally below the lower critical temperature.

So, you go to a temperature close to about 600 degree centigrade and then hold it for some time and then further you are cooling in the furnace or you are free cooling in that case the stresses are relieved that is known as a stress relieving treatment, next nextly we will discuss something about the aging treatment. So, again it is a type of treatment which is required for certain materials were you have the super rich solution of our super

rich solutes are some phases are there which are super rich at the room temperature. So, what happens that especially in the case of such materials what we do is we do the solution treatment. So, we are going into the zone where it is its solubility is more and then from that zone we are quenching fast so, that the solute is super rich.

So, basically the zone which you get you have the solubility now it is less so, what it does is that once we further heat it to some temperature the precipitates which are coming the phase which were which solubility is less they try to come they try to come as precipitate and then that basically improves the strength and that is known as the precipitation hardening mechanism.

So, that is this process of increasing the temperature and returning for some time and then further cooling that is known as aging treatment and aging treatment is of different type. Normally, you have natural aging when we do the cooling in the when we allow it to the transformation to take place in the normal temperature that is aging treatment natural aging. Otherwise if we increase the temperature and in improve the precipitation process that is known as artificial aging or so.

So, this way also we try to in those materials especially in the case of non material non ferrous materials you have this aging treatment which is given to improve the mechanical properties. So, these are the different type of heat treatments you can refer the standard books to study the different types of heat treatments so, that we can further correlate it whenever we discuss about the properties of the welded specimen in future.

Thank you very much.