Welding Metallurgy
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Lecture – 20
Heat Treatment of Non-Ferrous Metals and Alloys

Welcome to the lecture on heat treatment of non-ferrous metals and alloys, so whatever heat treatment processes we discussed so far, they were normally suitable with respect to steel and in most of the cases, we have taken these eutectoid transformation into picture, we were going to the austenitizing temperature, then from there we were quenching you know using different mode maybe by air quenching or oil quenching or maybe you know annealing or so.

Now, you have you know the presence of non-ferrous metals and alloys also which are very much a part of you know essential part of the materials used for engineering purposes and there also you have the heat treatment processes to be employed, so that you can attain the desired properties in those materials. So, when we talk about the principles of the heat treatment in those materials again, we are going to have you know certain discussions on how the you know the how that strengthening is achieved, that we already we have studied a little bit.

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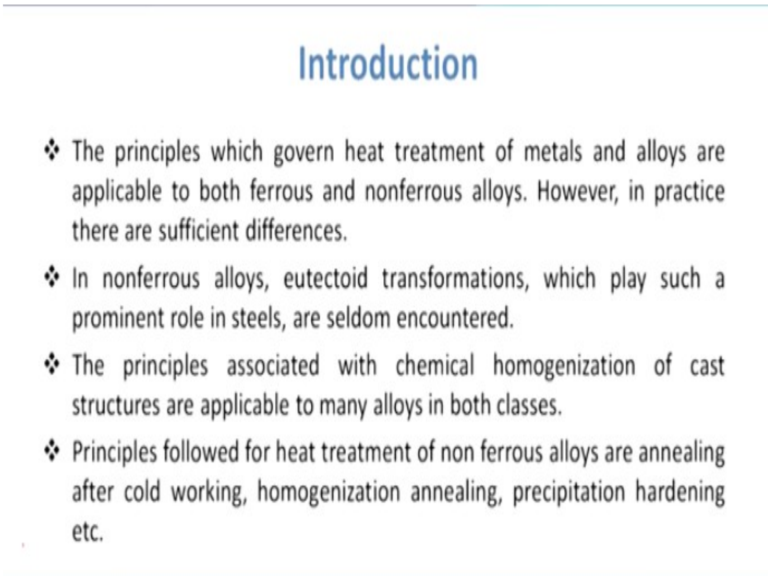

But what are those different methods by which you can think of increasing the; you know strength of the material by adopting the suitable heat treatment method, so the principle which governed the heat treatment of metals and alloys, they are applicable to both ferrous and non-ferrous alloys. So, in fact the principle will be same you; there also you would like to have the you know heat treatment in such a manner that there will be you know diffusion of atom taking place or you know there may be strengthening.

Because of other strengthening mechanisms like there may be cold working you know, so that followed by annealing and all that, so that is; certainly, there are certain changes, so in practice there will be some sufficient differences when we talk about the you know non-ferrous materials because when we talk about the ferrous materials, so we are mostly concerned with the ductile transformation or we are concerned with the martensitic transformation which gives the hard phase, which increases the properties of the material.

However, that will you know not very frequently been countered when we talk about the heat treatment of non-ferrous materials and alloys, so in this however you know chemical homogenization is the one of cost structure which is there for most of the materials whether it is you know the ferrous or non-ferrous. The chemical homogeneity of the caste structure is always important and that we try to achieve by using the suitable you know heat treatment method.

So, the principles followed for the heat treatment of non-ferrous alloys, they are normally you know either one is by diffusion, so how there will be diffusion you know mostly because of the solute diffusion and they will go into the different places and strengthening the matrix and so and that also because that will be varying with temperatures, so certainly that is one of the process.

Apart from that we have annealing after cold working that we will discuss because many a times when we do the cold working, so we need to have the annealing process in place, so that is the one, then you have homogenisation annealing, then precipitation hardening all these you know practices are adopted and they are mostly used you know heat treatment processes for non-ferrous materials.

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- In shaping of metals and alloys by cold working, there is a limit to the amount of plastic deformation attainable without fracture.
- Proper heat treatment (annealing) prior to reaching this limit restores the metal or alloy to a structural condition similar to that prior to deformation, and then additional cold working can be conducted.
- Homogenization treatment is used prior to mechanical processing of the cast ingot. The temperatures and times used depend on the diffusion rate and the starting structure

So, if you talk about the annealing you know so, if you see that if you go for you know the annealing of cold work structure, so in that case what we see is that when we go for cold working, so many a times because when we have to have the; you know geometry or the final shape which is the you know cold work product, so in that case you want that you know in one go you should be able to you know get that shape.

But that becomes you know very difficult and for that what happened there is the limitation is the hardness which is increasing, as you increase the degree of cold work, so what happens that in that case you know you have to have the proper heat treatment, so that because once you go for cold working you are basically reducing the size you know in one dimension and certainly there will be a change of dimension in other directions.

So basically, you are introducing the thickness and accordingly since there is plastic deformation, so you will have you know the strain hardening taking place and because of that the further you know up to certain extent, you can go for the reduction in the dimension or all the thickness but after that the material may you know may crack, it may be unsuitable for the use.

So, you know in those cases what we do is; we you know we give certain heat treatment process that is annealing prior to reaching this limit you know that so that basically will be restoring the metal or alloy to a structural condition which will be similar to that prior to deformation, so and then additional cold working can be further conducted. So, what happens is that when we go for such heat treatment processes, then certainly we come across the different you know stages in which; through which the material undergoes.

And these stages are basically depending upon the temperature so initially, you have the recovery zone, then you have the recrystallization zone and then you have grain growth zone, so all these zones are encountered in such cases.

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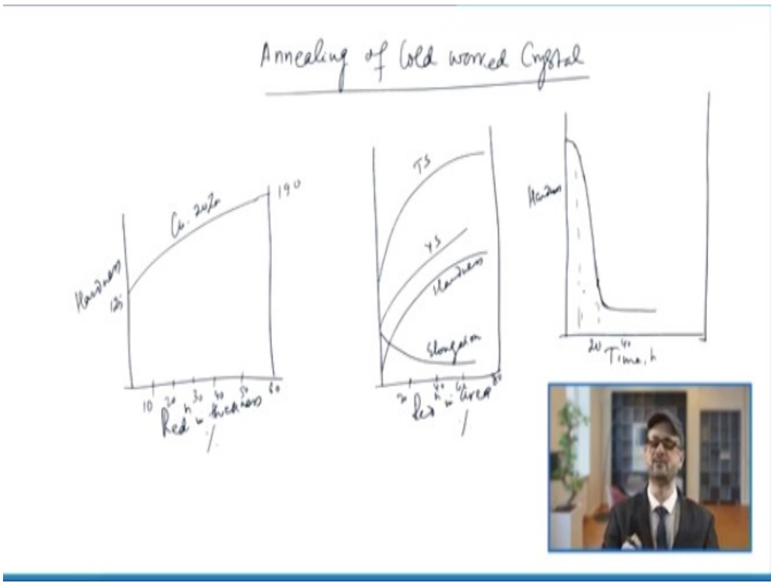

So, when you; you know if you talk about the you know annealing of the cold worked crystal, so normally you know so, in the case of non-ferrous metals and alloys you have these small components you know which are made or you have; because they have; they are used as the finished products, so you have smaller dimensions of products and then so what you do is; you do the cold working.

And as we know that when we go on you know cold working the material so the you know you know dislocation density will increase, we all know that how you know these because you know because of the dislocation you need the smaller you know, stress level to plastically deform, so that is what you know so, they are basically dislocations are playing a very important role in fact you know in plastic deformation.

Because they will be reducing that energy which is required you know for the you know deformation by slip, so we know that this deformation is either by slip or by twin, so you know, so that way your deformation you know starts, so because of these presence of these dislocations. Now, what happens that so up after certain you know limit, then when the distribution density has become quite high?

In that case, what we do is; we try to further anneal the material, by doing this annealing process the material becomes soft and then further you can do the plastic deformation of the material because at one point of time, it becomes difficult so, you can further go for the plastic deformation. So, accordingly this process of that treatment which is given, so that the metal can further be subjected to the plastic deformation that process is you know the annealing process.

So, if we recall that how this cold working affects the mechanical properties we have already seen that if you go for the reduction in thickness, then if the reduction in thickness is there you know if it is percentage, so suppose 10, 20, 30, 40, 50 and 60, so in that case if you take you know for the copper zinc solid solution, so for that your you know depending upon the zinc percentage, so what we see that there will be change in the you know hardness.

If the hardness is there so, if you increase the reduction percentage in thickness, so your hardness will increase, so that will be you know for the copper and a 20 zinc percentage, so it starts from 125 you know hardness and HRB and then it goes towards this range may be close to 190 or so. So similarly, for different so what happens that in the case of annealing, your strength is increasing.

So, if you take in general the variation of the properties; so, if you take the reduction in area percentage and if it is say 20, 40, 60 and 80, so if you look at the variation of the properties, what you see is your tensile strength will vary like this, similarly your yield strength will also have some variation, then hardness more typically varies like this but the elongation will normally be varying, going on decreasing.

So, your tensile strength and yield strength and hardness and this is your elongation, so elongation is decreasing. So, what you do is; normally, you go for the annealing and in annealing, you are taking a temperature, so suppose for the Cu_5Zn you know alloy, if you go do the annealing so, annealing will be done and if you so in annealing, normally you have the time; time is very important for how much time you are doing the annealing and also the temperature.

So, if you keep the temperature to maybe 400 ^{0}C in that case, what we seen is that the hardness has variation and hardness will be you know decreasing and ultimately, it will follow like this and then ultimately you will have somewhat constant after some time. So, if that time is taken in terms of hour, so what was seen is that this is time of 20 hours and then you have this has 40 hours, this is; so this way it moves.

And in this case normally, you have what you see is in this zone you have so, up to this you know this stays in this zone, so this zone will be for the you know for recovery and then this particular zone you know, this zone will be closed for these recrystallization and further you know the; in the third stage, you have the grain growth which starts appearing in this zone.

So, you will have zones identified you will have recovery here, then you have this is the recrystallization and then further you have the grain growth and once there is grain growth taking place in that case, you will have you know the property as you see the hardness becomes quite less, so that way with the process of recovery; recovery means basically what you do in this case is that your you know strained crystals are converted to strain free crystals.

So, you know initially you this that recovery process takes place, then you have the recrystallization, the birth of new crystals you know in those zones, where you know so and then further after if you prolong it, so there is a chance of having grain growth, so that also depends upon the temperature, if your temperature is you know higher then and you are holding for larger time.

In that case there is certainly, some chance for the grain growth to take place, so you will be taking suitably the temperature and then you are keeping for some time, so that the you know material you know, induces these hardness is decreased and in this stage you have the formation of new grains, so you will have; there will be the fineness you know and if you stop towards this side.

So, depending upon the temperature basically these you know, these stages are observed in the case of you know the annealing treatment.

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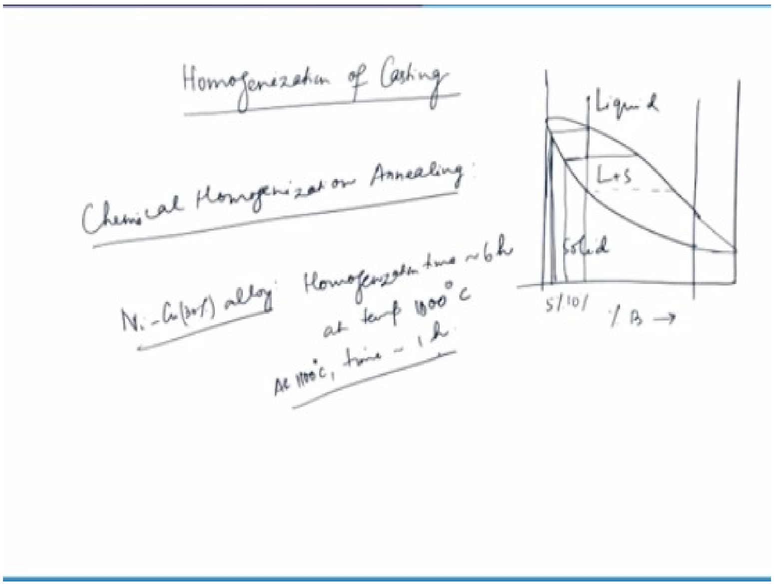

Next thing which is important in the case of these non-ferrous materials is the homogenisation you know of casting. Now, if you talk about the need for the homogenisation of the cast structure so typically, you know for the alloys, when we go for the solidification of alloys in that case, we do not have the homogenisation structure, we do not have the; you know chemical composition uniform you know, in the crystal.

When you are casting when you have; if you talk about the as cast structure, then the structure is not completely homogeneous chemically, now the for the because of that you know the one of the phenomena that is coring that is experienced and that can be understood you know by looking at the phase diagrams, if you look at the simple you know binary phase diagram for an alloy.

So, if you look at you know this kind of you know so, this is going here and then this is your; now what happens that if you look at the freezing mechanism for you know such alloys, if your percentage of B is going like this you have A 100% here and B 100% here, so what happens that when you try to you know so, this is your liquid and this is liquid + solid and this is your solid.

Now what happens that when the temperature is here, you are in liquid state, when the temperature comes down, you are coming here and at this point there is you know; so now once the temperature goes you know behind this, below this temperature then there will be solidification starts, at this point the solid which will be crystallizing out so, it will have this percentage, this composition actually, this was; this will be the composition of this solid which will be crystallizing out.

So initially, in the core of the crystal, the solidified part which is getting solidified, it has some you know composition may be like 5% of B is there now, you know as you go you know as that temperature is decreasing, so if you look at you know if; so if the temperature is decreased, so at this point suppose you know when if you see the solid which is formed that will have the you know composition you know that will be by this.

So, it will come to suppose say 10%, so like that as the temperature comes down, then in that case you know the concentration of the solute in the solidified crystal that portion or that amount of time will be changing, so this leads to; so if you look at the you know concentration you know of the solute or percentage of B in that crystal so initially, you will have very small amount of B and then that goes on increasing.

So what you see is that can be seen when you edge, then you can that can be that is visible and this is basically the chemical in homogeneity which is you know present and which is very much you know because very much a trait of such alloys when you are cooling fast because if the cooling is slow in that case, there will be sufficient time for the diffusion to redistribute the movement of you know atoms.

So that you know as you go towards the end so, if you suppose we are coming towards the end at that point of time, this will be you know at this point, this will be the concentration of solute, this is basically be the concentration of B you know, the solid crystal which has come out and you know the liquid has this concentration, so the thing is that when you go for the cooling that too in a fast manner which is normally normal case, the cooling is not the equilibrium type of cooling which is normally extremely slow.

But when you go for fast cooling, so you are not giving enough time for the atoms to distribute or diffuse, so that you have a proper chemical homogenization, so your you know; you have chemical in homogeneity which is present and this difference you know concentration difference which is caused that is that leads to the form you know process known as coring.

So basically, we also know that normally when you; you know go for solidification for such alloys in these cases you have the constitutional super cooling also occurs and because of that you will have the dendritic you know structures formed and then that in that also you will have the coring developed, so basically that is not you know a very much desirable structure.

So, you go for the annealing of you know the cast structure, so that you know this chemical in homogeneity which is there that should be removed and for that we do the chemical homogenization annealing. So, the purpose is you know through basically reduce these dendritic and cold structure to minimum, so that you know, so when you do the annealing so, you are going to a temperature range where again at that temperature range, there will be redistribution of atoms, the diffusion will be taking place.

And basically that chemical inhomogeneity which is there you know throughout, so that will be minimized, so that you have the acceptable level of this you know coring which is acceptable for the application that is observed. So, what is do; we do is again here also you have to select one temperature and a time up to which there will be you know that will be kept under the slow cooling you know.

And it will be kept at that temperature and then cooled, so that the proper diffusion takes place and the distribution of atom takes place and the chemical you know in homogeneity which is there, so that will be reduced, so for you know; if you look at the normal homogeneous in time, so for you know for typical nickel, you know copper alloys, so nickel copper 30% alloy it has been suggested that homogeneous and time; homogenisation time is at about 6 hours at a temperature of say 1100 ^{0}C.

And you know so, now this is at 1000 ^{0}C and if you do it for 1100 ^{0}C, so it will be at 1100 ^{0}C, this time becomes only 1 hour, so that such way if you increase the time because the you know diffusion of atoms or diffusion rate is basically increased, when you increase the temperature, so that way you know your this chemical homogenization takes place.

And the dendritic code structures basically the extent of these you know coring that reduces through our the matrix, so that is one of the principle heat treatment method in the case of non-ferrous metals and alloys.

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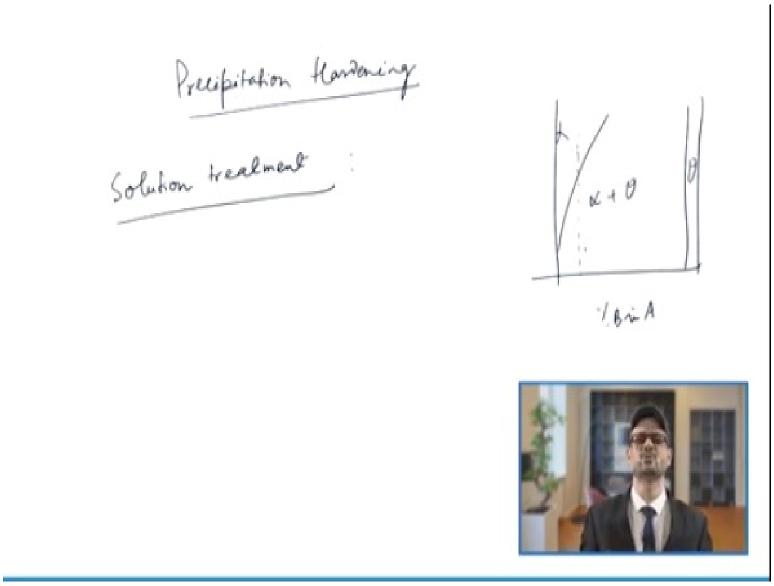

Another important you know process of heat treatment for the non-ferrous metals and alloys is the precipitation hardening and as we know that in this case, you have to have the you know alloys in such a manner that the solubility of one of the component is decreasing as the temperature is coming down and you know mostly for aluminium copper system we have seen.

So again, this is you know one of the method for the heat treatment which is very much widely used, we have already discussed about it where you know we are again further heating it so, first of all we are trying to have the supersaturated solution and then we are going for the solution treating, we are again heating going into that range, where the solubility becomes more.

And then you know in that what we do is; depending upon the temperature and the time, there will be nucleation of the precipitate so, the second phase particle that basically will be coming up so basically, now what; so we have seen already that there are different stages you have the you know coherent you know, there should be coherent interface, so you will have the different stages you have you know by the GP zone.

And then you have θ' phase and then you come to the equilibrium you know phase, so as we see that as which it moves to the GP zone theta prime, so you are getting the increase in properties and after that once you increase you know, the ageing time or the temperature also, so in that case there will be further growth, so that will you know be reducing the properties.

So, in this case you have you know the processes which are followed is the solution treatment, so you know, so you will be allowing this you know specimen to be heated you know so that you know what the; to ensure that the solute which is there it is dissolved because we are having a supersaturated solution, so we are going into a temperature range where we feel that so because suppose, you have; if you look at the percentage of B in A is there in on this line.

And if such is the line so, this is your θso this will be basically the $\alpha+\theta$and you have α here, so you will be you know heating and going into this zone, so this will be your you know heating point so the temperature will be raised up to this point, so that you go into this zone, so that is and then you are keeping in here because you are trying that and you are giving some time.

So that you know these precipitates you know they start coming out, solution treating is that one and then you will have the you know precipitates coming out, so after you reach and ensure that all the solute is resolved, you are basically cooling fast and then you know further you are you know edging, so you are heating to a lower temperature and then further you are keeping either you know so certainly, these the particles which are excess, so they will try to come up you know as you heat.

Or even naturally also, it will take more time but otherwise if you heat then in a lesser time they start growing and basically that the principle is that they impede the motion of the dislocation through the matrix, so that way your you know strengthening is achieved, we have already studied that how you know there are methods that how the dislocation will either they it will cut through the precipitate or it will bypass and it will move around.

So that way the main purpose is that you will have you know a mechanism by which the stress required to move the dislocation will go on increasing, will increase if you know a proper you know aging time and aging temperature is selected and that way the strengthening is achieved, so this; these are the you know different type of you know heat treatment methods for the non-ferrous metals and alloys as we see that homogeneous in temperature treatment is used prior to mechanical processing of the cast ingot.

And the temperature and times use depend on the diffusion rate and the starting structure that was in the case of homogenization you know annealing similarly, you have another you know example that was the precipitation hardening that we have already discussed, so these are the different you know methods. Thank you very much.