Heat Treatment and Surface Hardening (Part–1)
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Lecture Number 03
Few more case studies in reference to processing with Tt modification

Hello, let us start our third lecture.

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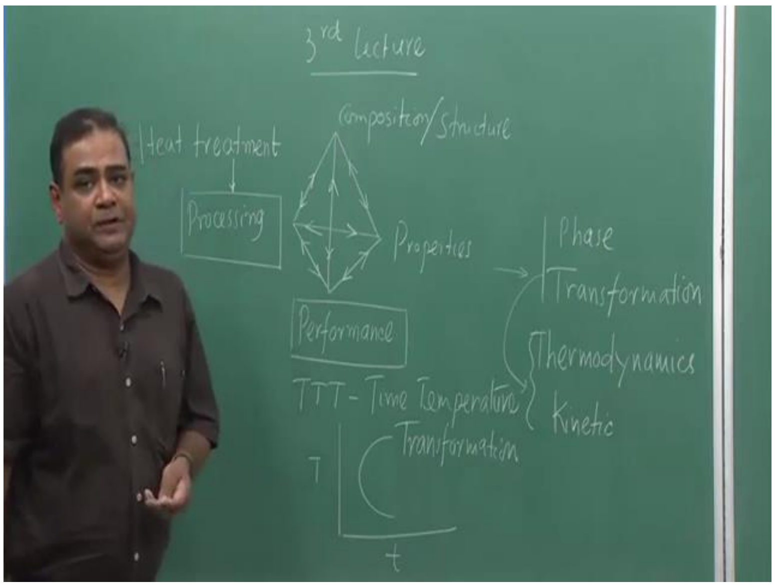

So today will be our third lecture, and in last two lectures we have talked about a material tetrahedron, and in that material tetrahedron we have seen that it has four rod sections. One is composition or structure, then you have properties, then processing, and finally we have performance. And all these four segments are interconnected, interconnected and we have also seen with examples that heat treatment falls in this category which is processing of material.

And this overall (tetragend) tetrahedron is valid for any material and rather any material which we use in our applications. And final aim is definitely performance, in order to get performance we need to look at properties and in order to get properties, we need to look at composition, we need to look at structure which could be microstructure, crystal structure or we would see that even macrostructure becomes effective in controlling the properties. And in order to make modification in the properties as per our wish, we can also change the processing condition on the same material.

And when we change the processing condition we can have change in the structure again, correspondingly change in properties and finally we have different performance. And in this processing we have heat treatment and heat treatment is nothing but a temperature time situation. Now we had example in case of mild steel 0.2 percent mild steel where we have seen that if you do furnace cooling with the window of, with the door of the furnace closed, we have also seen a condition where you put up the furnace and open the door, then another condition was you take the sample out from the furnace and place it in normal air which will be considered as rare cooling or normalizing.

In all three cases we have difference in structure, little more deification in the structure and we have changes in properties. And similarly if we do water quenching or voil quenching after taking it to thousand degree Celsius and holding it for 30, 40 minutes, we see that inter structure is changing there the crystal structure changes, even the microstructure changes and you see huge change in the properties. Now in the last class also we saw that whenever we see this kind of situation, these particular entire thing also talk about, talks this entire thing talks about few more things which are inherent to this particular diagram.

While considering while while seeing those all those options, all those parameters. Now those things are inherent like phase, and of course when we talk about phase, we also try to see what is there in the transformation, we also see the transformation transformation, for example, when we take the sample out from the furnace and place it in cool water, we have water quenching and then the phase transforms, we will see later on that austenite to Martensite, that is the transformation.

And if we do it furnace cooling, we will see that austenite transforms to ferrite and perlite. So like that, we have phase and as well as transformation. Now when we talk about phase transformation, we need to see that whether what condition that transformation would take place or what is the driving force for the transformation. So whenever we talk about any driving force, it talks about thermodynamics and of course once we see that yes there is driving force, but whether that transformation would actually take place or not, we need to look at kinetics part of it, kinetics part of it.

So that means, we talked about phase transformation along with thermodynamics and kinetics and need to see what is the time and temperature condition for getting that particular phase transformation as we desire. Many a times we would see that even we do this kind of situation we treat this kind of situation, we would finally see that some phases would appear which will not be desired. Rather those phases would lead to some problem in application and would also adversely affect this performance.

And in the last class also we took the example of mild steel, but at the same time we mentioned a two more things, one was in case of alloy, aluminum, copper which is popularly known as duralumin, as well as 18:8 stainless steel. We would like to see that what exactly happens if we change the time temperature situation and we would see that, yes there would be distinct change in the material properties as well as consequently, (conseq) consequent changes in the structure which could be microstructure or microstructure plus crystal structure both.

Now at the same time we also talk that just we touched that once we get this phase transformation thermodynamics and kinetics, we can have overall transformation kinetics which can be best suited in terms of a diagram which we call it TTT diagram which is called time, temperature, transformation diagram. And TTT diagram looks typically a kind of c curve where this axis is t and this axis is temperature and this axis is time. And once we get this kind of information we derive those information and then accordingly we can decide what should be the temperature and time required to achieve a particular structure and accordingly particular property as we desire.

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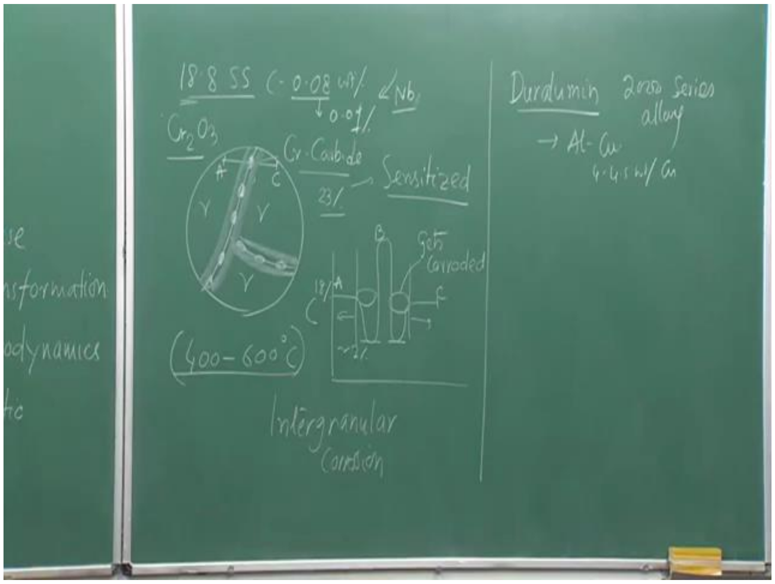

Now this part will come later on, but before that since we talked about two examples and in the last class we could not complete that discussion, let us have little discussion on those two things, one is 18:8 stainless steel SS with a carbon content of 0.08 weight percent. Now this is a special steel which is called stainless steel as we have discussed last time, and in this steel we use this steel in the form of sheet metal and now in this case, if we see the microstructure, microstructure look like a polygonal grains and every and if we see this crystal structure, we will see that all the grains are austenite and these are the grain boundaries.

Now in this particular case, we have 18 percent chromium which is 18 weight chromium and if we have 18 weight percent chromium in the material, and that 18 percent chromium is in solution we call it solid solution and that solid solution is also falling in the category of (ss) substitutional solid solution the chromium atom substitutes the base iron atom and forms a solid solution. Now once we have 18 percent chromium, it reacts in the environment in the presence of oxygen. It forms chromium oxide and this chromium oxide forms a thin layer on top of this surface which protects the material from fatal corrosion.

Because this oxide is highly adherent and in impervious oxide, impervious means it does not allow the oxygen or moisture to get through and come in contact with the base iron metal. So that is what it has a stainless steel property. Now if we can have little change in the processing by mistake, let us say by mistake we heat this material in the temperature range of 400 to 600 degree Celsius which is a kind of a not very suitable temperature to heat this material within this to heat this material, because once we heat this material because during operation, let us say we want to wield the particular sheets particular plate, let us say stainless steel plate of this composition.

If we wield it, somehow during cooling, it has to go through that temperature range, okay. Or sometimes when we quench it after solutionizing, we need to remove the quenching strength. So sometimes we have to do little stress reliving operation and during that stress reliving operation if we heat it to this particular temperature range, there something interesting happens, some transformation happens and that is nothing but the phase transformation. And at this particular (situa), in this particular temperature zone, the chromium carbide precipitates along the grain boundaries, along the grain boundaries which is chromium carbide.

And because this is a magic temperature for getting a very high kinetics of formation of chromium carbide along the grain boundary. Now once we have chromium carbide along the grain boundary, now this carbon has to come from inside the body and this chromium is also coming from this particular solid solution and then chromium and in the chromium (con) carbide the chromium percentage of the order 23 percent. So now from 18 to 23 it is increasing, now if we see along this particular line what is the composition, the composition if we see, so composition this is a, this is b, this is c. So now the chromium percentage further away from this is of course 18 percent.

Now as we go closer to the chromium carbide because here the chromium percentage has to increase in order to from chromium carbide. So the chromium percentage at locally around that precipitated decreases and then again go up little bit and then again decrease like this. So this is my a point, this is my b point, this is my c point along this line. So now you see that the chromium percentage has gone down and it can even go down to level of two percent. Now in order to get stainless property in 18:8 stainless steel we need to have more than 12 percent chromium all the time.

Now once the chromium content reduces to two percent, something interesting happens along the grain boundary, we do not find chromium oxide. So if we do not have chromium oxide along the grain boundary which is adjacent to the chromium oxide layer, this particular zone becomes vulnerable for further corrosion, okay. So this zone gets corroded. So now this, that means is a thin section along the grain boundary gets corroded. And that means, along the grain boundary all the time we have very high corrosion because away from the this particular precipitated zone we have 18 percent, so here we have all the chromium oxide layer, here we have chromium oxide layer so no problem, no corrosion takes place.

But this zone is exposed, so there corrosion happens. We will talk about this particular heat treatment more detail but I am just saying that because of change in temperature time information or heating it to this level and holding it for some time, we can get this kind of situation. And once we get this kind of situation, these particular steel we call it Sensitized, means it is subjected to intergranular corrosion and this intergranular corrosion is extremely bad in case of stainless steel, this entire plate can break like a kind of a brittle substance a kind of stick, okay.

It is so brittle it can break like a chalk, it can break into halves and this is also called intergranular corrosion. So that means because of temperature time information in this particular zone, we have this sensitization and that leads to intergranular corrosion which is not good for our performance. It damages our performance of that particular steel and it is no longer stainless steel. So that means it is not only that we whenever we do processing it would have positive effect on performance, it can also have negative effect on performance.

That is why, it is important to study what happens when you do processing? What happens to the phase transformation? And what happens to the final performance? So this is one of the classic examples that structure does not change, but simple phase transformation from solid solution 18:8 stainless steel to chromium carbide formation along the grain boundary leads to intergranular corrosion.

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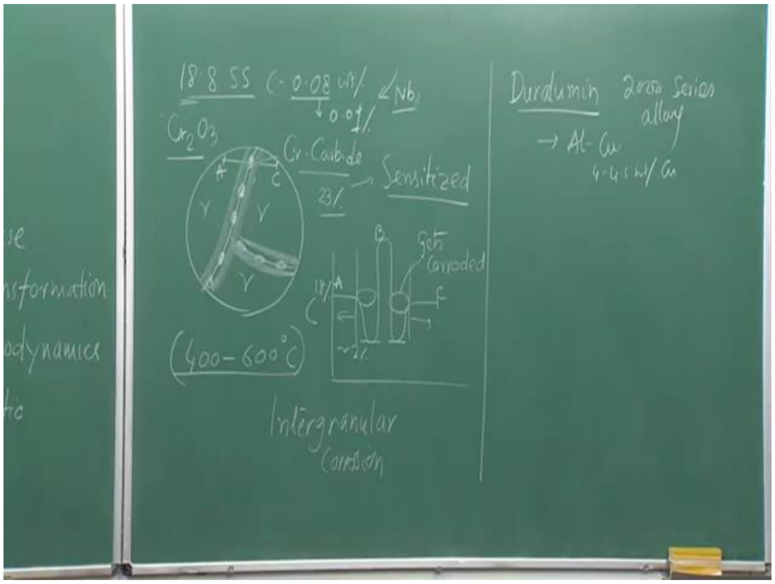

This is one example, the next example is 18:8 is duralumin which is two thousand series alloy and mainly aluminum copper alloy. And the best example is around 4 to 4.5 weight percent copper we have in this particular system. Now let us talk about this particular alloy in order to complete our discussion, that yes heat treatment or processing can lead to change in the properties and performance.

So that also would tell us that why it is so important to study this particular diagram and when we study this particular diagram, we have to see synergistically not like we can change the microstructure, it will give problem, it will; it will solve our problem or if we change the composition it will solve the problem, we have to see why we have to change, and that why, that answer would come if we understand this.

For example, before we going to this, if we have 0.08 percent, but if we can reduce the carbon to 0.01 percent, then this sensitization problem can be avoided to a great extent because for the chromium carbide formation though we have chromium, but we do not have sufficient carbon to form chromium carbide, okay. So that is a (possi), that is the possibility or we can also add little bit of niobium or niobium, so that niobium will take care of this carbon because niobium has a higher carbon affinity. So niobium would form niobium carbide, but it would not allow the chromium carbide to form.

And interestingly the stainless property comes from the solid solution of chromium presence of the order of 18 percent. So that suggests that if we add a little niobium, this can avoid this sensitization. So these kind of things we can be able to know if we understand this particular diagram and finally we need to also understand why need to do the heat treatment. Now coming to duralumin, in order to understand duralumin we need to see the phase diagram and let me draw the aluminum copper phased diagram or the part of that particular phase diagram.

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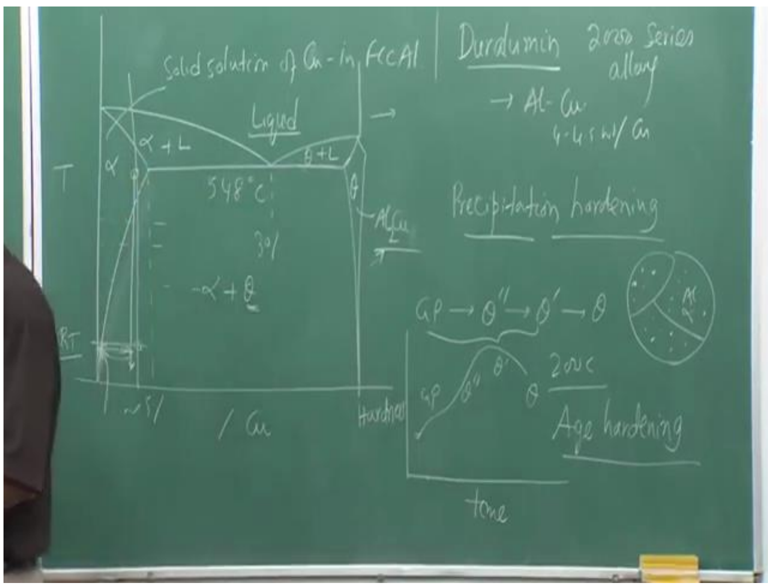

Now this is whenever we draw a phase diagram it’s a binary phase diagram, this axis is temperature and this axis is percentage copper. And if we see that this temperature is eutectic temperature which is 548 degree Celsius. Now here we have this kind of situation, a terminal solid solubility and we have eutectic system and this is almost about close to 30 copper and then this is theta phase which is nothing but, and the rest of the part I am not drawing because these part would be important for us. And here this section we have theta which is nothing but aluminum cu2 sorry aluminum 2cu.

And in this case this particular section is almost about 5 percent, roughly 5 percent and this join is alpha, this is alpha plus liquid and this is theta plus liquid and this is liquid. And in this zone we have alpha plus t. so if it is in equilibrium, that time this would be the phases we can arrive at, at different temperatures. Now we have something like this composition, let us say we take this composition, if we take this composition then at this temperature the normal phases would be alpha plus theta, fine and this theta is a second phase and this second phase would give me little bit of hardening, but the problem would arrive that this theta will not be able to increase the strength to a great extent.

But if we do little bit of change in the processing, we can have a huge difference. Now what would be the processing difference? Now if we, let us say I have some particular thing this is room temperature let us say, let us assume that this is the room temperature and at this temperature whatever phase mixtures what we have, if we take it to this level and at this level if you hold it, everything will mix and whenever everything mixes, okay and that time it forms a single phase alpha which is nothing but solid solution aluminum solid solution of copper in FCC aluminum.

Now solid solution of copper in FCC aluminum that means here, if we hold for some time, then it forms complete solid solution. That means all the theta phase which is the second phase al2cu that phase will dissolve and form a single phase. Now after that if we quench it quickly to a room temperature will have a little increase in hardness because quenching leads those entrapped copper in the solution, but at this temperature, at this temperature we do not, that system does not like to hold that particular amount of copper excess copper, so this is my excess copper, this is my excess copper and actual equilibrium percentage of copper in solution is this one.

Now, so that means what happens to this excess copper? And these excess copper at room temperature it takes years to come out from the system and forms a fine fine precipitance. But if we somehow increase the temperature to about 200 degree Celsius and hold it and because of increase in temperature, we accelerate the copper coming out from the solid solution and forming fine fine precipitance.

And that time, the precipitation does not happen directly to this, rather it goes to a several phases which starts from GP zone which is Gainer Priston zone to theta double prime to theta prime and finally equilibrium theta phase, okay. So now once we have this kind of situation, the hardness increases to a great extent. And that time we call it precipitation hardening and the hardness response, if we see the hardness and this is my time, why time? Because what I am doing? I'm quenching it, I am making it a solutionized aluminum copper solution and solid solution.

And then I am heating it to 200 degree Celsius and as a function of time I am seeing the response of, in the form of hardness. And hardness is what? Resistance of a material against penetration and the penetration of the index. Now if we measure the hardness, we will see the hardness plot looks like this. So that means this is my solid solution, okay and then gradually we have GP zone theta double prime, theta prime and finally theta theta. So the hardness increases greatly and this particular (hap) thing happens at 200 degree Celsius if we hold it and these entire process we call it age hardening, we call it age hardening.

So now if we come back and see what actually we did, we did nothing but a change in processing which is the heat treatment. And heat treatment is nothing but change in processing temperature and time, and here, we solutionized, quenched, taken it to little higher temperature, held it, held the sample and then measure the hardness, and we are getting this response, this is called age hardening and this age hardening is coming from precipitation hardening mechanism, precipitation hardening.

So that means, here we are fixing the composition but we are changing the structure, both the structure because whenever we have these changes, we are change in the crystal structure, okay. And then finally also we are changing the microstructure because the microstructure would look like if those are the grains of FCC aluminum which is alpha phase those precipitates would appear a small small precipitates and these precipitates would not allow those dislocations to move freely because those precipitates would hinder the most dislocation movements and whenever we have dislocation movement is hindered, we have increase in hardness, that means the more strength is required to cross that barrier, okay.

And that is what we get increase in hardness. So this is a typical age hardening which is coming due to heat treatment, due to processing. So that means heat treatment is extremely extremely important and we need to look at this heat treatment very very carefully and in our next class section onwards, next section onwards we would get to the phase transformation thermodynamics and kinetics and this entire 20 hour lecture will be concentrating on the fundamentals behind heat treatment.

Rather than looking at you take the sample to some temperature hold it, and then take it out and see what is the performance, but rather why we should take it to that temperature? When we should take it to that temperature? How long we should hold the (temper) sample? Those information, those answering of those questions, why, how, what when, that would give idea about heat treatment and that one will concentrate, will talk about in this particular whole 20 hour lecture. Thank you, so we will continue in our next lecture. Thanks.