Heat Treatment and Surface Hardening - II

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Lecture - 08

Effect of different parameters on heat treatment and concept of saturation vapor pressure with examples

Hello everyone. Today we will have our eighth lecture.

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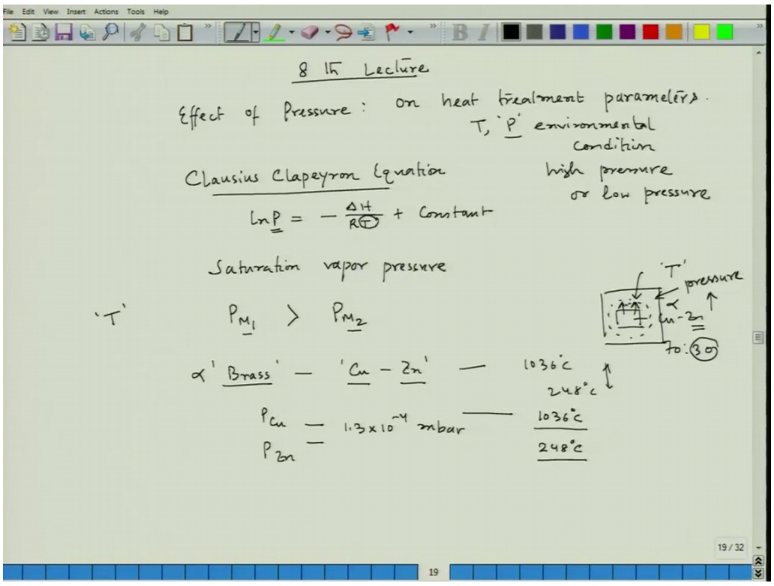

8 th Lecture

Effect of Pressure : on heat treatment parameters.
T, 'P' environmental condition
high pressure or low pressure

Clausius Clapeyron Equation

$$\ln P = -\frac{\Delta H}{RT} + \text{Constant}$$

Saturation vapor pressure

'T' $P_{M_1} > P_{M_2}$

α 'Brass' — 'Cu – Zn' — 1036°C, 248°C

P_{Cu} — 1.3×10^{-4} mbar — 1036°C

P_{Zn} — 248°C

And today we will discuss the effect of pressure on heat treatment parameter, mainly at temperature and environmental condition, whether we need to do it at high pressure or low pressure. In last lecture we saw one expression which is Clausius-Clapeyron equation, and that expression tells me the equilibrium of a system when the vapor is in equilibrium with solid or liquid metal, or rather any material, rather its an equilibrium between condense system and its vapor.

So, it says LNP equal to minus del H R T plus plus some constant. And in this case these temperature is the operating temperature, and that time the pressure equilibrium pressure is called saturation vapor pressure. It is actually the pressure exerted by its own vapor on that condensed phase. Now this is important, because if we compare two materials at the same temperature, and if we find that P of metal one; that is the saturation vapor pressure of metal one at a temperature t. So, both the cases the temperatures are same, and saturation vapor pressure of metal two. If we see that, this is greater than this; that means, metal one would like to form vapor easily rather than metal two.

Because in order to maintain that high saturation vapor pressure, we need more number of molecules in the vapor phase of that particular metal, and here we consider that metal one and metal two, both are in solid or it could be in liquid state. Now these particular understanding can help us in deciding temperature and pressure for doing heat treatment. Let us say we consider a heat treatment of a brass, we know that brass is a. if we consider alpha brass, alpha brass its an alloy of copper and zinc around close to 30 percent zinc can be mixed, and that can be made into solution with copper.

So, that brass, in that brass if we compare the saturation vapors pressure of brass and zinc. Let us say I fixed saturation vapor pressure for both the metals copper and P of zinc, and we have a, we can have some data and this data has been found out from book, which is a kind of handbook and that book is the steel heat treatment handbook, edited by Ge Totten and Mah Howes. So, there a kind of data bank, it shows that if we consider that vapor pressure to be saturation, vapor pressure to be 10 to the power minus 4 milli bar, both the cases. Then the temperature at which this saturation vapor pressure can be achieved, in case of copper it is. Let me just find out in case of copper, it is 1036 degree Celsius, whereas in case of zinc it is 248 degree Celsius.

That means same saturation vapor pressure in order to achieve that, the equilibrium temperature should be maintained at 248 degree Celsius in case of zinc, and whereas, it is 1036 degree Celsius in case of copper. It means that zinc has got much higher tendency to go to the vapor phase. Now if we try to heat, treat these two, this particular alpha brass at any temperature, which is close to below 1036 degree Celsius, and between 248 degree Celsius. In between this temperature range, if we would like to do heat treatment, then the possibility would be. Whenever I am doing heat treatment of this particular, let us say a piece of copper zinc alloy alpha brass, it would have its own vapor phase.

So, it could be copper, as well as it will be copper as well as zinc in the proportion, what we have there if we assume that this is happening there, but we will see that the zinc vapor formation would be much higher than copper, the tendency. So; that means, the zinc would try to go into the vapor phase in order to maintain that equilibrium, because at any temperature we must have some saturation vapor pressure, and we see that the saturation vapor pressure of copper is much lower than zinc.

So, zinc would evaporate, and if zinc evaporates would you think that this copper zinc, if it is 70 30 brass, this 30 percent zinc would no longer be there on the surface. The zinc content would go down. So; that means, we are changing the property of the metal or the alloy, because of this phenomena. So, what we can do in order to prevent this, because zinc evaporation cannot be stopped, it has to maintain its saturation vapor pressure, then one possibility is, we have to do that heat treatment at little lower temperature, this is one, but at the same time we cannot go further lower than that temperature, what we are thinking of, because if we go for a low temperature a heat treatment. So, the desired result would be obtained at a much higher time, because the kinetics would be very slow.

So, we cannot go a very low temperature for doing heat treatment. So, that case we have to look into the environmental part of it. So, this environment section we have to see. Now let us say we have this situation at some temperature, we are doing this heat treatment of brass, and in this environment if we already have some molecules, gas molecules, then whenever the zinc atom is trying to escape from the surface of that solid alloy. It would also collide with those already existing gaseous molecules.

So, when do we have that collision, there will be tendency that zinc atom would have much lower degree of formation of vapor, zinc atom would try to be stopped, because of that external gaseous molecules and the evaporation of zinc can be controlled or can be decreased. So; that means, we need to do at little higher pressure, pressure of this chamber needs to be increased. So; that means, we have to do it at little higher pressure than the atmospheric pressure. So, that we can stop this zinc evaporation and then also we have to see that we should not use some gas. For example, we cannot use compressed air into it, because that air contains oxygen, that oxygen might oxidize this brass. So, you have to use some inert gas; either argon or nitrogen.

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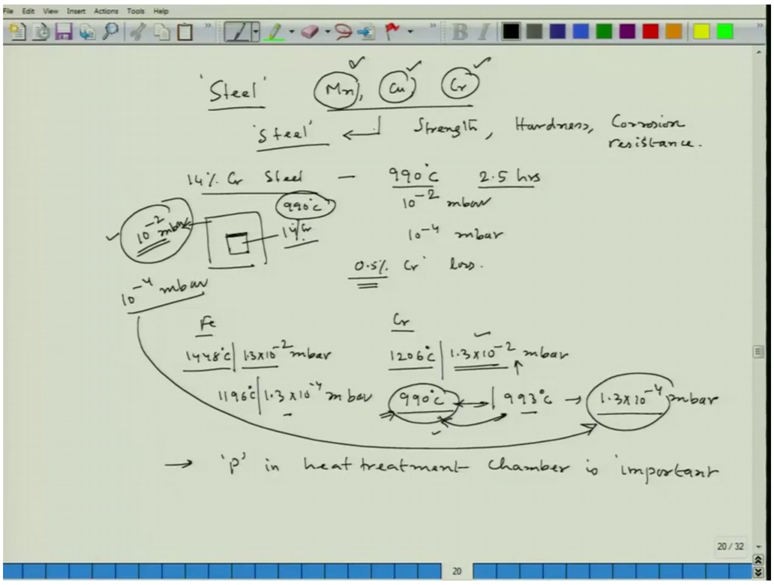

So, this is another way to prevent evaporation of metal, and then subsequently metal loss from the metal from that alloy. Now in case of steel, this is also taken care of. for example, in case of steel, if we have elements like manganese, copper, chromium, these are having with higher saturation vapor pressure than iron, and these are added into steel to improve many other properties; like strength hardness corrosion resistance. So, hence we have to also be little consider it, that we cannot consider any metal loss from that steel, and we have to protect the loss of manganese, loss of copper, loss of chromium from the surface.

One such example is, if we consider a kind of 14 percent chromium steel, if it is heated at 90 degree Celsius for two and half hours at a pressure of 10 to the power minus 2 millibar; that means, in a chamber, we have a steel containing 14 percent chromium, and that pressure is maintained at 2 to the power minus 2 millibar, and the temperature is 990 degree Celsius. We hardly have any loss of chromium from the surface of that particular block steel block.

However, if the pressure is kept at 10 to the minus 4 millibar; that means, we are introducing vacuum into it, and if we operate at the same temperature and for same time, it has been noticed that the surface from the surface region, the surface region we have loss of chromium about 0.5 percent. This is amount of chromium loss. why, because chromium has got higher saturation vapor pressure. For example, if we consider iron and chromium, if we try to see, if the saturation vapor pressure is in case of chromium, if it is 1.3 into 10 to the power minus 2 millibar at a temperature 12 0 6 degree Celsius; that means, these are the equilibrium pressure and temperature.

Whereas the same thing if I try to see in case of iron pressure, is saturation vapor, pressure is same 1.3 into 10 to the power minus 2 millibar, that time the temperature at which this particular saturation vapor pressure can be attained is at much higher temperature. So, in case of iron its 1448 degree Celsius; that means, if the pressure of that system is maintained at 10 to the minus 2, I could see that 900 degree 990 degree Celsius is below the equilibrium temperature to attain with the saturation vapor pressure of 1.3 into 10 to the power minus 2 millibar in case of chromium.

So; that means, the saturation vapor pressure at 9900 degree Celsius would be much lower, and we have a data which says that around 993 degree Celsius, the chromium has a saturation vapor pressure of 1.3 into 10 to the power minus 4 millibar. Hence if the temperature is maintained at 990 degree Celsius, and if the pressure is maintained at 10 to the power minus 2 millibar, I would not be able to reach to this saturation vapor pressure, and the pressure is already maintained to the minus 2. So, at 990 degree Celsius the saturation vapor pressure of chromium is much lower than this, lower than this.

So, the chromium vapor formation would be much lower at 990 degree Celsius. If the pressure is maintained at 10 to the minus 2, in case of iron the temperature at which this particular vapor pressure is attained 1.3 into 10 to the minus 2 is much higher. So, the question of iron vapor formation would be also minimal. So, the chromium loss can be prevented, but the situation would be different. if the pressure is 10 to the power minus 4 millibar, this chamber pressure is maintained at to the minus 4 millibar.

So, that time I could see this particular pressure is matching with the chromium vapor pressure at 993 degree Celsius, which is close to 990 degree Celsius, which is the operating temperature. So; that means, I would definitely have more chromium molecule formation in the gas chromium atom coming into the gas form, but in case of iron at 900. Let me see: if we could get the same vapor pressure 10 to the power minus 4 millibar, what is the temperature at which this particular vapor pressure is attained. In case of iron its 1196 degree Celsius. This is very very high compared to the operating temperature, which is 990 degree Celsius.

So, I will not have much of iron vapor formation, but I will have chromium vapor formation, because it is close to the saturation vapor pressure of chromium. This temperature is close to that saturation vapor pressure temperature that equilibrium temperature corresponding to saturation vapor pressure, and the chamber pressure is maintained at 10 to the minus 4 millibar. So, what would happen. So, now, iron vapor formation would be less, but chromium vapor formation would be more, if we compare the relative vapor formation, iron vapor formation would be less chromium would be more.

So, the chromium loss would be experienced. So, that is what we have 0.5 percent chromium loss. So, now, you will see the importance of this saturation vapor pressure. During heat treatment we need to be careful. For example, manganese chromium copper all of them have the low vapor pressure. So, when we operate these particular steels containing manganese, copper and chromium, we should see that the pressure should be such that it is higher than the saturation vapor pressure of that particular element, in that steel at the temperature where the steel is being operated.

Now,. So, we see that pressure in the chamber heat treatment chamber is important, and whereas, in case of zinc case we could see that the temperature also is an important factor, even in case of steel this chromium loss part we could see that we should choose a temperature which should be sufficiently, which would be sufficiently high, and at the same time, which should not be sufficiently low, and at the same time you have saturation vapor pressure of that particular element, which we fear to, for the loss from the steel, that we fear, that might that particular element might loss might go into the vapor phase.

So, the pressure should be such that should be higher than the saturation vapor pressure at that particular temperature.

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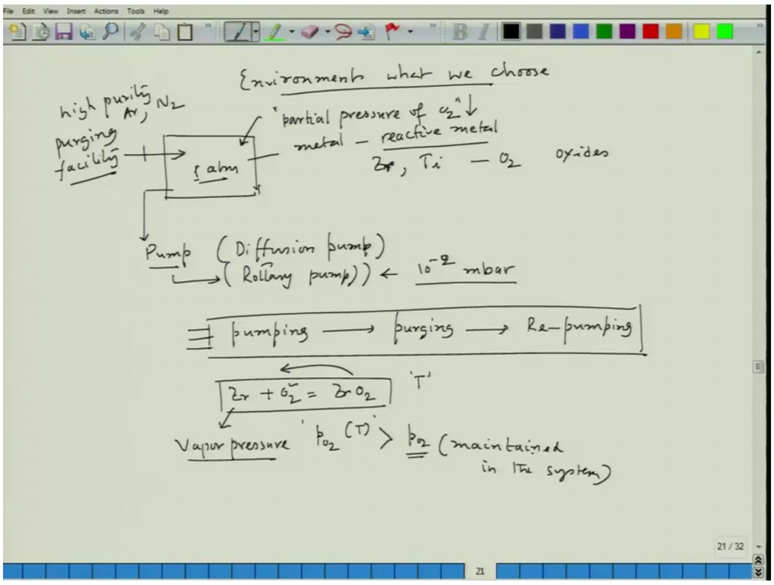

Now, sometimes you have to worry about the environment, what we choose for heat treatment. Now if we have a furnace, this is a practical aspect, and which is actually dependent on that Clausius-Clapeyron equation. If we have a furnace, and let us say it is a closed furnace, and we are working with some metal, which is reactive to oxides form a reactive, it is a reactive metal, and if it is a reactive metal, we must have something in this particular environment, which should reduce the partial pressure of oxygen, should be reduced. Means if it is zirconium, if it is titanium, then these metals have very high affinity to oxygen.

So, they can form oxides, and whenever oxide forms, because these are very costly metals. So, we have loss of metals at the same time. This oxygen, these metals have got very high solubility, this oxy solubility towards oxygen. So, the oxygen can go into the solution of zirconium, as well as titanium. So, the metal property will change. So, that case we have to considers, we have to do something. So, that the partial pressure of oxygen is reduced one way is, this chamber can be connected to a diffusion a pump, which could be diffusion pump or rotary pump.

So, whenever we have diffusion pump. Of course, it is integrated with the rotary pump. So, we have advantage of rotary as well as diffusion pump. So, the pressure would go down very low, and then if the total pressure of this particular chamber is reduced. Of course, automatically we have less oxygen there, but many a times diffusion pump would be very costly affair, if we want to operate a huge chamber. So, that case its better to have only rotary pump, and with the philosophy that how to reduce the oxygen partial pressure.

The thing that can be done, which is a very smart move; we can have a pump at the same time, we can have a purging facility. Now we have connected to a rotary pump, we take it down to the pressure of 10 to the power minus 4 minus 2 millibar, which is not that much low vacuum. Now once we take it to 10 to the minus 2 millibar. We stop the rotary and then purge with high purity argon or nitrogen. So, now, once again it will, the pressure would go to the atmospheric pressure, because we are purging in. Now again we stop it here, then open the part. Again this pressure is brought down to 10 to the minus 2 millibar.

So, now you see the initially, the partial pressure of oxygen was something; if we consider 21 percent oxygen presence in the atmosphere. So, now, because of one cycle; that means, pumping and then purging and another pumping. So, this is we can say the one cycle pumping, then purging, then again repumping this cycle, if I consider one cycle. Now I see that I have already reduced the amount of oxygen from this chamber, what was existing in the beginning before we started this pumping operation.

Now, again we continue this particular process couple of times, means pumping, purging, repumping like that way if we continue. So, what we are doing? We are taking the inside air and replacing with argon. So; that means, we are reducing the partial pressure of oxygen. Now every metal whenever they try to oxidize. For example, zirconium plus oxygen equal to zirconium O 2, you need at a particular temperature, where you need to consider the oxidation.

You need a partial pressure of oxygen, which is required for the equilibrium to attain, and if the partial pressure of oxygen at that temperature T is more than the partial pressure of oxygen maintained in the system; that means, in the chamber, then as per equilibrium, which is basically the Klaus Sattler principle, you need this much partial pressure of oxygen to have oxidation of zirconium.

But your actual partial pressure is this, this oxygen partial pressure. So, this is low compared to what we need to have this oxidation. So, the reaction would move in this direction, in order to maintain equilibrium. So, then you are actually protecting zirconium, but in this process if you see, you have reduced the partial pressure of oxygen, but you did not require a heavy duty diffusion pump, with the use of rotary pump, and with one simple attachment of purging facility, we could do this particular heat treatment.

So, now whenever we talk about it, treatment, its basically how smart you do the heat treatment. See we can have very sophisticated instruments, but many a times with little bit of smartness. For example, what we have done in the lab scale, this is very successful. We can do heat treatment and also another part, which is to be considered in our mind that whenever we are considering this pressure drop, we have to. Also take care of its vapor pressure, if the saturation vapor pressure at that temperature of zirconium is pretty high.

So, you have to maintain the pressure by using this argon or nitrogen, higher than that the saturation vapor pressure of zirconium at that particular temperature, in order to avoid zirconium evaporation. That means we could understand that the importance of saturation vapor pressure, and what is its effect on the time, and what on the temperature, choice of temperature of heat treatment, and the pressure which is to be maintained for doing the heat treatment.

Let me stop here. We will continue in our next lecture.

Thank you.