Heat Treatment and Surface Hardening (Part-II)

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Lecture - 02
Recap – II

Welcome back. In our last lecture, we ended at JKMA equation, and we have also seen how x varies with time at a different temperature at a particular temperature below the transformation equilibrium transformation temperature. Now, we would like to see how the TTT diagram is plotted from those x versus time plot at different temperatures; and remember we are in the regime of isothermal transformation.

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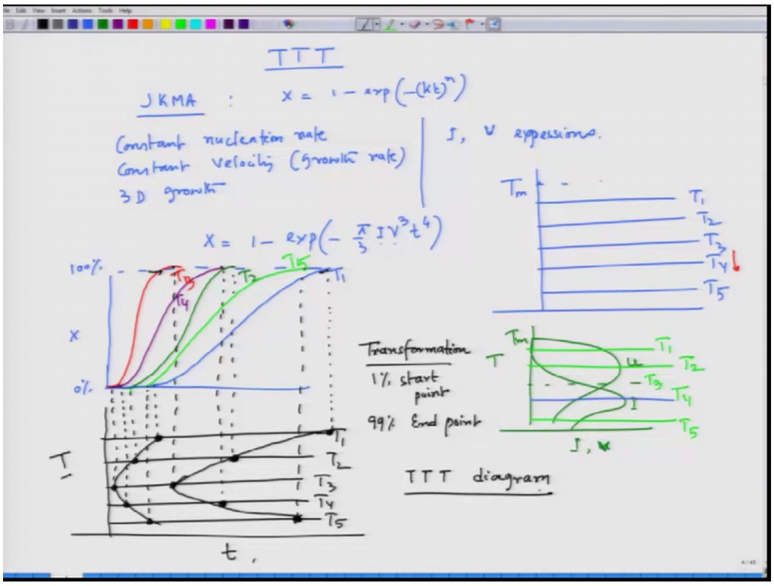

Now, if we. So, this recap would talk about few other things what we have done in our previous lectures. And the Johnson Mehl Avrami equation JKMA the general form is x equal to 1 minus exponential minus k t n. And we have talked about one particular condition and the condition is constant nucleation rate, constant velocity or growth rate and then 3D growth. And we have used I and V expression, and then we have gotten this formula which is exponential minus pi by 3 I V cube t 4. And now if I let say this is my let say in case of solidification, this is my melting temperature, I will go to this range and then make it liquid the entire solid is transformed to liquid.

And I take different temperatures and then try to plot this is T 1, this is T 2, this is T 3, this is T 4, this is T 5. So, I try to plot x versus time at different those T 1, T 2, T 3, T 4, T 5 temperature, since at T 1 which is very close to T m nucleation rate is low growth rate is very high. But combining these two I and V this I and V the x would start at a much higher time duration the incubation time would be very high. So, x plot would be like this where this is 100 percent and this is 0 percent.

And we are assuming that we can measure up to 1 percent, minimum 1 percent. For example, if the transformation product is less than 1 percent, we would say that the transformation has taking place and that depends on what sort of experimental techniques you are using for getting a measurement of fraction transformed. If you use a very sophisticated techniques, then you can also go to a very, very low transformation amount to be your transform fraction you can go to 10 to the power minus 2, 10 to the power minus 3 all those levels. But if you use optical simple optical technique you can measure up to 1 percent less than 1 percent, it will be an error. So, 1 percent is considered to be a kind of fraction, which we can measure.

Now, this I can consider to be 1 percent where I can see a kind of measurable amount this is at temperature T 1. If we try to plot at temperature T 2 growth rate is still very high nucleation rate is becoming little higher, so the transformation would start little early. But interestingly since both those things are having a little higher value, the slope is changing, this green slope has changed which is become which has become little steeper this also we have explained in our previous lectures.

Now, as we go to T 3, it is still in the regime for example, if we try to plot I versus I and V, which is the growth velocity; this is T m growth rate varies like this, nucleation rate varies like this. This is I, this is U, I can see as we are going towards around T 3 we are getting to this zone, so that means, we have sufficient growth rate as well as nucleation rate and the system would start little early, the plot would be like this. This is T 2; this is T 3. Now, if I try to go down further, for example, this way then again at T 4 if I find that T 4 region here, I see that growth rate has gone down, but nucleation it is very high, what does it mean means we have many more nucleus, but there since the growth rate is small. So, we would end up getting very fine structure.

And that time again since the growth rate is slow, again this particular slope, this slope is this slope would start tilting towards right, it would become shallower. So, then again this particular point would start little on the right side. So, if I try to plot that it will be like this, this is T 4. And T 5, if I see for example, if I plot it with this T 5 is here where this is T 5, this is T 4, this is T 3, this lead, this is T 2 and let say this is T 1. Again I see that growth rate and nucleation rate both are very slow, so that means again it will shift these point would shift towards right and the plot would become again it would become it would fall down the slope becomes less steeper.

Now, if we try to see and try to take those points on those access temperature axes, that means this is my T 1 this is T 2 this is T 3 this is T 4 and this is T 5. Now, I will just take down 1 percent transformation point and 99 percent transformation point, which is this point close to 100 percent that time let say this was the T 1, so this point let say here, and then this was here. Now, then T 2 and then T 2 here, T 3 and then start point was sorry we made a mistake and T 1 is deleted. So, this is T 1 let say. Now, T 2 we have taken the right one, T 3 we have to take it down, so this was T 3 and the T 3 plot is this one this one. Now, if I take it down, this is; and this T 1 start point is this one. T 3 is start point. Now, again we have to go back to T 4, the T 4 start point is this one which is shifting towards right again; and this is the end point of T 4 which is here. And again, now finally again we are going to T 5, T 5 is start point is this one, and the T 5 end point is this one.

So, now, we have the locus points this is one at T 1, this is at T 1, this is at T 2, this is at T 3 this is at T 4 this is at T 5. Now, if we try to connect those start points and end points, the start point indicates 1 percent is basically the start point that is transformation start point and 99 percent is the transformation endpoint, this is transformation. Now, if we connect them then we will get a curve like this, and here also curve like this. So, now if you see this is temperature and time, and it is taking shape of c, which is also called c curve. And since we are doing it at a constant temperature which is also we are following isothermal mode of experiments that is what it is called isothermal c curve also isothermal transformation curve and this is popularly known as TTT diagram. We have also looked into this aspect in phase one, but interestingly mostly this is in case of single component system.

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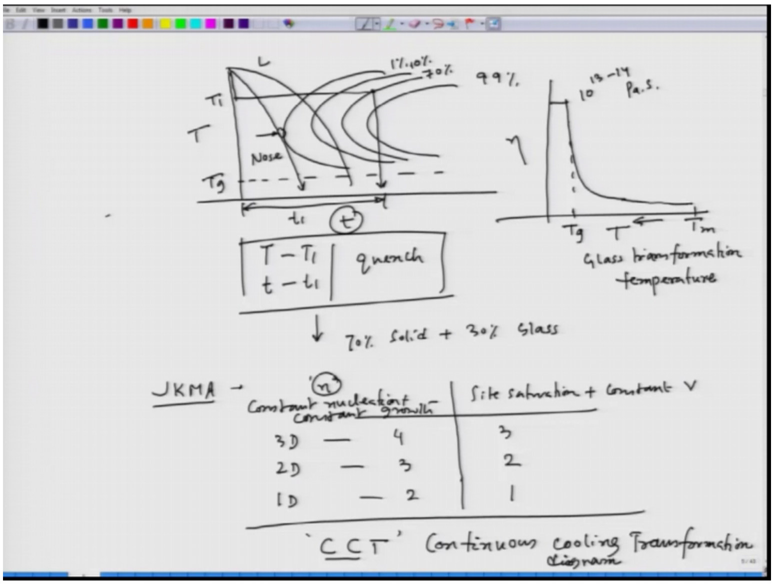

$T - T_1$	quench
$t - t_1$	

↓ 70% Solid + 30% Glass

JKMA → (n)

Constant nucleation + constant growth		Site saturation + Constant V
3D	4	3
2D	3	2
1D	2	1

'CCT' Continuous cooling Transformation diagram

And also we have looked at the aspects like if we have a TTT diagram like this, this is 99 percent, this is 1 percent. We can accordingly draw different other points which are corresponding to let say this is 10 percent, this is 70 percent like that way we can have different other TTT diagrams and this is temperature and time. And here if it is a liquid, this is the critical point, which we call it as nose. And if the metal is taken on the left side of the nose, gradually to the low temperatures, when you cool a liquid metal like this way which will not touch those lines those lines, if that liquid mater does not touch; that means, you are not getting any solidification. But when you take that liquid metal below melting point, the metal viscosity goes up; as the metal viscosity goes up, it becomes thicker and thicker melt.

But at certain point, for example, if I try to plot viscosity as a function of temperature in if this is my T m, initially viscosity lowering is viscosity increase would be sluggish. And suddenly close to certain temperature, it jumps and reaches to the viscosity of 10 to the power 13 to 14 Pascal second; and these temperature we call it T g or glass transformation temperature.

And now if we follow different heat treatment process, for example, let say I want to have only 70 percent solid phase and rest of the phase should be liquid, since glass is also a vitrified liquid. So, if we do this particular for example at this temperature T 1, if we cool it down very quickly and then hold it to this level. So, once it touches 70 percent; that means it is converting into 70 percent of solid and then suddenly we quench it to this level so that means, that liquid is not allowed to crystallize any more. So, you can have a fraction of 70 percent solid and rest liquid and that liquid would stay as a glass mode. So that way one can make by doing that heat treatment sequence that means, this is the temperature, that means, the temperature is let say T 1.

Time is, what is the time duration? So, this is the time axis that means, this is my time duration. This much time I have to; that means, this is converting T 1, T 1 time I have to relapse and then I have to quench. So, that means, this is my heat treatment sequence in order to get 70 percent solid plus 30 percent glass. Since and there is a temperature which is called T g, if the metal is taken below T g like this way then we get glass, so that means, on this basis we can design how to have a different fractions of glass and amorphous phase in polymer generally this gives an (Refer Time: 16:55) effect.

In case of metals, we have system called metallic glass, where you can do this kind of heat treatment in order to get different fraction of solid in glassy matrix. And the researchers have shown that sometimes in some metallic glass system partial crystalline; that means some fraction of total phase is solid and some fraction is glass, then we have better property in terms of mechanical, in terms of magnetic, in terms of surface properties like corrosion, those kind of thing can be improved. So, according to our need, we can do the heat treatment on the basis of TTT diagram. This is the thing we have also done in our phase one.

Now, apart from that we have also seen different other variations. For example, in case of JKMA equation, we have seen different other situation. For example, in case of n if we try to see, we see that n varies let say I have two different segments, one is side saturation plus constant V growth rate, and in this case if it is constant nucleation plus constant growth n varies like this. If it is 3D then here it is 4, here it is 3 is the variation of n; and if it is 2D, here it is 3, here it is 2; and 1D, it is 2, it is 1. So, these calculations as well as problems where discussed in our phase one.

But interestingly if you see this we are only talking about isothermal transformation diagram which is TTT. And in our next phase we will also talk about another diagram which is also very critical from the point of heat treatment, for example, here we have decided this heat treatment cycle as per the isothermal way, for example, everywhere I am quenching to certain temperature and then holding certain time and then again quenching. So, we are doing those transformations isothermally. But one transformation can happen like this.

Then we have to decide that what will be the amount of transformation, but since these diagrams the c diagram, c curves have been drawn on the basis of isothermal transformation. We will no more be valid for this continuous cooling, this c curve is to be modified a bit and the CCT diagram we end up getting CCT diagram which is continuous cooling transformation diagram that would also take a shape of C. But how to get there we will have to handle and that in this phase we will do that. And that is more suitable for many practical heat treatments mainly in steel, steel heat treatment we do have to use the CCT diagram information.

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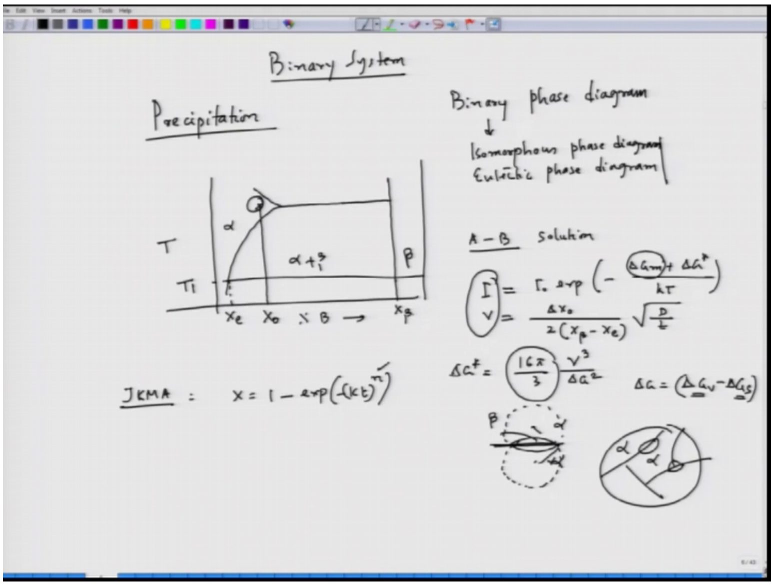

Binary System

Precipitation

Binary phase diagram
↓
Isomorphous phase diagram
Eutectic phase diagram

A – B Solution

$$I = \Gamma_0 \exp\left(-\frac{\boxed{\Delta G_m} + \Delta G^*}{kT}\right)$$

$$v = \frac{\Delta x_0}{2(x_\beta - x_e)}\sqrt{\frac{D}{t}}$$

$$\Delta G^* = \frac{16\pi}{3}\frac{\gamma^3}{\Delta G^2}$$

$$\Delta G = (\Delta G_v - \Delta G_s)$$

JKMA : $x = 1 - \exp(-(kt)^n)$

Then we have also looked into binary system and here we mainly talked about precipitation. And while taking the precipitation into our treatment, we briefly discussed how to derive a binary phase diagram, isomorphous and eutectic. These two phase diagrams have been derived; and we had to do the derivation in order to have some idea how this precipitation is taken care of mainly the overall transformation kinetics are in case of precipitation. And there we actually considered a phase diagram which looks like this. And this is the beta phase, this is alpha phase, this is alpha plus beta, and here it is temperature and this is percentage B.

And here we are considering A and B solution. And when we considered this particular phase diagram, we try to treat it from the point of nucleation rate as well as growth rate. And that time nucleation rate also takes a form like this; and growth rate takes a form like, this form. Where this is my x 0, that means this is the alloy composition we have chosen and this is the temperature we are trying to see let us say this is my T 1, what are the variations of I and V growth velocity. And this is the point which is x e and this is the point x beta.

And here we stepped into a solid state transformation, where the precipitation is observed. You can also have precipitation in case of liquid, but mainly we are concerned here with a solid that case this delta G m is nothing but again activation energy per atom jump. Delta g star is also takes this shape, this form were delta G is also volumetric term. But in case of solid-solid transformation, we have to also take care of another free energy change, which is the strain free energy change apart from a volumetric free energy change. The volumetric free energy change is all the time negative, but the strain free energy change is positive, because it actually increases the energy of the system if something is strained getting strained, it is a natural because anything gets strained it is the energy level of it increases.

So, this particular term is written as this way; and both the term are volumetric term. And whenever we have this form, it is based on a spherical growth of the product phase, but the spherical growth can happen like this. For example, if this is the interface, this is the grain boundary of alpha, let say we have alpha phase in the beginning, if we try to see the alpha phase diagram can look like this, where this is alpha grains. And if we try to look at this point, this is the grain boundary of alpha-alpha; and there we can have beta formation like this or we can have beta formation there, like that way this beta can form at grain boundaries, grains corners, triple point. And then accordingly we can treat it like this, this is a length cept. So, this is the sphere, this another sphere is growing, and we have also done those treatments. So, this is my r of that particular sphere. So, we have done that treatment also in our previous lectures.

And using this I and V expression will also end up getting JKMA and which is a general form is x equal to 1 minus exponential minus k t to the power n. And there k has got the term I and V, and this n is the exponent time exponent, and T is the time which is again the isothermal condition. But it can also be tricked little bit to get into the non isothermal regime which will consider the rate of cooling. And in this next phase, we will also look at that part also. Now, this is another treatment, we have done, and we have done some calculations also.

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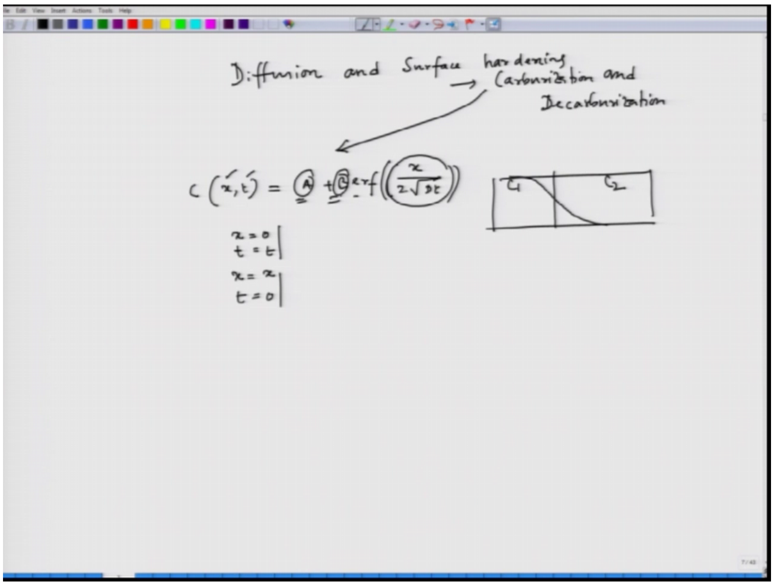

Diffusion and Surface hardening → Carburization and Decarburization

$$c(x,t) = A + B\,\mathrm{erf}\left(\frac{x}{2\sqrt{Dt}}\right)$$

$x = 0$, $t = t$

$x = x$, $t = 0$

And finally, we have gotten into diffusion and surface hardening mainly carburization and decarburization. And in case of surface hardening, carburization and decarburization we actually solved diffusion equation. And the general form of that solution is c x, t; x is basically here is the distance equal to A plus B error function x by 2 root over dt. Where x is the distance, T is the time, and error function, finding this value from the knowledge of d, we can get error function; and then from boundary conditions we can get these constant values.

And let say two blocks are joined this is c 1 side this is c 2 side then this diffusion path will look like this. And from the point from that boundary condition for example, x equal to 0, t equal to t, or x equal to x, t equal to 0, all those boundary conditions we can use to get to the knowledge of A and B. And try to find out how long it takes for example, in case of carburization, how long it would take for a particular condition to have let say a 50 micron case depth of carburize layer.

Or when you do heat treatment in furnace there will be always a possibility of decarburization in case of steel. And if we keep let say 900 degree Celsius a particular steel composition a particular carbon percentage, we keep it for a certain time we can also calculate what is the decarburization case depth solving this equation. So, this one also we looked at in our previous lecture. So, now since we have done the recap of what we have done in our last phase - phase-one, it will be now easy for us to go to the next phase.

So, in our next lecture onward we will start looking at what we will be doing in our next phase; that means this phase which is phase-2.

Thank you very much.