Phase Transformation in Materials
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Lecture – 37
Precipitation Age- Hardening Alloy (cont.)

So, let us continue our discussion on precipitation hardening aluminium copper alloys. I have already discussed with you about the structure free energy, as well as the sequence of the phase transformation in the aluminium copper alloy. As you know if I artificially age aluminium copper alloy, first phase which forms from the super, such as solid solution will basically G P zones, and then it followed by theta double prime theta prime and finally, theta. So, people have actually measured the hardness as a function of ageing time to understand what actually happens.

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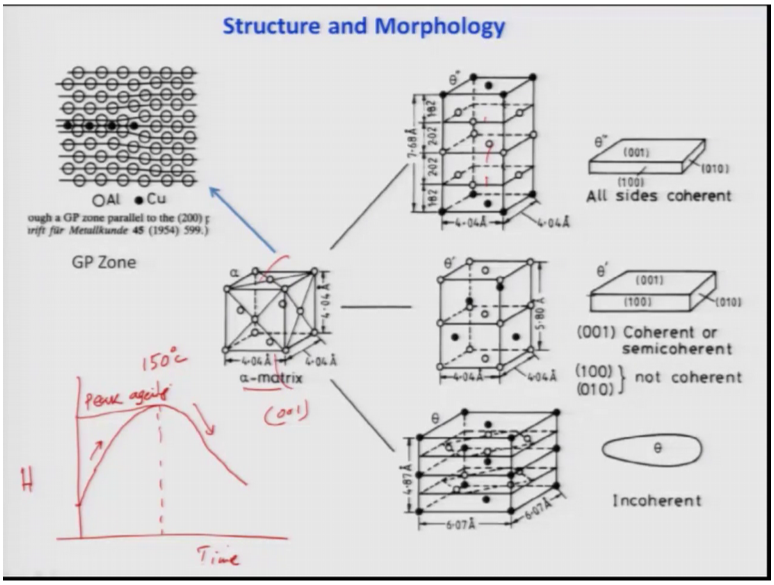

Say if I plot hardness is nothing, but an important mechanical property which characterizes a strength. So, suppose if this is my strength of the initial special as solid solution, and as the ageing time goes on, it has been found that hardness of the alloy goes on increases. This is the maximum value and in decreases. So, this kind of curve which is nothing, but a hardness of the aged alloy at, suppose 150 degree Celsius time for a schematically, is known as the ageing curve hardness seriously increases, this is a maximum then decreases. So, initially increases, because basically, because of the formation of the G P zones, and theta prime theta double prime.

So, because they are coherent precipitates. So, the matrix coherent in all along crystal of a directions. Therefore, if a dislocation has to move through these to cause deformation in the phase, in the alloy, it has to basically cross huge barrier, because of the coherency nature of the precipitates. And once theta double prime starts transforming to theta prime and theta, the coherency is slowly getting lost between the precipitate, and then early matrix. And because of that the hardness decreases, because once the coherency loss dislocation can easily cut the precipitates and move, but when it is coherent, dislocation has to use or once mechanism for it to cross over. So, because of that the hardness decrease here, hardness increases there.

So, this is very important. So, therefore, in industrial alloys if you want to make it proper heat treatment of the industrial aluminium copper alloys. You must heat it in such way that we form theta double prime, more large numbers in the micro structure. So, the strength this very high, and that is what actually happens initial the values, what I have shown you in the earliest slides, basically corresponding to the peak age sample. The sample which has the maximum value of hardness, and this is known as peak ageing. Remember this is artificial ageing why, because we are heating it to higher temperatures after quenching the sample.

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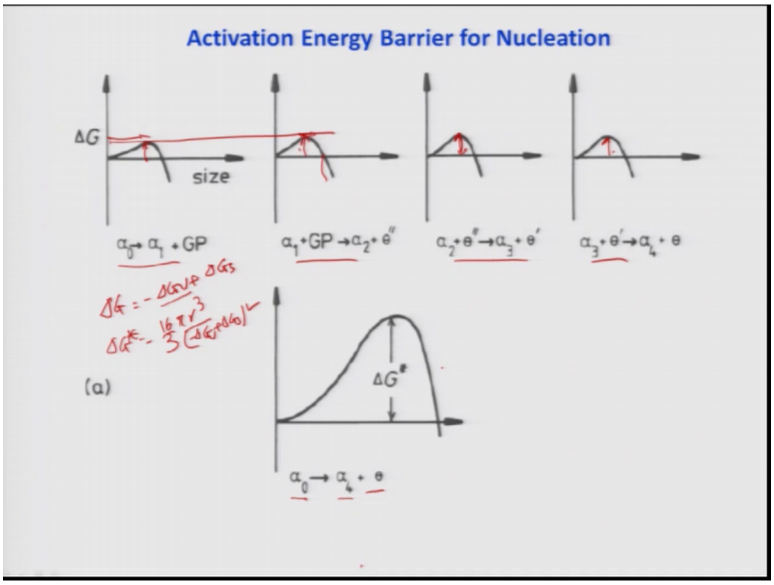

Now, how the transformation actually happens, is basically happens, because of sequence of precipitations. Why the sequence of precipitations takes place that I have already discussed. That mainly, because of the activation energy barrier for the nucleation fairing actually go from G P zones to theta.

Schematically this slide shows you that, if you see this is delta G as a functional size, G P zones have a very small size right. There are very small and there basically sheets of copper layers on the aluminium alpha phase. So, because of that the barrier is very low, because the matrix is coherent with the precipitates, and strain is also low, because only few layers of copper, that barrier is very low, because delta G is nothing, but minus delta G V plus delta G strain, as you know this delta G V is basically comes from chemical free energy change, and delta G as specifically coming from strain. We want to have a more negative delta G V for the activation barrier reduce, because activation barrier delta G star is nothing, but 16 by 3 pi R pi gamma cube divided by delta G V minus plus delta G S square.

So, as you see here the gamma has a strong roll, because gamma cube gamma is the interfacial energy between the precipitate the matrix. So, gamma for the G P zones is very low, because every matrix is the precipitates, where complete coherent to the matrix; such as the ideal situation you can think about it. On the other hand delta G B minus is also high, and this value minus delta G V plus delta G S is high, because delta G S is small strain is very small in G P zones, because of that delta G star is slow at delta G star, is the activation barrier for the nucleation, but as you go from G P zones to theta double prime, it will, there will be a slight increase of the activation barrier is, you see here this is slight increase, but not much, basically is size is increase, but the activation barrier has not changed drastically is very minute change.

This obvious, because again theta double prime is coherent, only thing which could have changed with normally, we can change is, basically strain energy, which is little higher, because of the presence of the copper atoms. More logically, it represent or more specifically represent in the crystal, but on the other hand if you look at theta, theta prime activation, energy is high correct; that is very high, and slowly it is increasing. Sorry step wise correct. So, if you have to add these and these to obtain this one, although it is not shown schematically. So, finally, total energy change is basically each of these together this, plus this plus this plus this. So, that is what actually happens on the sequential transformation happens, and this is the reason why the sequential transformation written, because the energy change, it happens in the sequential manner not in one step.

It has to happen in one step, the energy barrier is very high, you see here alpha 0 going to alpha 4 plus theta. So, precipitation of theta energy, the activation barrier for nucleation is pretty high, and this is not desirable in a solid state phase transformation, because energetically they are very demanding, and because of that, this direct transformation is never observes in the alloys.

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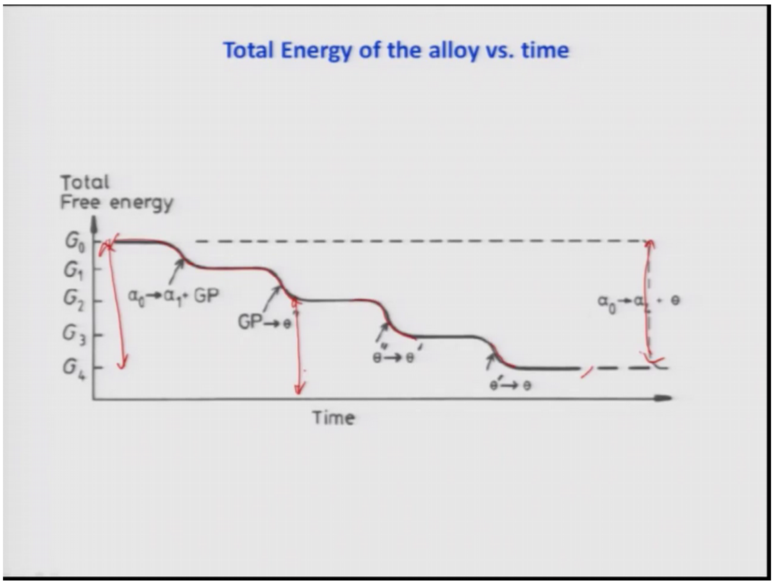

And again I am showing you total free energy versus time is, you see here if it has to change G 0 to G 4; that is the total free energy change, but it happens in the slow manner. First it decreases this much from the G P zones, then A decreases this much to, form theta double prime, then it decreases this much to from theta prime, and theta. On the other hand as you shown here, total energy changes, if you want change alpha to theta alpha generate to theta is very high ok.

So, therefore, system behaves in a logical manner; that is what I have been telling, that in transform in a sequence from G P theta is form alpha zero to theta, and we can actually control that. We can stop or heat treatment here, then we will have only theta double prime in the microstructure, and some amount of G P zones will be present; obviously,. So, this give us the best combination of the mechanical property is hardness on the strength. Hardness strength also ductility, because theta double prime in G P zones is completely coherent. So, hardness will be high, and because of that this is a very useful. Remember all the plane bodies for the commercial aircrafts, there are actually aluminium copper alloys in which these precipitations are directly used, to create high strength; that is one part.

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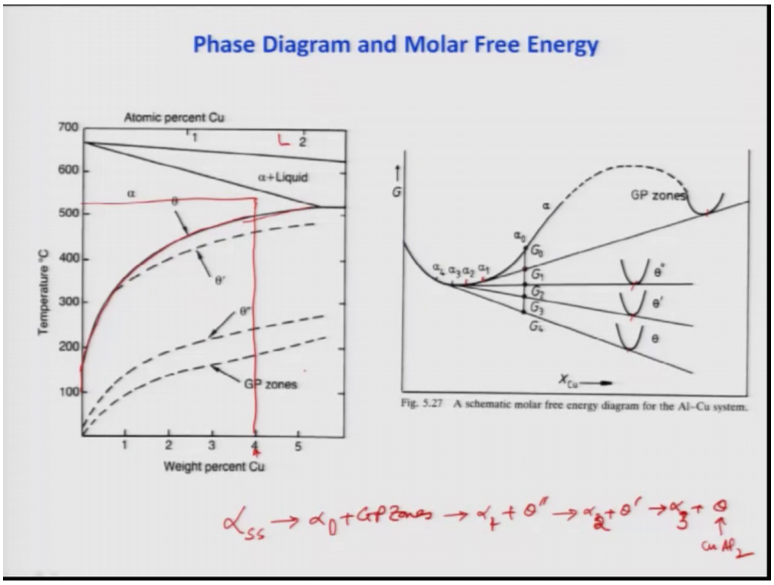

Now, I just want to go back and discuss with you some more things about this precipitations. As I said G P zones actually can form in a very logical manner, we can actually generate this using this data. We can actually generate a time temperature curve, and let us do that. This is their actually on the phase diagram. First I will do the phase diagram, and then I will draw the rest of the things to show you how things actually happen.

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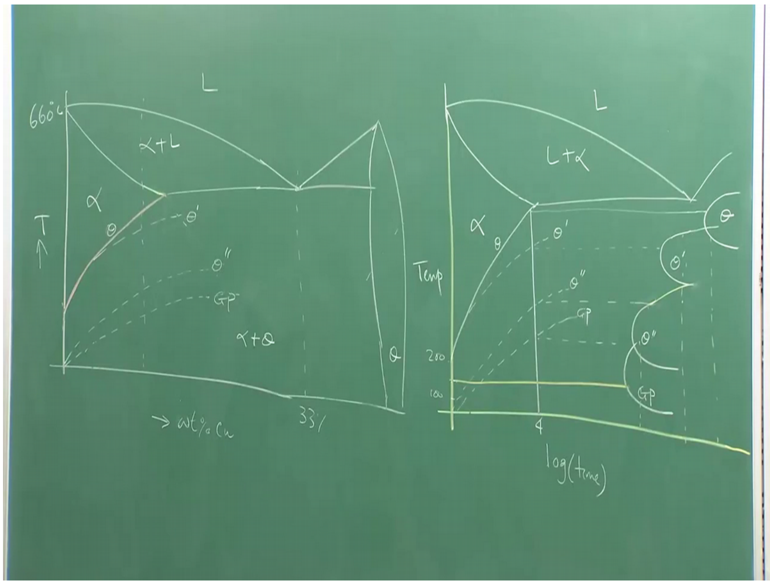

So, let me just do it on the board. So, as we have seen in the phase diagram looks like this. This is 660 degree Celsius, because this aluminium alloy temperature, and this is weight percent copper and we are not drawing it.

Let me show you that, as you have seen that, actually this looks like the phase diagram, looks like little bit like this. So, this is basically theta solvus, basically there is eutectic reaction here this much higher, and there is, and this is theta actually. So, ideally speaking this will be alpha plus theta, but our always will be all less than these values. So, 4.4 percentage. So, therefore, this is theta and theta double prime. So, theta prime will be this one, the solvus line, you can see clearly see that, and similarly we can actually draw solvus line for theta double prime and solvus line for the.

This is a solvus. Let me just draw it very carefully, and showing why it is solvus, because it shows you the solid solubility of copper as a function of time in the alpha phase. You see here its decreasing continuously. So, because this phases theta prime G P zones, there are actually meta stable. So, you show them by dotted lines in the phase diagram. Now these are the solvus for that. So, therefore, if I have to draw the whole phase diagram, now this because this has shifted. So, everything will shift.

So; that means, this will shift like this. You see here this, this line will shift like that. So, similarly we can actually shifted within and do that. So, this will also shift into this, and become like that. So, which, normally it is not shown in the books. So, may does not do that, but kindly speaking this is how it will look like. So, these dotted lines tells you how the precipitation happens in the alloys. Now using this data we can actually make time temperature plot. This is temperature, this is log time at, this is known as basically T T T curve in the literature that will discuss much detail in the,, because of steel.

But here it is basically ageing curve. Now how I am going to draw it. Please look at carefully; first I have built on this things, these dia, these thing, these phase diagram. So, I will just take the phase diagram directly from it. So, this is my alpha and then one can draw it. It does not matter whether you keep it or not, and let me just then draw theta. This is theta, this is theta prime, theta double prime correct, and then this is G P zone. Now if you simply draw the vertical line at about 4 percentage copper. Remember this vertical line, although this axis is time, but we can actually transpose this things into here. So, what I will do now.

So; obviously, for the theta, this is the T T T curve. So, it will look like A C separate, and this is theta correct. Then this is for the theta prime, this is for the theta double prime. Theta double prime will be something like that, and for this G P zone. So, as you clearly see here, if I heat the sample at about say this is about 200. So, 150 degree Celsius and this is 100, something like 100, this is 150, if I do that first thing, first phase which will form, which is the G P zone, because I am increasing the time.

So, if first it will heat the G P, it will heat here, from the G P zone. Then if you heated temperature, if you increase the time more slowly, slowly this phase will start appearing. As you see here, this phases are connected the, this diagrams are connected. So, slowly theta double prime theta prime and finally, theta will appear from longer time duration. So, depending on our use, depending on the our need, we can actually stop the heat, any time, as very clear that we can never have single precipitate at any time, except a very high temperature, very high time, when theta will completely form out of the this sequence, but if I stop, here will have a mixture of theta prime double prime in G P zones. If I stop there will have mixture of Z P zones plus theta double prime, and theta. If I stop, there will have a mixture of Z P zones theta double prime theta prime and (Refer Time: 16:03) of theta.

So, simply by doing our heating mean cycle; that is by simply adopting temperature and time properly, basically temperature we do not change, first a time, we can actually have combinations of different mixtures of the phases in the microstructures, and by doing so we can actually create different mechanical properties. We can actually get different mechanical properties create different microstructures, and get that; that is what is the major advantage of these alloys aluminium copper alloys. You can actually do lot of different types of heat treatments, and to improve their properties of, to get different combinations of the mechanical properties is possible to do that. So, simply by this, this things are available, normally to the people who are working in the industry, these diagrams and they can I choose. They will have values written here, also they can actually choose the time scale required at different temperatures by 100 150 and get. Thus the precipitates in phases combinations differently depending on the need.

So; obviously, as you seen only getting G P zones will not give the best properties, you must have a combinations of theta double prime, and G P zones in the microstructure. So, depending on your need one, we can actually choose different heat treatment cycles; this is very important in the. So, you can remember this is an eutectic. Alloy is another important aspect I should discuss this is an eutectic alloy. Normally this about 33 percentage of weight percent of copper with about 67 percent of the aluminium provides you eutectic between alpha and theta. So, all this alloys, although it looks like that if I have a about 4 to 4.5 percent copper alloys, small amount to be eutectic is present in this alloys.

So, very difficult to stop that, because when they are actually continuous, this solidified from the liquid, this. Although it looks like that this will have a single alpha phase, but because of the coding, because of the coding in the, then you continues solidification. There will be always some liquid leftover at the end, and this liquid as a copper reject into liquid. This liquid will have a very high comp copper concentrations, and that is the one of the problem in this alloys, because of that some eutectic will be anywhere, will be present, and this eutectics many cases actually creates in heat treatment, because all the heat treatment temperature is very low. Eutectic will not upgrade, affected, but the presence of the eutectic will hamper the mechanical properties, and that is why one has to be very clear about choosing the alloy compositions.

One should not choose a alloy composition which is very close to this point, is about 5.5 percentage of the copper. So, that is the reason actually 4 is optimally swished copper concentration in this alloy, and that is what I have been discussing with you for the last one hour. So, it is very clear that by simply you know, by simply looking at these precipitates one can do that, and this book has real descriptions of these micro structures nicely done, and you can actually look at. In fact, it is possible to series microstructure nicely in this books, which is required for you to understand how these precipitates form.

Remember this precipitates actually very small size, and they can only viewed under transmission electro microscope, and not only that, because of the crystallographic nature which I discussed with you last lecture. They must be seen under electron electro microscope. So, that is actually about this precipitates, and remember there are other precipitates as I shown you. Like in the first few slides; like aluminium copper magnesium or aluminium silver. Also I have shown you some, sometime right the aluminium silver here. So, we will discuss some part of the aluminium silver alloys in the next lecture, which is, and then wind it up this particular chapter, but you know these sequence of precipitation, which I shown you sometime, gets affected by the size of precipitates. If you are actually keeping the sample at a certain temperature for long time. Let us suppose I will keep it in some of the precipitates will go bigger, and once they become bigger, they will again double up the size, dependent in coherence in the ma,t in the interface and that is boils the property.

So, therefore, size control is also be very important in this alloys. Let us stop here. So, once we discuss, we will discuss some beta with the aluminium silver alloys, which is also classical system, but never use, because of the cost, because silver is very expensive compared to copper, but it is a very classical system in which less sequence is present.

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Table 5.2 Some Precipitation-Hardening Sequences

(Mainly from J.W. Martin, *Precipitation Hardening*, Pergamon Press, Oxford, 1968.)

Base metal	Alloy	Precipitation sequence
Aluminium	Al–Ag	GPZ (spheres) → γ' (plates) → γ (Ag_2Al)
	Al–Cu	GPZ (discs) → θ'' (discs) → θ' (plates) → θ ($CuAl_2$)
	Al–Cu–Mg	GPZ (rods) → S' (laths) → S ($CuMgAl_2$) (laths)
	Al–Zn–Mg	GPZ (spheres) → η' (plates) → η ($MgZn_2$) (plates or rods)
	Al–Mg–Si	GPZ (rods) → β' (rods) → β(Mg_2Si) (plates)
Copper	Cu–Be	GPZ (discs) → γ' → γ (CuBe)
	Cu–Co	GPZ (spheres) → β (Co) (plates)
Iron	Fe–C	ε-carbide (discs) → Fe_3C (plates)
	Fe–N	α'' (discs) → Fe_4N
Nickel	Ni–Cr–Ti–Al	γ' (cubes or spheres)

You have only G P zones and theta in gamma prime; that is all and then gamma is the equilibrium phase, which is nothing, but l 2 H to be l is same as like C u l 2, but it has different structures, not the same as these structures we will discuss about that.