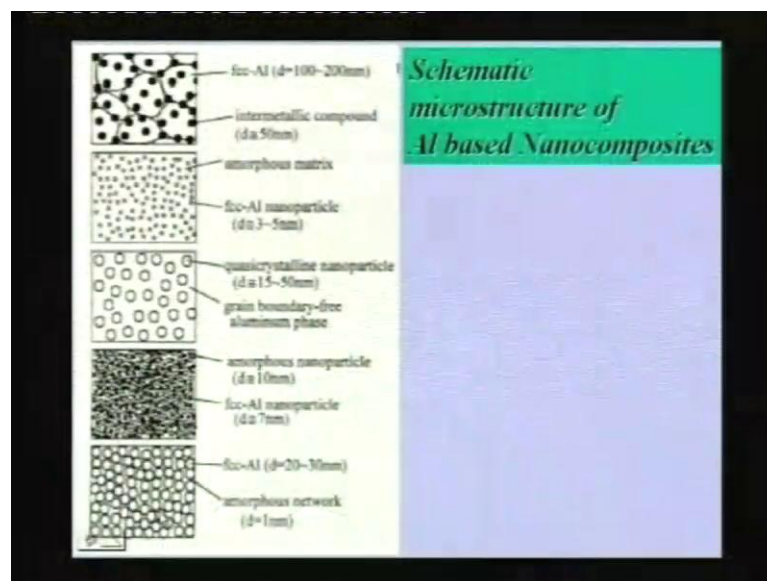


Advanced Materials and Processes
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Lecture - 18
Advanced Al Alloys Part – I

We were talking about the various nano composites, in aluminum based alloys. I have showed you some of the possibilities of these nano composites in this view graph.

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And most of these types of nano composites are made by two methods either by rapid solidification processing, or by mechanical alloy, because these are the two non-equilibrium processes, which are easily available for most of the metallurgist. So, mostly people use any of these two techniques. And when you talk in terms of FCC aluminum, with some inter metallic composite as nano particles, precipitated in aluminum matrix.

This kind of phase can be easily obtained, by first generating a super saturated solid solution. For example, we know every system, there is a solubility limit at room temperature. Beyond which under equilibrium conditions is precipitates suppose to come out. And in most of the systems, particularly aluminum base systems, the solubility is very restricted at room temperature.

Even if you take aluminum copper also, the solubility at room temperature is very low, 0.5 or something like that. And in most of the other aluminum alloys, it is very much

restricted. And even the maximum solubility also, is very small in many aluminum alloys. In copper, it is about 5.56 we have seen, but if you look at many high temperature alloys. What I mean by high temperature alloys is, most of the people know, that aluminum copper alloys that cannot be used that temperature.

The moment you go to around 300 degree or so. You have either precipitates coarsening, or precipitates dissolution technique place. Depending all the alloy composition, that you are choosing. So, as a result you can really go to high temperatures in this. So, what is the best way to go to high temperatures, in a aluminum alloys; to bring new alloys, where the solute element as a very high melting point.

One such examples are aluminum titanium alloys. People want to put elements, such as titanium, zirconium, hafnium. All this kinds of elements or even iron for that matter, iron as such higher melting point than copper. So, if you iron into aluminum, you can have the overall diffusivity of these alloying elements. In the aluminum being very low, than precipitation coarsening is going to be very difficult. And precipitate dissolution is also going to be more difficult.

As a result you can have precipitates, strengthening to higher temperatures. One can improve what is called high temperature strength of these alloys, by adding the alloying element which have melting points. So, that was one of the basic alloy design criteria, in developing newer aluminum alloys. And people have develop, for example aluminum iron, vanadium, silicon alloy is one of the very popular alloy, where people are all working on.

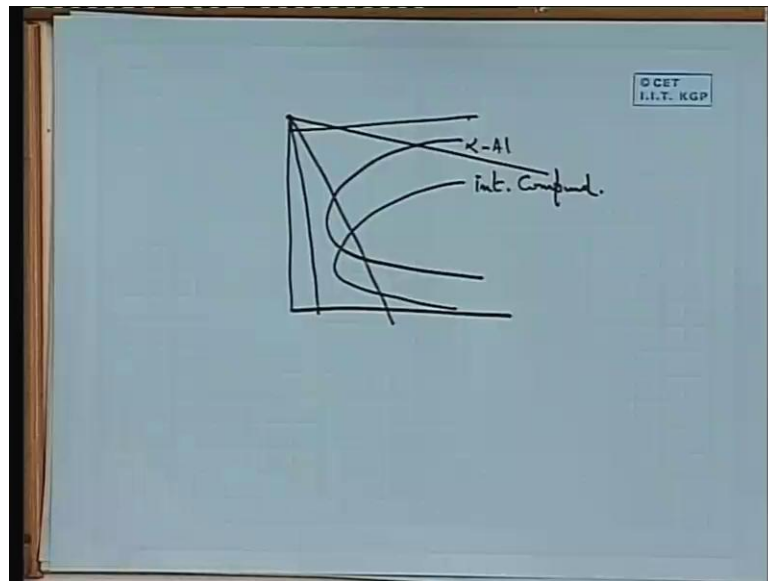
So, for example, iron, vanadium, silicon all of them are the high melting elements. So, when you put them into aluminum, and get precipitates out of this. For example, aluminum iron you get a Al_3Fe , aluminum vanadium again you have $Al_{11}V$ precipitates. And even Al_3V also possible, under some metastable conditions. And silicon any way gives precipitate strengthening, I mean silicon particles come out. So, can give you strengthening.

So, like that when you have this kind of alloy, people have been able to get much higher strengths. So, all this kind of alloys can be melted and in the liquid state we all know that, all of them are soluble. So, if you can have high solubility in the liquid state. So, dissolve all these elements in the liquid state, and then cool it rapidly. So, that you get

ultimately a super saturated solid solution. Solutions having higher solute atoms dissolved in aluminum.

And now start doing age hardening, so that you can precipitates. And that is how you can get this kind of intermetallic. And produce intermetallics like that. One can also do it directly by rapid solidification, by choosing a proper combination of cooling rates. For example, if you talk into terms of CCT diagrams or TTT diagrams.

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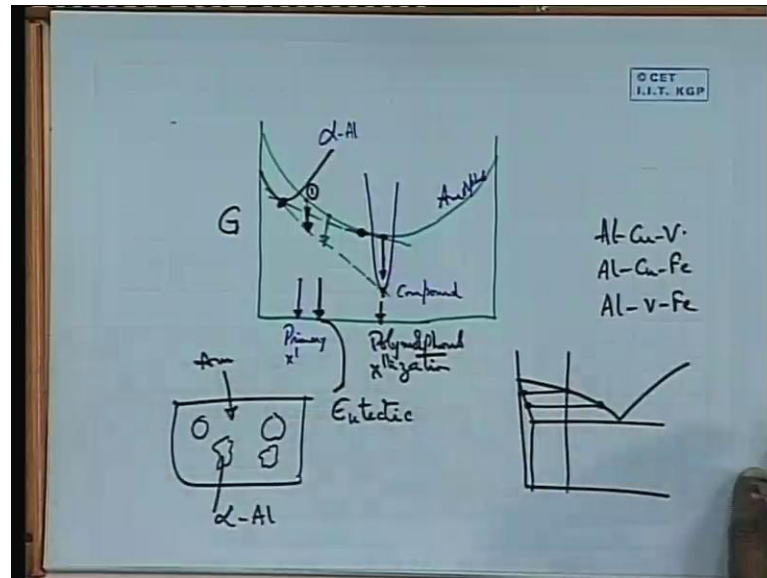


For example, if you look at this, if you think of alpha aluminum as like this. And if you another intermetallic compound, like this. If you are taking a liquid aluminum, and then cooling, you can choose a proper cooling rate, if you cool it very slowly, you may end up in alpha aluminum. Because, that is easiest to nucleate in a aluminum alloy, because alpha aluminum is nothing but FCC aluminum. So, very easy to nucleate and whereas, inter metallic compounds to nucleate is much more difficult.

So, but if you can have a cooling rate something like this. You can have a combination of aluminum. So, initially aluminum comes out the remaining liquid, which is there will come out as some of the intermetallic compound particles. So, that you can have these particles distributed in a aluminum matrix. So, otherwise one can also cool it slightly, slowly get a super saturated solid solution of aluminum. And then precipitate it by ageing, that also one can do it.

And in addition, if one cools it very rapidly, get an amorphous phase. And start crystallizing this amorphous phase. And when you crystallize this amorphous phase, depending on the composition that, you chose you can have various possibilities.

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For example, if the composition of the amorphous phase, is exactly same as that of the a compound, which is possible in that system. You will see that, amorphous phase transform to the compound, by what is called polymorphous crystallization. So, this what is called polymorphous crystallization, where the composition remains the same. This is one type of crystallization process, for the amorphous alloy.

And that can lead to a number of inter metallic compounds. Depending on the alloy composition, that you are choosing. And these components, if you can control the temperature and time of your ageing treatment. You can have very fine precipitates of this intermetallic coming out. And can give you what is called nano composite, within amorphous matrix. And intermetallic, nano intermetallic distributed in amorphous matrix.

And if you do that transmission complete. That amorphous matrix can finally, transform to either alpha aluminum. Or if it is polymorphous transmission, completely all the amorphous phase transform to a nano intermetallic. There will not be any composite here finally. It is only one single phase, because it is polymorphous crystallization. But, all this grains of this intermetallic will be much finer.

So that, you can have fine inter metallic. But, mostly people are not really happy with this kind of single phase micro structure. Now, a days most of the people, do not want single phase micro structure. Particularly single phase microstructures of intermetallic, because intermetallic are brittle. So, everybody wants composites, nano composites. So, that you can get the combination of both the, I mean high ductility of the matrix, such as alpha aluminum.

And the high strength of the inter metallic. And they being very fine, you can have additional advantage of being a nano material. So that, you can have good combination strength and ductility. So, that is advantages of these nano composites. So, everybody want to go for that kind of composite. How do you get that, one possibility is what is called, primary crystallization.

That means, if you chose your alloy composition, such that what is give here. Let say alloy number 1, if you chose that alloy number 1. So, the amorphous phase which is shown here, these all basically what we are drawing is free energy composition diagram. So, the curve that reshow here, is a free energy curve from amorphous phase. And the free energy curve from alpha aluminum. And the free energy curve from inter metallic compound, that is what we have show here.

This intermetallic compound, can be in crystalline or quasicrystalline. If it is a quasicrystalline, then a quasicrystal, nano quasicrystal particles come out of the amorphous phase, by polymorphous crystallization process. There are examples, for example such as aluminum copper vanadium kind of alloys; where amorphous material can be by made by rapid solidification. And if you start heating it, the quasi crystal will come out of on that amorphous phase.

And there also examples, such as aluminum copper iron. A number of such examples, there is also example, I will show you is aluminum vanadium iron. Mostly aluminum transitional metal kind of systems. So, if you choose aluminum transitional metal kind of systems, you will have this kind of possibilities. That if you have cool it very rapidly. you get amorphous phase and start heating it. Because, in these systems, what I told you before are the Frank-Kasper phases.

There are certain systems, such as aluminum copper iron, aluminum copper vanadium, aluminum iron vanadium. These kind systems, the Frank-Kasper phase do exist in the phase diagram. And because of which, the possibility of formation of quasicrystal in

phase, is much easier in these alloys. So, that is one possibility, either polymorphous crystallization to crystalline intermetallic compounds. All polymorphous crystallization to quasicrystalline intermetallic compounds.

Or if you are alloy composition slightly off the composition, you can have crystallization of these intermetallic or quasicrystals. To give you what is called nano composite. That you have an amorphous matrix, into which you have a quasi crystalline particle, or an intermetallic particle. If the composition is not exactly same as the intermetallic compound composition, but if the amorphous phase composition is slightly off, then you will not have 100 percent single phase intermetallic coming out.

But, you will have some amount of amorphous phase will be left out. If the composition of the intermetallic, and if the composition of the amorphous phase are not exactly the same. If they are exactly the same, then you can have perfect polymorphous crystallization taking place. If they are not the same; obviously, mass balance cannot be maintained, if you want to have 100 percent of the second phase coming out. Because, the composition is different, so that is one possibility. The second possibility is what is called primary crystallization; where you have amorphous alloy it is composition, is close to that of the alpha aluminum composition. Because of which alpha aluminum can easily nucleate, from the amorphous matrix.

So, will have amorphous matrix, into which an alpha aluminum. may be dendrites of alpha aluminum or nano particles of alpha aluminum, depending on the nucleation rate. That is available, which is a function of the under cooling that you are providing. You can have this kind of possibility. This is possible, either directly during rapid solidification. As I told you before, or you can have during the after the amorphous phase has formed one can crystallize. So, this what is called primary crystallization.

And the other possibility is what is called, eutectic crystallization. Primary crystallization you have to remember one thing. That the moment the alpha aluminum comes out, you can see from this common tangent. The moment alpha aluminum comes out, you have to draw tangent a between alpha aluminum, and amorphous phase. Because, there is an amorphous phase, which is here.

This is the amorphous phase, in which the alpha aluminum has come out. And we know the alpha aluminum composition, is different from that of the amorphous phase. Otherwise, we do not call it as primary crystallization. What is the meaning of primary

crystallization? The primary crystals that are coming out, have a different composition than that of the amorphous phase. This is similar to our for example, if you look at a hypo eutectic alloy, solidifying.

You take a hypo eutectic, what is the one that comes out first, that is the alpha phase. The alpha phase has a composition, which is different from that of the liquid composition. So, as a result, usually it is rich in the what is called the solvent. So, if it is rich in the solvent, the liquid becomes richer in the solute, because the composition of the liquid will change. So, you will have a mixture of alpha aluminum and liquid; liquid having a different composition than that of the alpha aluminum.

This is what happens exactly, if you look at the, let us say this is the composition that we are thinking. So, this is the starting composition of that. And the starting alpha aluminum coming out will have a composition like this. And after you come some lower temperature, you will see the alpha aluminum composition is this. And the liquid composition is this.

Why, because the alpha which is mostly rich in A atoms, has come out of the liquid as a result. The liquid becomes richer in B atoms. All the A atoms are coming out of the liquid. So, what happens is the A atoms get depleted in the liquid, so it becomes richer in B atoms. Exactly similarly here, if you take amorphous phase from which an alpha aluminum comes out. That amorphous phase, which is remaining will have a composition, which is given by this, common tangent.

If you look at this is the alpha aluminum composition, this is the remaining amorphous composition. So, now you have a nano composite; where an amorphous matrix is there, whose composition is this, and an alpha aluminum whose composition is this. So, you will have that kind of a situation. But, that situation is not the lowest free energy situation, is it not. Because, the amorphous phase, is never a stable phase.

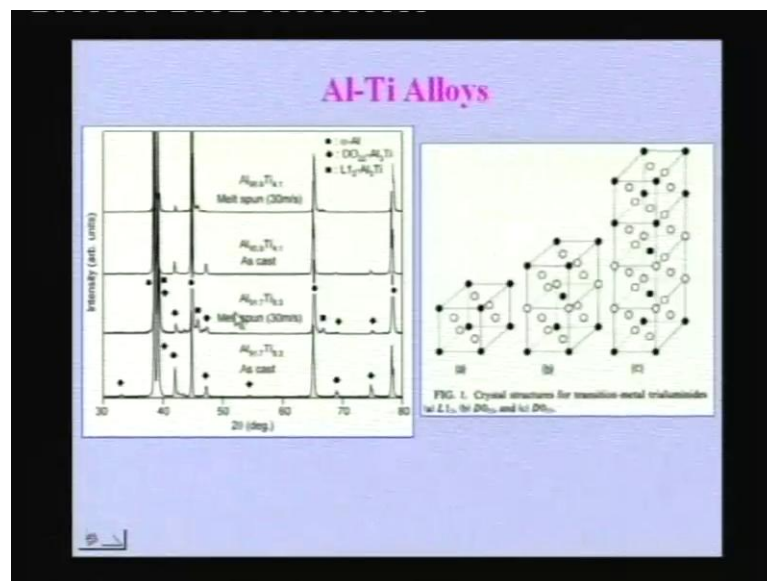
If you hold it for long period, that amorphous phase has to transform to something. And usually in most of these systems, there are certain intermetallic compounds, do exist in the system. And the lowest free energy situation, is the combination of the alpha aluminum and the intermetallic compound. That is the lowest free energy. So, as a result you can see this phase, further transforms.

Initial by primary crystallization alpha aluminum can come out. And further, if you hold it longer period at higher temperature, or at the same temperature for the longer period. Ultimately the remaining amorphous phase, whose composition is close to that of the intermetallic compound, will give you that intermetallic compound. So, that you will have a now a combination of alpha aluminum plus the intermetallic compound. That is final microstructure.

And this microstructure can have, very fine precipitate of the intermetallic compound. If you control the nucleation rate of this temperature and time, they are controlled properly, and if the composition is controlled properly. So that, you can get a fine nano composite of alpha aluminum in and intermetallic, this is one possibility. The third possibility is directly the amorphous phase, gives you a combination of alpha aluminum plus intermetallic.

This is what is similar to a eutectic kind of reaction. Liquid gives you alpha plus some other second phase. So, this is called eutectic crystallization. But, eutectic crystallization has much higher activation barrier, than either polymorphous crystallization; or the primary crystallization. Because, two phase have to nucleate. And interphase energies of these two phases have to be consider. So, usually eutectic crystallization is more difficult process. So, there are all the various possibilities of crystallization, and that can lead to this kind of microstructures, a number of inter metallic compound. Let us try to look at some examples.

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One such example is aluminum titanium alloys. Aluminum titanium alloys, particularly if you look at aluminum rich side of aluminum titanium alloys. On the aluminum rich side of the aluminum titanium phase diagram, you have one intermetallic compound called Al_3Ti , which has about 75 percent atomic percent of aluminum, and 25 percent of titanium unit.

And this Al_3Ti under equilibrium conditions, has a structure, which is like this DO_{22} structure, it is called B crystal structure, that you are seeing here. It is mostly, if you look at the first structure, which is A it is called to L 1 2 structure. This is nothing but the FCC type of structure, where all the body corners are occupied by one type of atoms. And phase centers are occupied by the another type of atom. And that is what is called L 1 2 structure.

And the DO_{22} is similar L 1 2 to accepting that, there are two such unit cells of this. And because of that, you can see that you have an atom, belonging to the body corners. Atoms of, one type of atoms are at all the body corners. And other time of atoms are all at the phase centers. And that is what is called the DO_{22} . And because of which the actual lattice, if you look at it this whole thing is 1 unit cell.

And because this whole thing is 1 unit cell, you will have the c-axis, much longer than the a-axis. And that is what makes it tetragonal type of structure. And this tetragonal structure makes the alloy more brittle. So, the DO_{22} structure is more brittle than the L 1 2 structure. So, if you have Al_3Ti particles with this DO_{22} structure, in an aluminum matrix, you are not going to get very high ductility. The alloys is going to become brittle. So, there is lot of interest nowadays, many people want to see how to make this Al_3Ti into a cubic structure.

Because, there is lot of correlation between these two. So, one can think of some possibilities by which one can make this kind of thing, and people have found out, that if can have a certain ternary element, we can stabilize the L 1 2 type of structure. In fact, this kind of stabilization, we know from steels that we always add different alloying elements, to stabilize either ferrite or austenite or carbides. All kinds of stabilizers we know.

And we know that if you adds certain alloying elements, which have similar crystal structure, that of the parent phase. There is possibility of the that particular structure being stabilize. So, if we want a austenite to be stabilize, you add some FCC elements. If

you want a ferrite to be a stabilize, you add some BCC elements. Similarly, in some of these intermetallic compounds, if you add certain elements.

For example, chromium, manganese, copper, nickel. These are all the elements which people know, which can stabilize the L 1 2 structure. So, people try to add these elements. And to see, if they you can be stabilize, a number of people have worked on this. But, in addition one can also even without adding any element, if you do rapid solidification. One can get the L 1 2 structure.

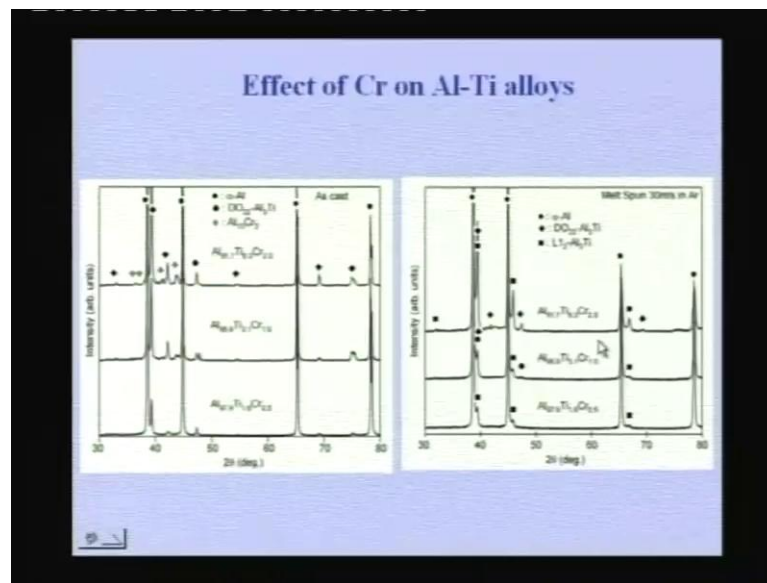
Why, because when you are rapidly solidifying, you are not providing sufficient time. So, the phase that comes out will that which has a similar crystal structure as that of the matrix phase. What is the matrix here, it is the aluminum matrix, aluminum is FCC. So, the L 1 2 phase, whose structure is similar to that of the FCC aluminum. That can easily come out than the DO₂₂ structure, which is the body centered tetragonal type of structure.

So, if you look at this various aluminum alloys, with about 4 percent titanium; and about 8 percent titanium. Two different alloys as have been shown here. One is as cast structure. If you look at the As cast structure, you have nothing but aluminum peaks, and the peaks which are in between here. These are nothing but they DO₂₂ Al₃Ti peaks. And if you cool this alloy rapidly, you start getting a peak here, which is the L 1 2 peak.

L 1 2 peak is FCC type of peak. So, always you will have that peak very closed to the FCC aluminum peaks. So, will have the FCC ordered, FCC L 1 2 peak, always coming next to the FCC aluminum peaks. Because, there it is also FCC, it will have similar peaks. So, that is why you can see in this alloy. And particularly, if you go to higher titanium, you will more volume fractional of this phase coming out.

That is why the peak becomes more strong. So, that is why, you can see, if you take As cast you will have only aluminum plus the BCT Al₃Ti. But, if do melts spinning you will have this phase. But, you can still see some amount of DO₂₂ still remains. So, you cannot completely surface, at this particular cooling rate. May be if you go to much higher cooling rate, one can probably surface this or if you add certain alloying elements, possibilities is more easy.

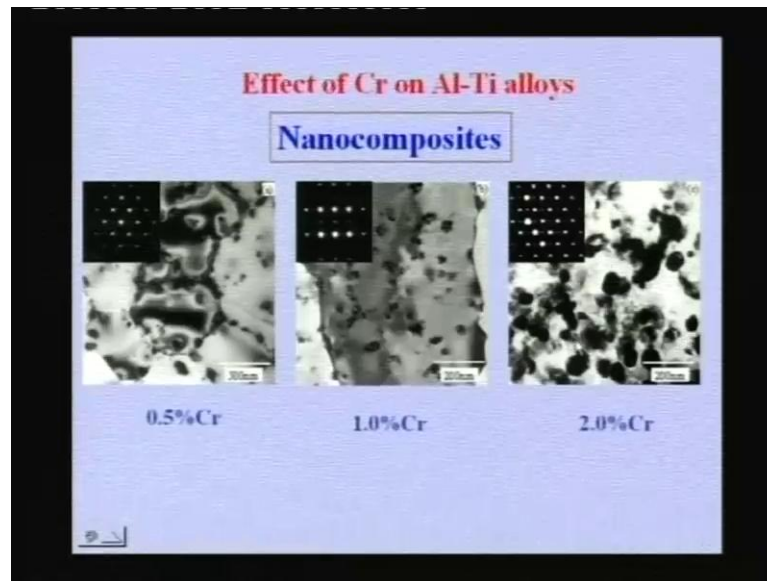
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So, people try to do alloying elements. Once such thing is chromium here, if you can look at this, if you take the As cast alloys. As cast means, just make alloy without any rapid solidification. Just add these alloying elements to it, cast it. Melt it and cast it under normal conditions. If you do it, you will see basically the alpha aluminum plus the DO₂₂ Al₃Ti. And some amount of at higher chromium content, you will get aluminum chromium intermetallic compounds.

And the same alloy, if it is cool rapidly, you can see 0.5 chromium, 1 chromium and 2 chromium. Different amount of chromium is added in to it. And you start seeing that, this peak which is adjacent to this aluminum. And that peak is a Al₃Ti, L₁₂ phase peak and that peak amount keeps on increasing, if you increase the copper content.

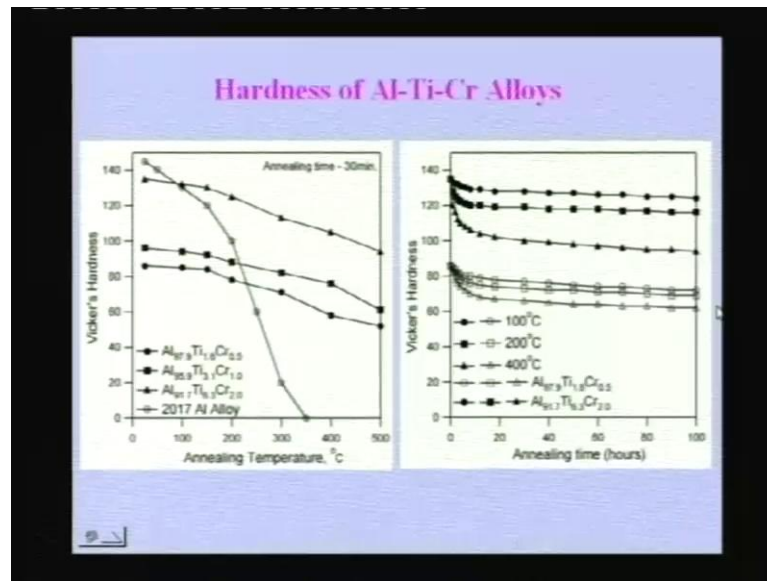
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And if you want to confirm this, you go to the tem. And one can look at this alloys. And these are basically the aluminum grains, in which a small precipitates, more are less spherical precipitates of Al_3Ti L 1 2 phase, how do you now it is L 1 2. You can see this ordered reflections, which are the faint small dots that you are seeing which confirm. And even in this also you can see, the hexagonal arrangement of atoms in the lattice these diffraction spots. And into which you see this faint spots here, which tell you that it is the FCC ordered structure.

So, one can look at this ordered reflections, which are we know in x-ray also. Whenever, there is ordered structure you get super lattice reflections. And super lattice reflections always have a lower intensity, than the fundamental reflection. That is what exactly you are seeing here. And you can see nice spherical particles of the order of around 20 to 30 nano meter particles, in an aluminum matrix.

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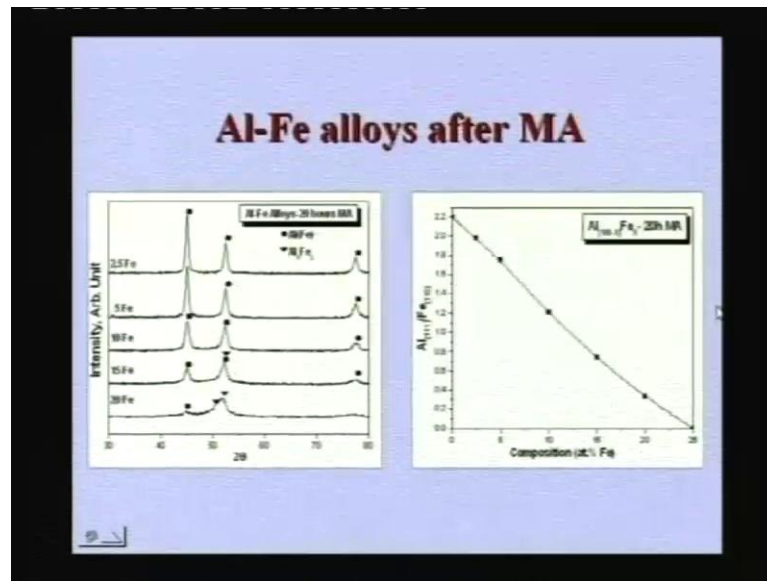


And this gives you strengths, which are higher than the conventional aluminum alloys. Particularly at high temperatures, if you take conventional 2017 type of alloy, which is aluminum copper alloy. It loses its strength rapidly, as you increase the temperature. And whereas these alloys can retain the strength to a much higher temperature, basically because these Al_3Ti particles do not dissolve back into the matrix.

That is one interesting thing in these particles. That their solubility limit of titanium in aluminum, maximum solubility limit is very small, if you look at the aluminum-titanium phase diagram. So, because the maximum solubility limit is very small, the dissolution of these particles does not occur. In fact, even when you melt this alloy, the Al_3Ti particles will remain in the liquid.

So, you have that kind of situation that you have high melting intermetallic particles, which do not dissolve back. And which are in a nano-crystalline state, and which gives much higher strength at high temperature. And you can also study at various temperatures. What happens as a function of time. And you can see, the creep resistance of these alloys is very good. So, that even at long holding at temperatures, 400 degrees also, does not really reduce the strength to a large extent. So, that is one of the advantages of these alloys.

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And other type of nano composites could be again. I told you titanium can be one addition, iron is another addition. You can add iron, to make the alloying element, which is high melting alloying element added to aluminum, to give high strength at high temperatures. And one such thing is iron. When add iron different amounts of iron, what you see is that a new phase comes out Al₁₅Fe₂ phase.

In fact, this is not an equilibrium compound, equilibrium compound usually is Al₃Fe. And, but Al₃Fe phase, for it come out is much more difficult from aluminum matrix. So, usually you see that, this phase can easily come out, because of lower activation barrier. And this is phase which comes out, when you take different amounts of iron. And do what is called mechanical alloy.

That means, you take aluminum and iron, powders together. Put them in a mechanical ball mill and then do mechanical alloying. For various compositions. And interestingly if you see, at very small amount of iron, you get mostly aluminum peaks. What happens to iron?

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Yes, that aluminum that iron goes into the solution. And form a solid solution basically. And it is so small, that you cannot really see any precipitates coming out. And those precipitates cannot be detected, because the volume fraction is very small. But, as you keep on increasing this iron, you can see this first peak becomes smaller and smaller.

What is the first peak, it is nothing but the first peak of aluminum. What is the first peak of aluminum.

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1 1 1 peak, it is a FCC, so 1 1 1 peak, what is the second peak?

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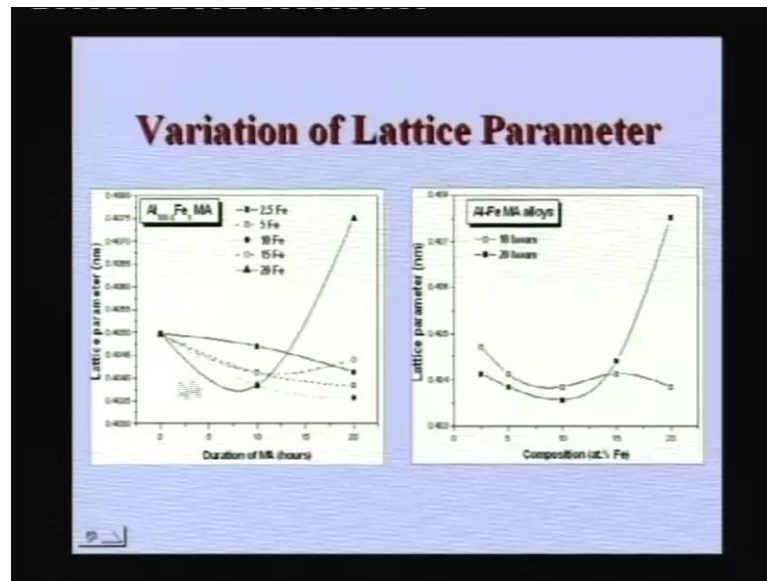
2 0 0. And we always know that, the second peak has lower intensity than the first peak, in most of the pure metals. So, as a result, you can see here, if you do pure aluminum also, you get a similar situation. That aluminum 1 1 1 will be more intense, aluminum 2 0 0, aluminum 2 2 0 will be still lower intense. But, what you see here is, as I keep on increasing iron amount, this peak is decreasing, whereas this peak is increasing.

So, the relative intensity of the 1 1 1 versus 2 0 0, 1 1 1 versus 2 0 0 peak are in fact, a iron 1 1 0 peak also exist here, near the 2 0 0 peak of that. And if you try to plot that, you can see that ratio keeps on decreasing. And that is because, you get a new phase here. And that is the Al₅Fe₂ phase, which whose peak position is exactly same as the aluminum 2 0 0. That you cannot really detect separately. But, from this fact that the aluminum 1 1 1 peak is decreasing.

If the aluminum 1 1 1 peak is decreasing, then aluminum 2 0 0 peak also should correspondingly decrease. But, you see the aluminum 2 0 0 peak is bigger now. That is because, there is a another phase that has come out. And that is overlapping with that. And from that, you can make out that the actual aluminum phase is come down. And the amount of precipitate has gone up.

So, here basically you have a kind of a nano composite. And from the peak broadening, one clearly see, that you have a very fine crystallite size.

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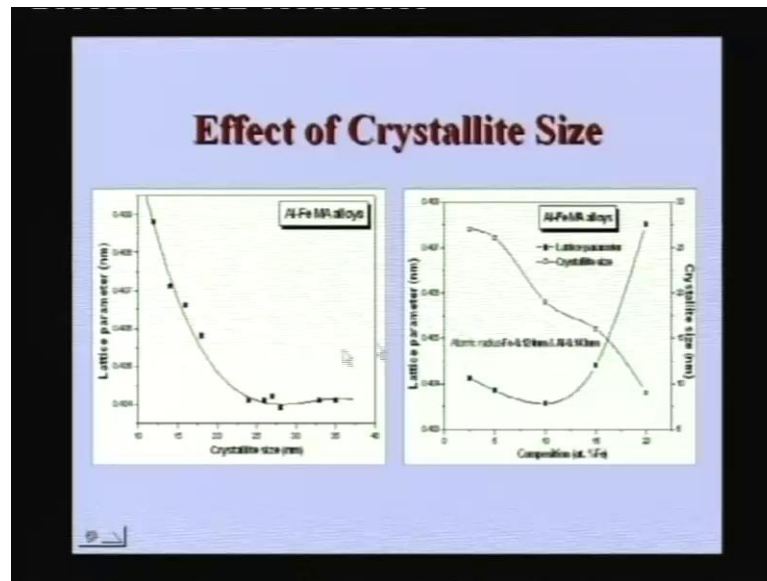


And one can calculate, the lattice parameters of all these. And then show that if you take the aluminum 20 percent iron, there is a lattice parameter increase. As a function milling time, that is basically because of the formation of Al_5Fe_2 . Whereas, in all other cases where you have solid solution formation, there is a continuous decrease in the lattice parameter of aluminum. Because, when you take iron, iron is slightly smaller atom size, when compare to aluminum.

So, when you put iron into aluminum, the lattice parameter decreases, because the atomic size decreases. So, whereas here suddenly you start seeing, that when you put 20 percent, you can see much bigger. This is because of the second phase that is coming out. And one can also plot as a function of composition, what is the lattice parameter. And you see up to 10 percent, there is a continuous decrease in the lattice parameter.

And then you start seeing that there is an increase. And this is because of the formation of those precipitate, which does not form up to here. And beyond 10 percent, you start seeing the formation of that precipitate. And that precipitate is what gives you a the increase in the lattice parameter.

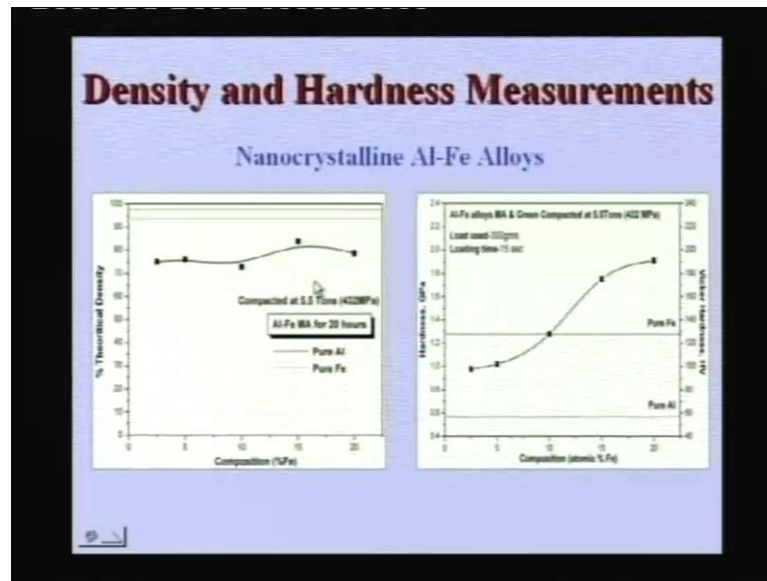
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And one can talk, how the lattice parameter changes as a function as crystal size. And one can clearly see that up to certain crystallite size, there is no increase in the lattice parameter. That means, the solubility does not increase up to a certain crystallite size. Once you go below a certain crystallite size. Let us say below about 20 nano meters are so. Then, suddenly you start seeing, that the lattice parameter starts increasing.

Lattice parameter starts increasing means, the solubility is increasing more and more solubility taking place. And that is what exactly you see here. And this one can also talk, in terms of crystallite size, how the crystallite size is changing. And simultaneously the lattice parameter increasing. So, you can see crystallite size keeps on dropping down, the lattice parameter keeps on increasing. So, there is strong correlation between crystallite size and the lattice parameter or crystallite size versus solubility.

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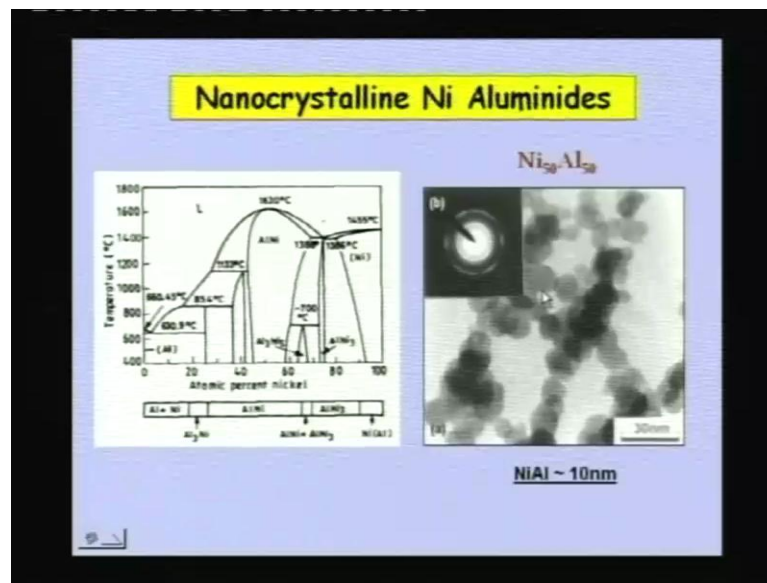
And one can also show that, these nano composites have much higher strength. And that is what you see here. These are green compacts of aluminum, iron kind of alloy with about different amounts of iron shown here. And the green densities are of the order of the 75 percent to 85 percent, here for various compositions. And you can see here, pure aluminum and pure iron, green densities are also shown here, which are much higher than this.

This is basically, because when you add some iron to aluminum, there is some strain that is generated, because of solid solution hardening. And because of the strain, the compacts will not have higher density. Whenever you have the strain, inside the lattice compaction is more difficult. So, that is why one has to heat these powders to certain extent. So, that the strain can be relieved and then you can have much better densities.

So, that is why you can see pure metals, you have much densification than the alloys. And if you look at how the hardness of this changes, you can see the hardness can reach almost 2 Giga Pascal's. So, you can have hardness, Wickers hardness is also shown here. And that is converted into stress equalants of that; which shows you about 2 Giga Pascal's, which is much higher than any normal aluminum. For example, pure aluminum you get only this much, pure iron you get this much.

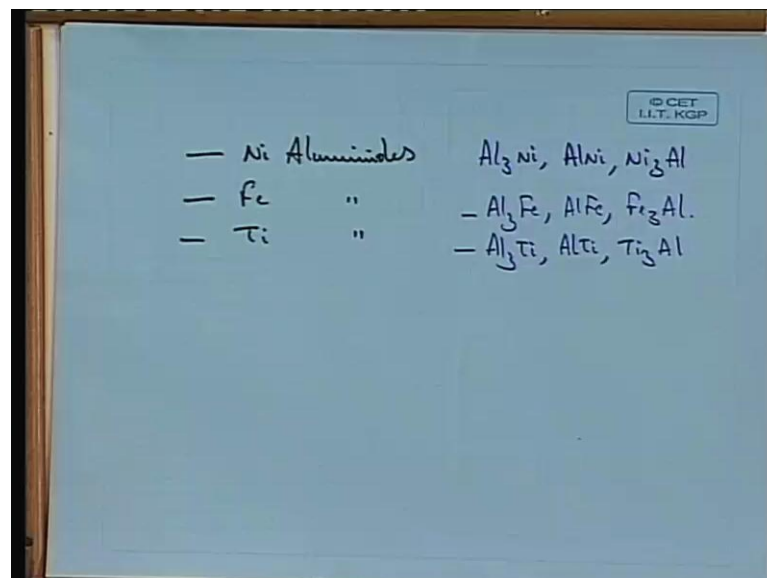
And you can see what you get for aluminum iron alloy, is much better than both of them. And that is basically, because of the nano precipitates of this Al_5Fe_2 , which is coming out in an aluminum matrix.

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So, this is the story of aluminum iron. One can also produce intermetallics, nano crystalline intermetallics, in an aluminum alloys. One such thing is what are called aluminides. Lot of people are working on these aluminides. Aluminides are nothing but intermetallics containing aluminum. There are basically three classes of aluminates, which people have studied to a large extent.

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One is called nickel aluminides, second is iron aluminides, third is titanium aluminides. The most popular aluminides in this series is, for example in the nickel aluminides series. You have either Al_3Ni or AlNi or NiAl , anything you can call it or Ni_3Al . These are the

most important compounds in this system. Similarly, in the iron also you can have Al_3Fe or AlFe or Fe_3Al , same thing true for titanium. You can have Al_3Ti you can have AlTi or TiAl or Ti_3Al , these compound how become very popular, among all these particularly the aluminum rich compositions. That means, not the third compound, the first two are more interesting why because of...

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Lower density, higher aluminum means lower density. And because it is lower density, you can have high specific strength. So, for example, Al_3Fe , Al_3Ti , Al_3Ni or AlNi AlFe AlTi , these are much more popular than these alloys. And all of them have high melting point, high strengths. And can give you good strengthening in these aluminum matrix. So, if you can have these particles, either as single phase particles or particularly in an aluminum matrix, if you can put these particles. That is what we have shown one example as Al_3Ti as one example. Al_3Fe and another example I have shown you. And this is single phase intermetallics. A number of people have studied an, how to make single phase aluminides. There are many people who have studied for example, Ni_3Al , we know that Ni_3Al if you can have in a nickel matrix.

You can have much higher strength. That is what is nickel base super alloy? So, people thought why should I put it in nickel mesh, I make Ni_3Al separately as single phase Ni_3Al . People have made single phase Ni_3Al , which has a much higher melting point then a nickel base super alloy having Ni_3Al particles. And obviously, if you have high melting point, creep resistance is much higher.

So, people wanted to try that. And if you have a single phase, there are no phase boundaries. If there are no phase boundaries, creep problem is also restricted. So, people have tried single phase Ni_3Al . And they made turbine blades, using single phase Ni_3Al number of people have. For example, Inco is a company international nickel company has made single phase Ni_3Al . But, the problem was, they were quite brittle. And people try to avoid, I means overcome that problem also by adding something, do you know?

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No, boron, boron is a wonder element, which when a added to the Ni_3Al by small amounts, just 0.1 percent or so. Can give you tremendously improved toughening. That is basically, because boron is very small element, goes to the grain boundaries, and

improves cohesion at the grain boundaries. And improves, what is called the trans granular cracking, instead of the inter granular cracking, and because which you get much higher toughening.

So, people have studied boron, what is called ductilization of Ni₃Al by boron, lot of people have studied. So, these are intermetallics. But, conventional procedure of making this of intermetallics is by the normal liquid metallurgy route. That means, you take aluminum and nickel, melt them together and make the casting. But, if you want to do that, many of the eliminates you have two problems. One problem is there, their melting points are very high.

If the melting point is very high, obviously you need high temperature furnaces, to melt these alloys. And then there is a lot of power consumption involved in that. And whether really you can have the furnaces, which can withstand that high temperatures is a problem. Most of them have melting points of the order of 1600, 1700 degree centigrade, very high melting point. So, that is one problem.

Second problem is that, the melting point difference between the two elements here is very large. If I look at titanium aluminides or nickel aluminides, or iron aluminides, the melting point difference between, the iron and aluminum, titanium and aluminum, nickel and aluminum is very large. Aluminum is 660 whereas, nickel melts around 1500, 14 15 or so. And as a result such a high difference in the melting point, when you are trying to melt the two elements together. There is a possibility of some vaporization of aluminum, before the nickel melts. So, you have a lot of problem of loss of aluminum.

Student: ((Refer Time: 42:18))

Yes, will stop here.