Advanced Materials and processes
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Lecture - 17
Mechanical Alloying

First materials such as nano crystals, nano quasi crystals, normal quasi crystals, glasses, bulk metallic glasses and number of nano composites. So, today will start on the aluminum alloys. And what kind of advances has taken placing an aluminum alloys. If you look at aluminum alloys precisian look at the history of it.

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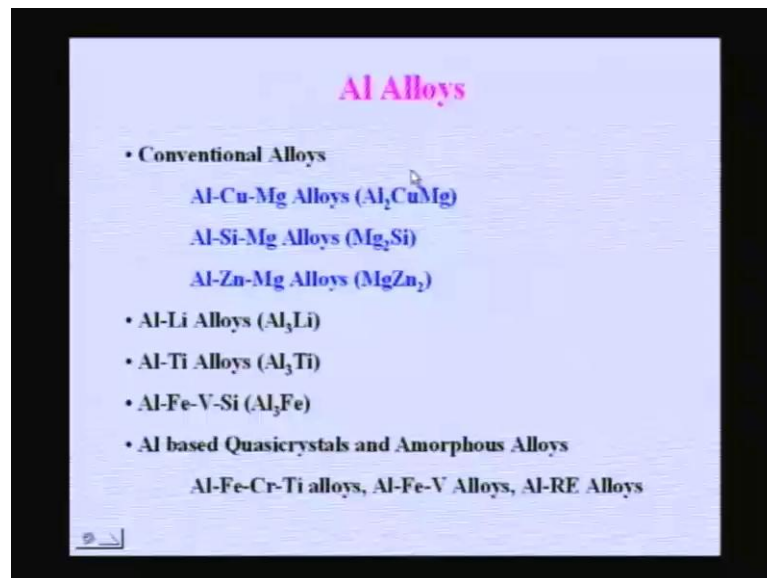
The most conventional alloys in aluminum alloys series are aluminum copper, we all know.

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So, the most common aluminum alloys are the aluminum copper series we all know. Particularly the duralumin alloys, where a some amount of magician usually added to get the Al to Cu Mg phase. Otherwise if you do not at the magician it basically the Al to Cu phase, which is called the theta phase and has orthorhombic structure.

And we all know that, this kind of phases very brittle. So, we do what is called precipitation hardening in the in this alloys aluminum copper alloy, where we solutions this alloys set high temperature something nano around 550 degree are so. And then

quench this high temperature single phase region to room temperature. And do ageing at various temperatures, including what is called naturally ageing, which is at room temperature.

So, when you aged this aluminum copper alloys usually you get a number of phases starting from what are called GP zones, theta double prime, theta prime. And finally, the equilibrium theta phase this is what is people called usually as Ostwald step rule. That when you have product phase which is equilibrium phase, which has structure, which is much different from that of the parent phase as to come out. It will have a lot of activation barrier. For example, if you look at the typically nature.

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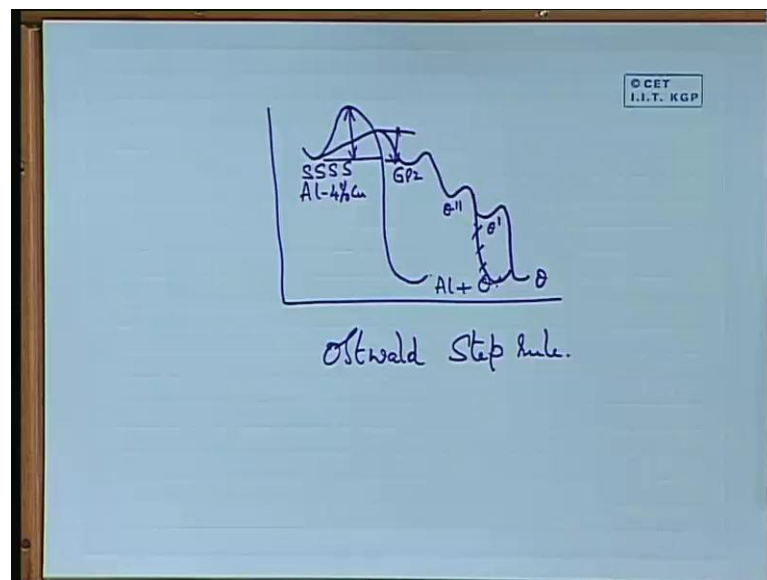
If you take the super saturated solid solution of aluminum copper. Let us a 4 percent copper and if it has give you the theta phase aluminum plus theta phase. For such a transmission to take place are, such a precipitation to occur usually you have large activation barrier. Though there is large driving force also, but because the structure of theta phase is much different from the FCC, which is the parent phase. Solid solution of copper in aluminum is nothing but the FCC phase

So, from that if the theta as to come out it has a large activation barrier. Instead the process will occur in number of steps. Finally, leading to the theta phase, the first step is what we called the GP zones. Second step is called the theta double prime. In fact, I think I should have put another step here. So, that is the final, so this is the third step theta prime and finally, the theta.

So, this is how the transmission occurs in steps. And this is famous name people give Ostwald step rule. Why does this happen this way, is because the phase that are forming at in intermediates steps have their crystals structure which similar to that the parent phase. And as a result the activation barrier for this intermediates phases is much lower than the activation barrier for the finally, theta phase.

So, there is a continuous change in the structure from GP zones to theta double prime and theta prime. And finally, to theta which is on orthorhombic structure. So, there is a continuous change in the crystal structure. For example GP zones we all know are nothing but copper clusters which is nothing but an FCC.

So, when an FCC phase as to nucleate an another FCC phase it is very easy we know. Because, coherence can be easily maintain as a result you get what are called coherent precipitates. In fact, we call them as zones, because they are, so small to be even called as precipitates. One cannot really see clear boundary for the precipitates. How do we define a second phase a second phase is that which has a definite composition definite crystal structure and has a definite boundary to be distinguish from the parent phase.

If the boundaries is quite diffused it is it becomes very difficult to call it has second precipitates particle. So, we start calling them as zones. So, a small zone where the composition is completely different, but structure is exactly the same. So, it is again the copper structure. So, it is copper having the FCC structure. So, all copper atoms come together from a small cluster and that cluster is what we call the GP zones, where some aluminum atoms are also there. It is not really hundred percent copper, but some copper with mostly it is copper reach with some aluminum in it.

So, such zones can easily nucleate in aluminum matrix, because they structure is exactly similar. So, as result the activation barrier for it is formation is much smaller as you can see here. And then from there to the next step, which is the theta double prime again some transmission some change in the structure take place towards the theta phase. And again, because now the transmission is not a large change, but a small incremental changes that are taking place at each step. And as a result the activation barrier is not going to be very large in each step. And that is why transmission occurs like this.

But, this need not have to happen in every system there are certain systems, where the transmission occurs in just one step. For example, if from an aluminum alloy if Al3fe has to come out. Al3fe usually comes out in one step, there are number such systems. For

example, aluminum silver is another example where the transmission occurs in just one step.

So, whether it occurs in step are number of step. Basically depends on how far away the structure of the product phase from the parent phase. If the structure of the product phase is largely different from that of the parent phase, then you see that it has to because kinetically it is very difficult for the product phase to come out. So, the system will choose an easy path for the transmission. So, as a result it goes in a number of steps.

For example we have see also in iron base alloys, when we take a marten sight and start heating the marten sight in steals. We know that the transmission from the marten sight to the what is called the tempered structure does not happen in one step the fe3c does not come out in one step. First phase that you get is what the, ((Refer Time: 09:28)) we call it which is hexagonal structure. And we know the fe3c is basically orthorhombic

So, from BCT marten sight or BCC marten sight depending on how much is the c by a ratio depending on the carbon content. So, from that BCT marten sight, which is cubic mostly cubic with a small distortion of c by a ratio. If you look at the c by a ratio in a marten sight it is very close to 1, 1.03 are something like that it is not very large. So, it is very close to the cubic. So, from such a cubic structure closed to the tetragonal.

So, we that is why call it as BCT from such a structure, which is very similar to the cubic structure. In fact, we know the BCT is generated by the shear of an FCC structure which is last night. So, as a result there is clear one to one correspondence between the FCC austenite to the BCT marten sight. So, if look at that kind of a structure and an orthorhombic FCC orthorhombic fe3c. So, for that phase to come out is very difficult. So, it goes by an intermediate which is hexagonal and we know hexagonal structure is very similar to FCC structure, so as the result the formation of hexagonal carbide whose carbon content. In fact is higher than tough the fe3c do you know what is the composition of fe3 epsilon carbide.

Student: ((Refer Time: 11:00))

2 say. So, if you look at fe2.2c definitely carbon content of that is more than carbon content of an fe3c. That means, that you need a carbon atoms to come together in a small region by a larger amount for the fe2.2c to come out. Rather than if fe3c has to come out.

If fe3c has to come out you need only the less them of carbon atoms to come together in a small region.

But, then though we know a diffusion wise this is more difficult process. But, the activation barrier for the nucleation of a new structure is, so high, that the system would prefer this process of higher diffusion, higher amount of carbon diffusion. But, we know the carbon is the interstitial element. So, it is diffusion is not really a major problem. Particularly if you are doing tempering at around 300, 400 degree centigrade at lows temperatures. Unless you talking about really room temperature tempering, which is where carbon diffusion is very difficult.

Usually tempering is done at around 200, 300, 400 degree centigrade at that temperature the interstitial element can easily defuse. So, you can definitely have a 2.2c without any problem and that is what happens in the steels. So, you can see that there is clear comparison between the aluminum alloys what happens and the conventional steels that we look at. So, you can see this is how most of the precipitation in conventional aluminum copper alloys of course. And when you add a small amount of magician to it you get a new phase called.

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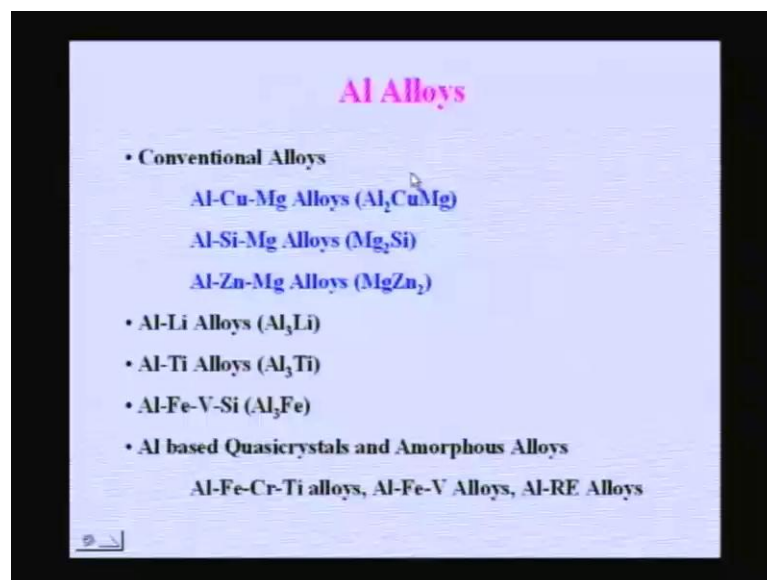
Al 2 Cu Mg, which is more stronger than the aluminum copper. So, as a result most of the aluminum copper alloys have some magician unit. The other conventional alloys are the aluminum silicon alloys, which we are all aware of. What is the most important application of aluminum silicon alloys.

Castings, yes where do you use those castings.

Student: Sir engine block.

Engine block correct, most of the automobile engine blocks are all elements silicon alloys two important reason for it. Among all the aluminum alloys aluminum silicon alloys are the ones which have very high castability are high fluidity. Because, they have eutectic, which is much lower 577 is eutectic temperature. So, among all the aluminum alloys. Aluminum silicon alloys are the ones, which have very good fluidity.

So, they can easily castled into any complicate shape. For example, if you look at engine block in most of the bikes now-a-days engine block is visible from outside very easily. If you look at hero Honda are something like that. So, you can see the in order to improve the cooling process of this engine blocks, because they get hot. So, there are lot of flings on the engine blocks. So, if you want to get flings, in a casting unless the liquid as high fluidity. The liquid will not fill those intricate regions in the mold. So, as result you really need a very high fluidity, high castability, which is what aluminum silicon gives you.

But that is not the alone there is reason why you use aluminum silicon alloys. The other major reason is the thermal coefficient of expansion is very, very low. For example, when you have piston in an engine block, which is moving continuously at high temperatures, when the gasses are generated. So, you do not want the piston to expand and then jam the whole engine block.

So, you want a very low coefficient of thermal expansion and that is what an aluminum silicon alloys provides. It is light at the same time easily castable and is strong, because of the silicon. You know the silicon is very hard diamond cubic face. When have this silicon in a aluminum matrix you get much higher strength.

So, that is why aluminum silicon alloys have good strength. Expecting that one has to modify the silicon morphology to improve the toughness or the ductility of these alloys. Because silicon usually comes out as needles in this aluminum silicon alloys, where is silicon actual located in aluminum silicon alloys.

Particularly, if you locate the conventional aluminum silicon alloys which are about 7 percent silicon or 12 percent a silicon. These are the very common aluminum silicon alloys, which you use in the engine blocks. Where is silicon in this alloys, can you recall

the phase diagram of aluminum silicon anybody. What is the eutectic composition in aluminum silicon?

Student: ((Refer Time: 16:27))

Yes, so.

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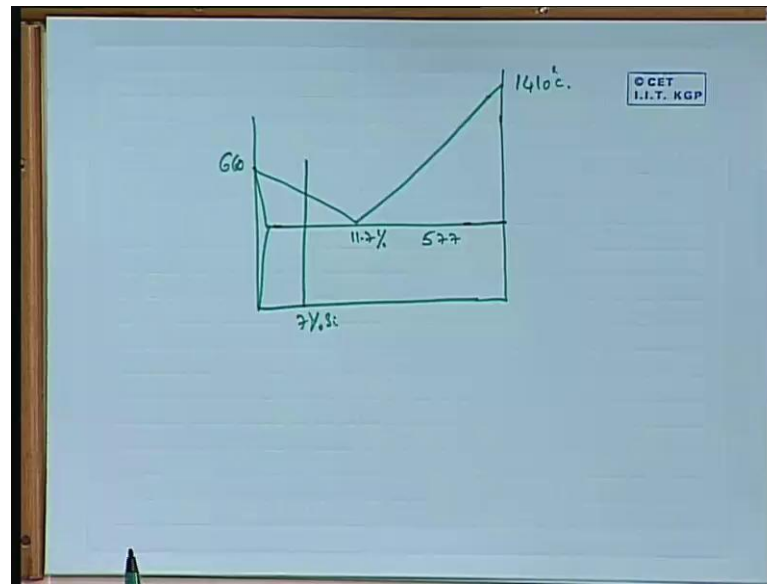
Aluminum silicon phase diagram looks something like this, what is the melting point of aluminum?

Student: 660

660 and this eutectic temperatures is…

Student: ((Refer Time: 16:55))

577 and this is about 11.7 percent and what is that of silicon melting point anybody remembers.

Student: ((Refer Time: 17:08))

1410. So, if you look at a typical 12 percent silicon silicon usually about eutectic. Because, actually the eutectic composition in aluminum silicon alloys is only under equilibrium condition it is like this.

The moment you adds certain alloying elements into it or add water are called modifiers immediately the composition changes in it little bit. That is why people usually give it as range 11 to 12 percent something like that. So, if you look at around 12 percent silicon

alloy is usually eutectic alloy or if you look at a 7 percent silicon alloy. Let us say 7 percent silicon, so it usually a high poly eutectic. So, in these two cases, eutectic and hypoeutectic silicon usually in the eutectic mixture.

So, that silicon in the eutectic mixture is usually in the needle form unless you do something. There are different ways of doing it. One way is to cooled alloy very rapidly. When you cool the alloy will rapidly there is not sufficient time for the silicon to grow into needles. So, it becomes like small like as if you have chopped the needles it gives a comes out a small particles. And as a result you can better ductility, because we know that whenever an aspect ratio of precipitates is very large.

Aspect ratio means the length to the diameter of length to the width. If that ratio, if it is very large then the tip of these particle acts as what is called the stress raiser. And you will have triaxial state of stress coming out there and because of which the material fails in a brittle manner.

So, you want to avoid such long needles in any micro structure. So, that is one of the reasons why for example, gray cast iron is. So, brittle and that reason why people try to do what is called sparadisation. And gets a sg iron or not cast iron where you get a nodules, so exactly in a similar fashion. So, silicon in a needle from it is not very good. So, that' us why we do either fast cooling are what is called modification. The number of modifiers people add such as sodium strontium. All these modifiers are known to be what are called surface active agencies.

So, when you add a small quantity of these. We usually do not add more than about 0.02 percent, 0.03 percent this range that we adding. They are not really alloying elements in very small quantities that you are adding that the really do not change the alloy characteristics much. But, from a thin layer on the silicon particle, which come out, are the change surface tension of the liquid. In such way the silicon particles do not grow. But, become paradise. So, you get more or less spherical particles, fine particles that is what you get.

Another possibility is what is called people have used some kind of deformation process. Such as warm rolling; that means, you take this solemn silicon alloys, where the silicon is in the needle from. And deform it to some extent at temperature such as 200 300 degree centigrade or so.

But that is not real frankly speaking in an advantages situation. Because, you want to use aluminum silicon alloys as cast alloys not mostly as a rot alloys. So, as a result once you make the casting there is no question of again deforming that. So, as a result though number of studies have been made by people that is have become really popular. But, the most important techniques is fast cooling, if you can achieve and the modification.

So, these things give you good modification and which give you a good combination of strength as well as ductility in this aluminum silicon alloys. And in addition to this if you want to add some precipitation hardening to it. People add a small amount of magnesium to it. Usually about 0.3 percent of magnesium is added to all the aluminum silicon alloys to give you what is called Mg2Si phase. And that gives you some precipitation strengthening in this aluminum, silicon, magnesium alloys.

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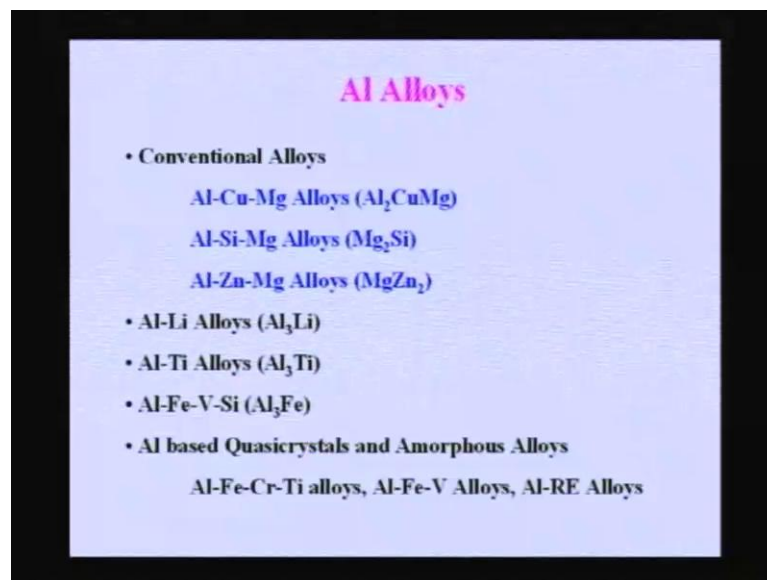
Other class of conventional alloys, whatever we are taking, so far are the basically the conventional alloys. The other class of conventionals are the aluminum zinc magnesium alloys where you have MgZn2 as a precipitate. And gives you more are less good precipitation strengthening. But, the most popular of all these precipitation hardening alloys are the aluminum, copper, magnesium.

Because the strength levels achieved are much higher you get very good coherent precipitates in this. Then there has been a lot of perk to develop newer aluminum alloys, which is what is the primary objective of our class. Today is to look at what are the new alloys that have come up in the aluminum alloy series.

One is what is called aluminum lithium alloys still lot of work is going on. And even in India DMRL Hyderabad a lot of people have been working on this aluminum lithium alloys. The measure interest in this aluminum lithium alloys is in the lithium. Lithium is has an important characteristics, I think most you of know it what is that.

Student: ((Refer Time: 23:14))

It is lightest metal not very light it is the lightest metal. What is the density anybody remembers it is 0.53, it is 0.53 is a density of lithium. So, if you add lithium to aluminum. Obviously, you are decreasing the density particularly in air space industries. Everybody want to have the lower density as low density as possible, because you want to have light alloys at the same time strong alloys.

That is where lithium has another advantage that lithium is also known to improve the Young's modulus safallon alloys. In fact, lithium is one of those few elements, which dramatically increase the young's modulus of aluminum. So, you have a double advantage. And one side you are decreasing the density. On the other side you are increasing the young's modulus. So, if you look at what is called specific modulus? The specific modulus is much higher for aluminum lithium alloys than any other aluminum alloy.

In fact, is the highest specific modulus; that means, modulus versus density. If you divide the modulus with density, you go get the highest specific modulus and highest specific strength for these alumina lithium alloys. Where from this is coming? This is coming again by a precipitation and what is the precipitate? The precipitate that you have here is what is called al alloy aluminum, 3 lithium phase, which is called the cubic phase L 1 2 cubic phase.
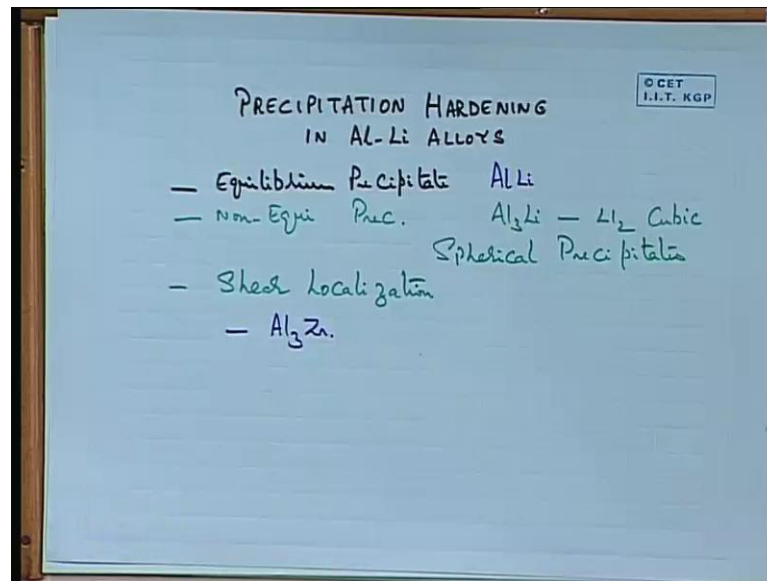
What is L 1 2 phase? It is basically an FCC structure where all the corner atoms are occupied by one atom. And all the phase centered atoms are occupied by another type of atoms. For example, if you look at Al3li. Al3li you have 3 atoms of aluminum and 1 atom of lithium. So, you can easily imagine that in a FCC kind of arrangement. Lithium will go to the corners, corners of the unit cell and the aluminum will occupy all the phase centered positions. And that is what is L 1 2 structure. And that is the phase, which comes out in the aluminum lithium alloys. But, that is not equilibrium phase, the equilibrium phase in aluminum lithium alloys is AlLi equiv atomic lithium.

Lithium 50 percent lithium and 50 percent aluminum as per as a the atomic percent is concerned and because lithium has a very low atomic number atomic weight. So, as a result the weight percent wise if you consider it. It will be much lower amount of lithium. So, that is the actual equilibrium phase AlLi. But, this AlLi phase again has a structure, which is not very close to that of the aluminum. And as result its formation is more difficult.

So, when you take a typical aluminum lithium alloy with about 3 percent of lithium in it. Usually most of the alumni lithium alloys you have 2 to 3 percent weight percent of lithium aluminum copper alloys what is the maximum we go.

Student: ((Refer Time: 26:53))

4.5, why cannot you go beyond that…

Student: ((Refer Time: 27:01))

Eutectic yes.

Student: ((Refer Time: 27:06))

No

Student: ((Refer Time: 27:08))

What limits the maximum amount of a solute in any precipitation hardening alloy. It is the maximum solubility, that is the crucial aspect. In any precipitation hardening, what is crucial is, what is a maximum solubility. And in a aluminum copper alloy, the maximum solubility is about 5.5. If you look at the typical phase diagram of aluminum copper, it is become very clear to you.

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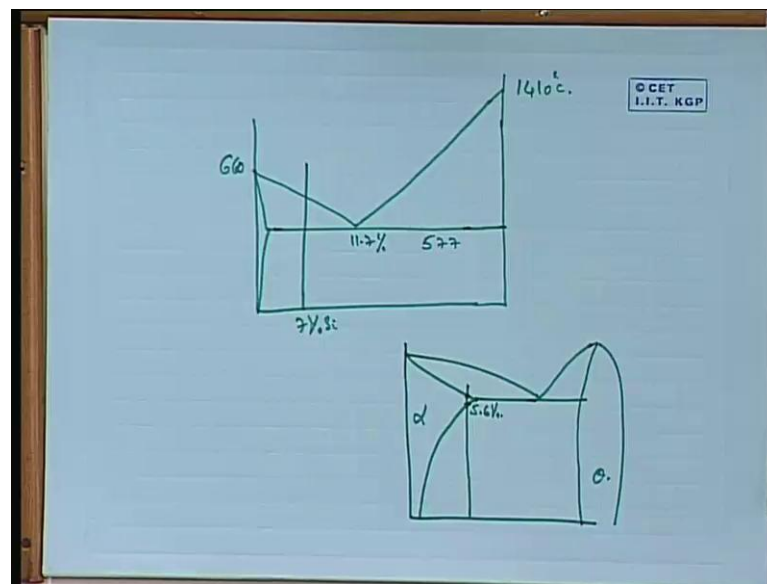
This is a theta phase and this is the alpha phase and this composition is 5.6 percent. So, that is the maximum, but at the same time, you cannot say I will make a 5.5 percent alloy of aluminum copper. Because, you can see if make a 5.5 percent alloy like this. The salva's line is very close to the solidus line. If the salva's line is very close to the solidus line when you are doing your solutioning treatment, then there is a possibility that it can melt, if you are furnace is not maintained very well with a high degree of temperature stability.

If it is not there in the furnace there is a chance that there is a melting. And once the melting occurs then you cannot have homogenization. What is the basic goal of solution

treatment, that you want everything in form of one single phase having a uniform composition. And that you want to quench it, to get what is called super saturated solid solution.

So, as a result one do not usually go beyond about 4.5 percent that is more or less the maximum. So, similarly in aluminum lithium alloys, usually about 3 percent is the limit that we use. And in such a alloy, if you normally cool it. Under normal conventional cooling conditions, you will get AlLi at the grain boundaries.

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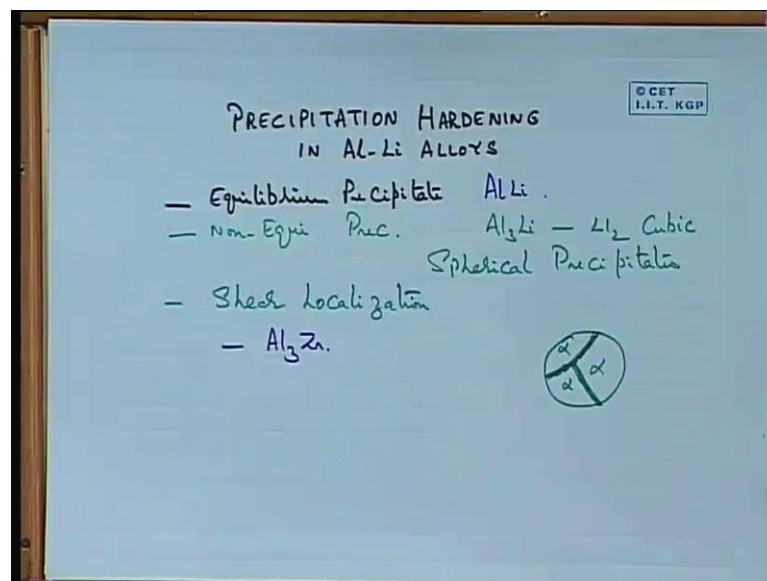
You have ha in the solutionized condition you have let us say all alpha. And if you start cooling it slowly, you will have the phase of AlLi coming out at the grain boundary. So, this whole grain boundary is decorated with AlLi. This is the typical problem even in aluminum copper we all know. If a aluminum 4.5 percent copper alloy after solution treatment.

If you do not quench it, if you cool it normally inside the furnace or bring it out into the air. And then leave it there. What is going to happen the theta phase, which is the equilibrium phase is going to precipitate at the grain boundaries; because grain boundaries act as the nucleating sites.

So, it precipitates at the grain boundaries and forms a network of theta at the grain boundaries. So, you have a brittle theta phase at the grain boundaries. And that is what makes the whole alloy very brittle. So, this is the basic problem even in steels, when do you get this kind of a problem in steels have…

Student: ((Refer Time: 30:51))

Yes, in case of hyper eutectoid steels. You have the cementite network at the grain boundaries. When you are cooling the austenite the cementite gets the precipitated at the grain boundaries. And you have the cementite network. You can see in most of the alloy the criteria the design criteria of alloy, design criteria more or less similar.

So, their also we do some treatment for sparadisation those Fe3c, we call it sparadisation treatment. So, similarly here instead of doing sparadisation of this theta. In fact, if you want one can do sparadisation of this theta. But, that is not going to give you much higher strength it can only make it ductile. Because, a theta phase is a incoherent phase, because it is structure is orthorhombic, which is much different from that of the matrix.

So, you are not able to get improved strengthening, because of the just spheroidization of theta. If you want one can hold at slightly higher temperature for a long period any network kind of a phase. Will definitely become spheroidal, basically because surface area to volume ratio is decreasing, that is the basic driving force for any spheroidization is it not?

So, but if you instead of that, if you cool it fast and age it and get what are called coherent or semi coherent phase precipitates. You can get a much higher strength. That is the basic philosophy behind the whole precipitation. Otherwise you would have been satisfied with just theta and somehow do some kind of a spheroidization treatment there.

So, similarly incase of this aluminum lithium alloys also. If you cool it normally you get AlLi. Instead of that if you quench it and then do age hardening, you get the Al3Li precipitates. And here the precipitates are completely in the spherical form, this is another aspect in precipitation. What is the shape of the precipitate. The shape of the precipitate depends on what. The strain what is called the misfit parameter, if and of course, the surface energy, interfacial energy that is also crucial.

So, if you look at a precipitate which is coming out and measure what is the lattice parameter of the precipitate. And know what is the lattice parameter of the parent phase? If the lattice parameter of the product phase is largely different from that of the lattice parameter of the parent phase, then we say the misfit is very large.

And this misfit is going to decide whether you are going to coherent precipitates or semi coherent or incoherent. Even if the structure is same keep this in mind. Even if the

product phase has the same crystal structure that of the parent phase. If the lattice parameter of the product phase is entirely different, from that of the parent phase, if the what is called the misfit parameter is more than about twenty percent or so.

Then you will definitely end up in incoherent precipitates or semi coherent rather than getting about. For coherent precipitates you need the misfit to be very small. Now, the question is if you look at the strain aspect. If, you have spherical precipitate, in order to maintain the coherency between the matrix and the spherical precipitate. The strain generated is more, when compared to a flat kind of a precipitate, if you have a precipitate in the form a disc. Let us say in the form of a disc, then the strain is much smaller because the coherency can be easily maintain between the matrix and the precipitate.

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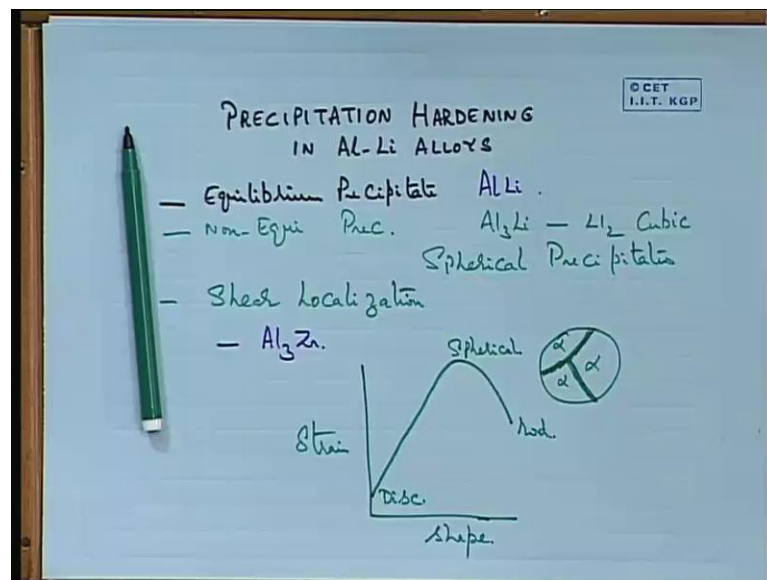
That is why, if you plot what is called the strain versus the shape factor. You will see the disc have the lowest strain. And the spherical particles have the highest and rod like particles this is the disc. This is the rod like, this is the what is called the spherical. So, usually discs have the lowest strain. So, every system, would like to have disc type of precipitates. Usually, but at the same time a spherical precipitate, has a lowest surface area to volume ratio is it not.

So, if at if you can have a spherical precipitate, you can have the lowest interfacial energy. So, there is always whenever a precipitate is coming out of a matrix. There are two energies, which are going to restrict the precipitation. There is one energy which drives the precipitation. What is that energy, which is driving force for the precipitations.

If the precipitate has the lower free energy then the matrix, then you are going to have the precipitation. And that is the driving force. And this driving force is restricted by two positive contributions for the free energy. One is the surface energy, another is the strain energy. So, the driving force has to be more then these two.

So, that you can have the overall precipitation in thermodynamic, we use to talk about this. So, one has to minimize a combination of these two. Strain and the surface energy. You can see the disc has a lowest strain energy, but if you have spherical that will have the lowest strain energy surface energy.

So, how do you have a combination of these two. So, that is where what is important is, what is the actual misfit parameter? If the misfit parameter is very small, between the parent phase and the product phase. Then the system would prefer to have a spherical precipitate, because the surface energy can be lower, already the misfit is very small. So, if the misfit is very small the strain is anyway going to be small. Weather it is going to be spherical or definitely spherical is going to have slightly larger strain, then the disc.

But if their misfit is very small; that means, if the lattice parameter difference between the parent phase and the product phase is less than about 5 percent or so. In all such cases you end up in spherical precipitates. Aluminum silver is an example and aluminum lithium is another example that Al3Li always comes out as a spherical precipitate.

Whereas, aluminum copper is an example where the precipitates or disc shape like that. So, the actual shape of the precipitate depends on these two factors. One is the misfit parameter, another is interfacial energy. So, as a result as we can see Al3Li is nice spherical precipitates. So, you see simply the situation is that you have an ordered, FCC type of ordered. In fact, we should not call it anymore FCC as a have explained to you earlier. In fact, it is not really FCC, but we can say it is FCC based it is an ordered structured based on the FCC.

So, you have an L 1 2 ordered precipitates in an aluminum matrix. This is exactly similar to, another high temperature alloy, have you ever come across a very high temperature alloy, which is used in air crafting engines. Super alloys the nickel based super alloys. If you look at nickel based super alloys. What is the actual primary strengthening phase. In a nickel base super alloy, it is call gamma prime gamma prime is the Ni3Al, you have an Ni3Al in a nickel matrix. So, it looks like this.

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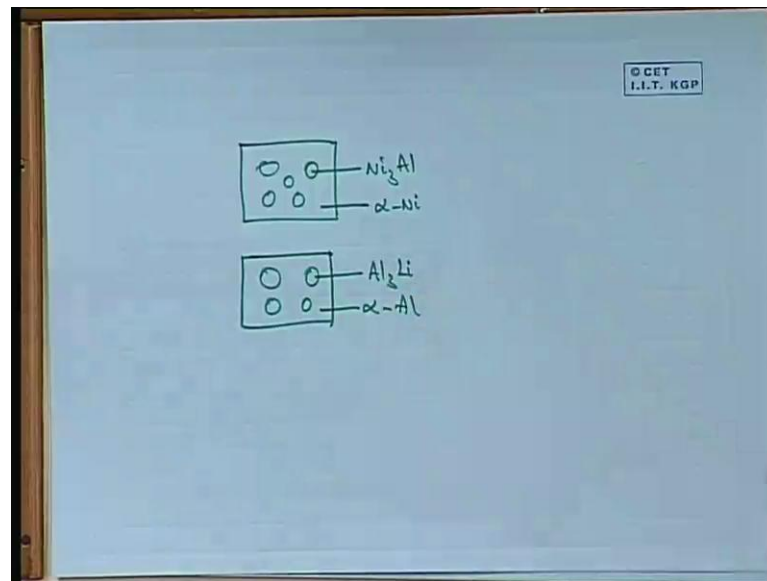
If you look at the micro structure you have a nickel matrix and spherical Ni3Al particles. And this is alpha nickel solid solution of nickel, with some other elements in it. Exactly similar situation you have in a aluminum lithium alloy, that you have spherical Al3Li particles with an alpha aluminum matrix.

So, this is the one which tells you that you can have very good strengthening. You have ordered FCC particles in an aluminum matrix. And you will also have sufficient ductility because aluminum is FCC. So, good ductility and the ordered particle is also the cubic ordered not really tetragonal or orthorhombic. Cubic phases is always have a higher ductility ha because of what where's from ductility comes.

Close pack nature of the plains and directions. Ductility is related to the slip, we know if in any structure if the slip can occur is more easily. That particular structure is more ductile than any other structure. So, if you look at the cubic structure compare it with any tetragonal type of structures.

You can or orthorhombic or any other low symmetry structures. The high symmetry structure, the cubic structure has more close pack plains and directions And because of which you have better slip systems larger number of slip systems. And easy slip to occur. So, that is why, in fact, I will show you a little later why in particular.

One particular system we want to convert a tetragonal precipitates into a cubic precipitate. To improve the strength and the ductility of the alloy will come to that a little later.

So, this is AlLi seem to be a very good, but ended up into some problems. There was a lot of interest in these aluminum alloys for quite some time. And then slowly people started feeling that there are problems one major problem is what is called shear localization.

What happens is the moment a dislocation cuts through this particle. If you have fine Al3Li particles. Once a dislocation goes through this particle and cuts particle. Then all the remaining dislocation, which are there go through the same path. And that path provides an easy path for the dislocations to move. And what you have localize shear taking place, instead of shear occurring in a number regions.

So, you have localize shear and this localize shear makes a alloy. The reduces the ductility of alloy, those regions act as in the crack initiators. And you have easy crack propagation taking place. So, in order to avoid this. People still tried some more additional methods. One of that is what is called addition of them zirconium to these aluminum and lithium alloys. These all just alloy design criteria, how to make the alloy stronger at the same time sufficiently ductile.

What they did was added some kind of zirconium. And zirconium is known to react immediately with aluminum in an aluminum alloy. And form Al3Zr. Al3Zr is incidentally is also can a cubic phase. Again an L 1 2 cubic phase and this Al3Zr when it is present in an aluminum alloy, and if you do solution treatment and quench it and start aging it. During this aging process this Al3Zr acts as a nucleating site for the Al3Li. Because, both are same structure Al3Li is L 1 2 Al3Zr is also L 1 2.

So, as a result you can have the Al3Zr on which Al3Li nucleates. So, you have Al3Zr in the center and Al3Li on top of it. And in a matrix of let us say alpha aluminum. And if you have this kind of structure. And again look at their deformation behavior of this kind of a structure. you will see that more difficult for shear localization to occur now, because you have an Al3Zr, which is a much more difficult to be sheared because you have zirconium which is a high melting metal. So, obviously, Al3Zr has much stronger bounds aluminum and zirconium have much stronger bounds. Then the bounds between aluminum and lithium and as a result the breakage of those bounds is very difficult.

For example, whenever you have to have a shear, for the dislocation. The shearing a particular particle, you need to break the bounds of the two elements in that particle. And

for if the bound strength is much higher, then breakage of the bounds is much more difficult.

As a result the particles cannot be sheared. So, that is one of the advantage of this kind Al3Zr with that people could solve to some extent this. But, there are additional problems with lithium is that the lithium is very light element and very small element. So, as a result there is possibility of lithium being diffusing out of the aluminum alloy. If you make a aluminum lithium alloy component. Hold it for a long period ha people have observed that the surface composition is definitely depleted in lithium, then the core of the alloy; because of the lithium defusing to the surface.

And then getting oxidized ha with the atmosphere, because with him can immediately get oxidized. In fact we never keep lithium just like that lithium, sodium all these elements cannot be kept outside. They are always kept under a protective environment. So, that can easily react with oxygen. And then you can have a loss of lithium. And then that provides a kind of a driving force for further lithium to go out, because you have a concentration gradient, now. And if you have a concentration gradient lithium can go. So, many times one has to have some coatings on aluminum lithium alloys. So, that one can prevent this kind of a things.

So, there is a lot of resources still going on an how to use these aluminum lithium alloy. And make best use of the increase in the Young's modulus that the lithium gives and the decrease in the density that it provide to us. So, that is the type of work that has been going on aluminum lithium alloys.

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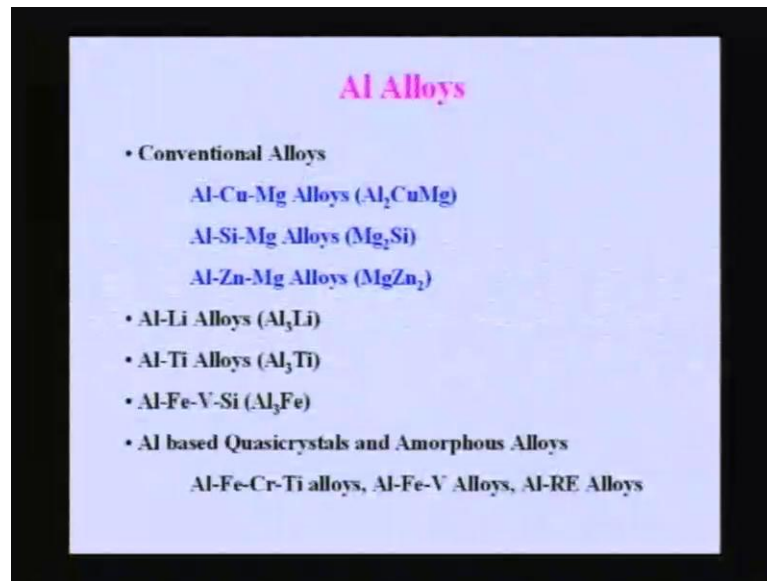
Then there are a number of other alloys, which have come up one is aluminum titanium alloys. And the aluminum, iron, vanadium, silicon alloys and a number of aluminum alloys where quasicrystals and amorphous phases form. And some these alloys have very high strength of the order of around 1.5 or 2 Giga Pascal's which is much higher strength for any aluminum alloys. Usually an aluminum alloys in such as a aluminum copper alloy. it is very difficult to get more then about 300 MPA or 400 MPA maximum could be about 500 MPA. That is the maximum strength that one can think of on in conventional aluminum alloys. But, a number of composites nano composites are coming up now-a-days. With various kid of phases present and those nano composites have much higher strengths.
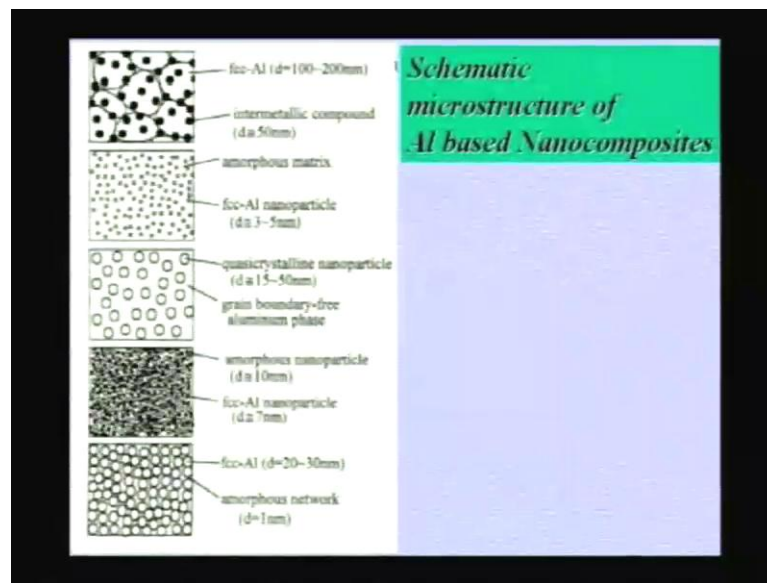
What are the various type of possibilities of nano composites there are various types of micro structures that are feasible. I have just put down some of them, but there can be many more. One such thing is that you can have FCC aluminum grains in which you have very fine inter metallic compound particles. Nano particles of inter metallic compounds.

You will see some of the examples, in what I am going to show you in future. And that is one type of, so but here it is all crystalline. So, you have crystalline aluminum grains. And into which you have crystalline Al3Ti particles are any inter metallic particle. Al3Ti is one example, you can have Al3Ti, Al3Fe are any type of inter metallics or nickel aluminates.

For example, you can have aluminum matrix and nickel aluminates particles in it. So, are for example, Al3Fe, Al3Li if you can make it into nano, particles you can have Al3Li nano particles in a aluminum matrix, though not many people have tried in that kind of thing.

Other possibility is that you can have an amorphous matrix. The second one and into which you can have an FCC aluminum nano particles nano grains nucleated in an alpha amorphous matrix. That means, you make an amorphous matrix and crystallize this amorphous alloy. When you crystallize it alpha aluminum comes out, what is called primary crystallization will talk about it a little more detail later. So, you can have

different types of crystallization. One type of crystallization is what is called primary crystallization were you can have FCC a aluminum nano particles coming out.

Third one possibility is that you can an alpha aluminum matrix into which quasicrystalline particles. As I told you, the first one is alpha aluminum matrix into which you can have crystalline inter metallics. You can have crystalline inter metallics you can have quasicrystalline metallics depending on the type of alloy that you are choosing. And depending on the cooling rates that, you are choosing one can have this possibility.

One can also have another interesting thing is that you can have an alpha aluminum matrix. In which the amorphous nano particles how do you generate. This can also be possible by if you are cooling the liquid very rapidly. During this process, if alpha aluminum can nucleate as fine grains as dendritic alpha aluminum. The inter dendritic regions are these the liquid phase that you have.

So, if this inter dendritic regions if they are very small. And when you are cooling it very rapidly, this liquid at the inter dendritic regions can become an amorphous, if the cooling rate is sufficient. And if it is composition is such efficient to give your good glass forming ability. So, you have already aluminum, which has formed as dendrites and you have inter dendritic liquid. And this inter dendritic liquid can undergo a glass transition and give you a glass. So, that you can have the small pockets of amorphous pockets in an aluminum matrix, that can give you another possibility of mechanical properties. Another possibility is that you can have amorphous network in an with FCC aluminum. how do you get, I you can get again alpha aluminum nucleated in an amorphous matrix. By, getting initially a either an amorphous phase and then nucleate a large number of alpha aluminum.

For example, if you can somehow increase the nucleation rate of aluminum, you will have a large number of fine precipitates. And when you have, so many fine precipitates the amount of amorphous phase get reduced. And becomes a very small quantity and that small quantity will remain at the boundaries of this aluminum if you can imagine that.

So, you can have a aluminum with a thin network of amorphous. That can give an additional possibilities of the chemical properties. All this kind of possibilities exist and will try to take up some of them and look the real life examples of all these in the next class.

Thank you.