Phase Diagrams in Material Science Engineering
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Lecture – 60
Case Studies on Ternary Phase Diagrams – I

Students, in the last two lectures I am going to discuss few case studies of the ternary phase diagrams. So, I am going to take from the very first, like in ternary phase diagrams I first discussed the two phase equilibria for the ternary isomorphous system followed by three phase. And the four phase equilibria and the cases, which I am going to consider, are stainless steel super alloys and the ceramic phase equilibria between aluminum oxide, silicon dioxide and calcium oxide.

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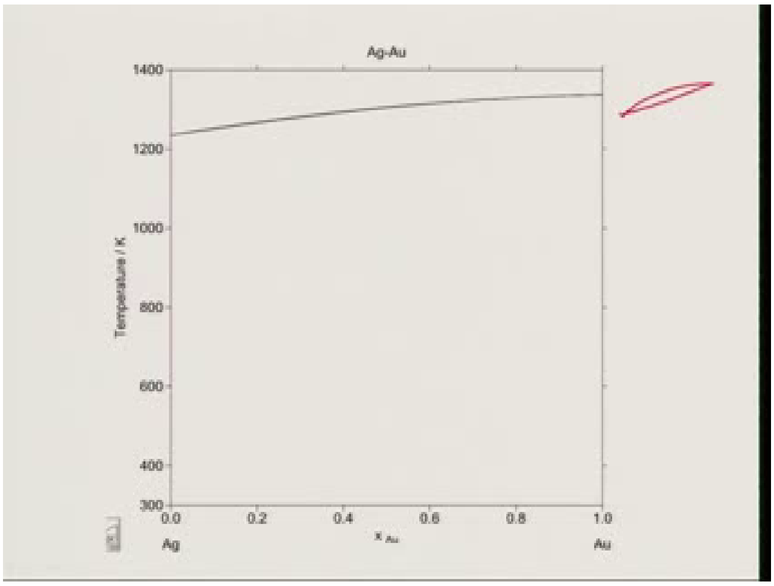

So, the first thing, which I will do is, that I am going to show you, the binary, ternary isomorphous system of gold, silver and palladium, is very simple, but let, let us look at it carefully. As you know, silver melts at about 961 degree Celsius temperature where gold (Refer Time: 01:13) melts at about 10, 1064 degree Celsius temperature. The phase diagram, binary phase diagram, it is silver and gold is isomorphous type.

That is what is shown here. This is all taken from the empty data, database. As you see here, the phase diagram between gold and silver is, looks like a line, but it is not. Basically, it looks like a, its looks like a, let me just go back and tell you, its looks like a isomorphous type, that is, a lens, correct. But because of melting temperature difference between gold and silver is very small, that is why, you do not see the loop very clearly.

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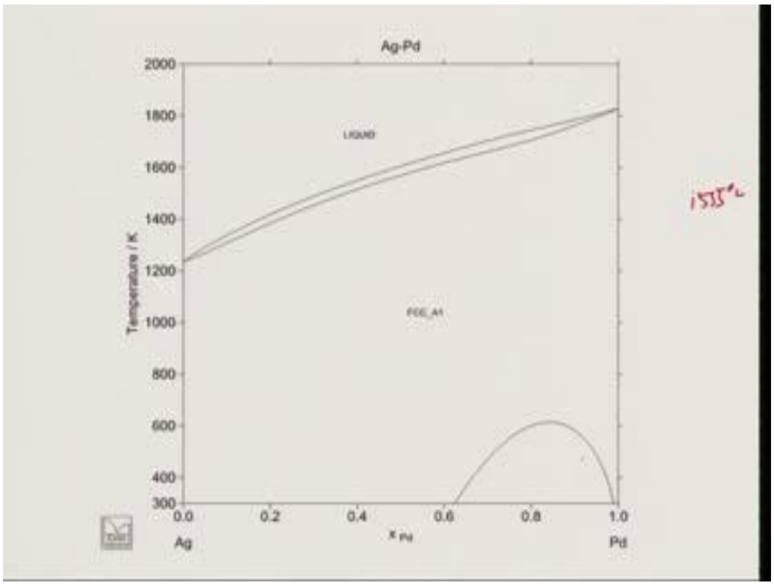

Now, this is what is actually the binary phase diagram between gold, silver and gold and between silver and palladium. You have a binary phase diagram of isomorphous. Again, palladium melts little high temperatures, it is about 1500, 1 5 5 5 degree Celsius temperature and it seems, there is a miscibility gap or dome kind of structure, the palladium reach region, but at low temperature. So, that does not make much difference.

Solid solution is again FCC type. Remember both, - silver, gold and also palladium have specific (Refer Time: 92:33) structure. Now, between, between silver and the between gold and the palladium same kind of phase diagram exist, all it depends will be, that melting temperature of silver will be placed on melting temperature of gold, okay, that is all.

So, once we have such kind of phase diagrams let us now built in, that the three-dimensional space model here and I am going to do it using color chocks, so that you understand it nicely. So, it is very easy.

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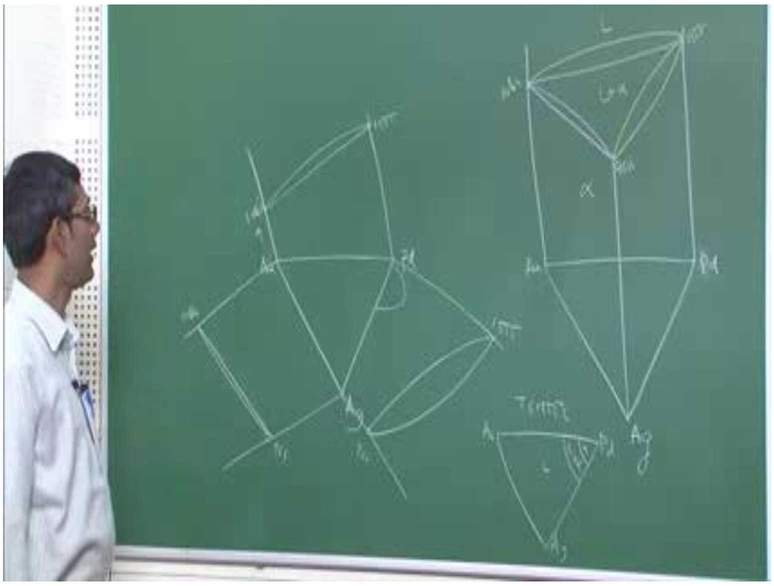

So, if you have a, let us first draw the Gibbs triangle, that is, the compositional triangle. This is suppose gold, this is silver, this is palladium, correct. So, now I think, better we put palladium here because palladium has a high melting temperature. So, the binaries are like this. So, between gold and silver is very small difference, sorry, it will be much thin, smaller gap. So, 961 and 1064 and between silver and palladium, again isomorphous, time, type, 1555, 961 and you have a dome, the palladium rate region. Gold and palladium again same, 1064 and 1555, these are the melting temperatures, right.

So, if this is the binary system in which all the components form isomorphous type, the ternary phase diagram will also be like that, so gold and silver will exaggerate, but there will be no gap seen, silver and palladium and palladium and gold this is a phase diagram. So, you have a liquid, alpha, liquid plus alpha, correct. This is 961 degree Celsius, 1064 and this is 1555. It is not to the scale properly, that is why, it should have been (Refer Time: 05:57), that is what it is. So, one can actually draw the astral positions and all this things, very easy, you know, astral positions look like cups. If I take astral position little below, 1555, suppose it will look like this, slightly below, correct. Similarly, you can built in all this things, you can draw little below, 1064, then you have a region on this side and silver side, very easy to understand and do it correct.

So, this is the first phase diagram, which I thought need to be discussed because there are many such isomorphous system, ok, exist in the, in the literature and they are not difficult to understand. So, now, let me go, go to the next one. Next one is, this is two phase equilibria, and next one is three phase equilibria. So, for three phase equilibrium, first I will show you the binary phase diagrams then I will try to develop the ternary phase diagrams. So, the case which I am going to discuss with you is little different. I would discuss silver, copper and gold phase diagram.

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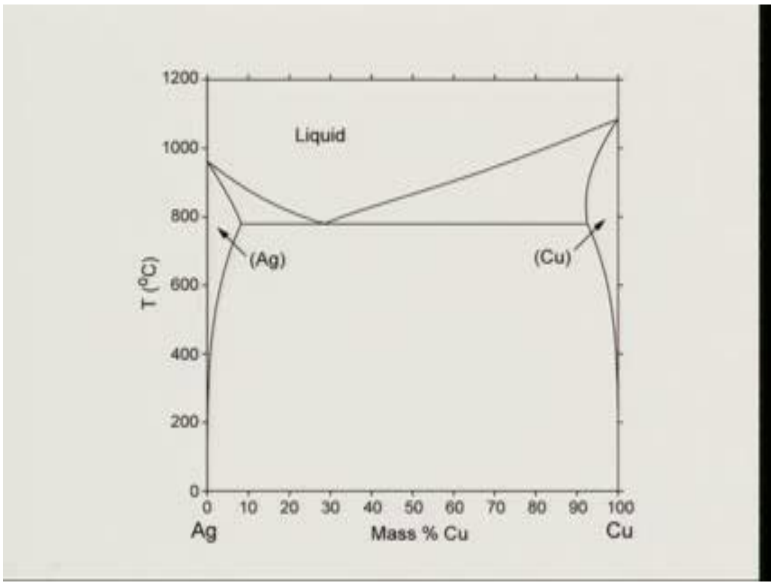

Silver, copper and gold phase diagrams. Silver-copper as usual, as eutectic phase diagram between themselves, classical eutectic phase diagrams. Silver and copper both are FCC, but they form FCC where this eutectic phase diagram instead of isomorphous, because their atomic size difference are large, that is why. So, it values the (Refer Time: 07:55) rule. As you see here, there is a solid solution of silver, solid solution of copper, eutectic reaction between solid solution of silver and the copper in which liquids decomposes to those two solid solutions.

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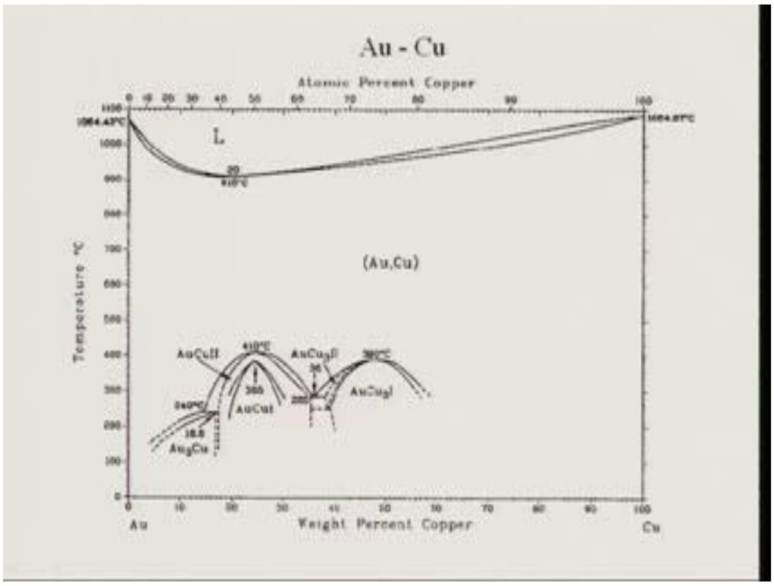

Now, between gold and copper there is, at high temperature between the liquid and solid phase diagram is isomorphous type with a congruent melting at 810 degree Celsius temperature at 28 percent of copper. But a lower temperature solid state, there are intermetallics compounds forms like Au 3 Cu, AuCu 1, AuCu 2, AuCu 3, AuCu 3, these compounds are actually truly intermetallic and they have many distinctive features like they undergone (Refer Time: 08:42) transformations. So, we will, which we will not going to discuss in detail.

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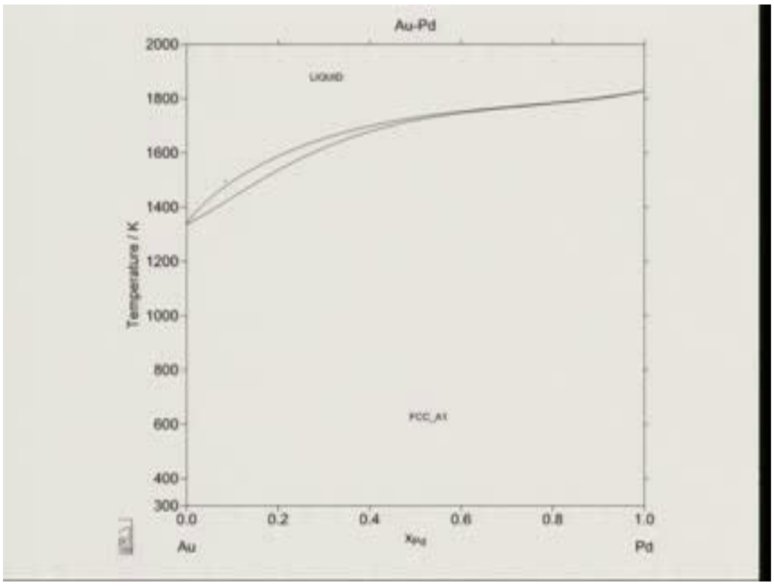

Then, between gold and palladium, in fact, I should have shown you earlier, this is the isomophous phase diagrams in forms. If you can see here, the gap is more on the gold end, but very small at the palladium end.

So, once you have such a kind of phase diagram in which two systems form isomorphous and one system forms eutectic, you will have a three phase equilibrium system, right. So, let us now look at it, the three phase equilibrium system on the board.

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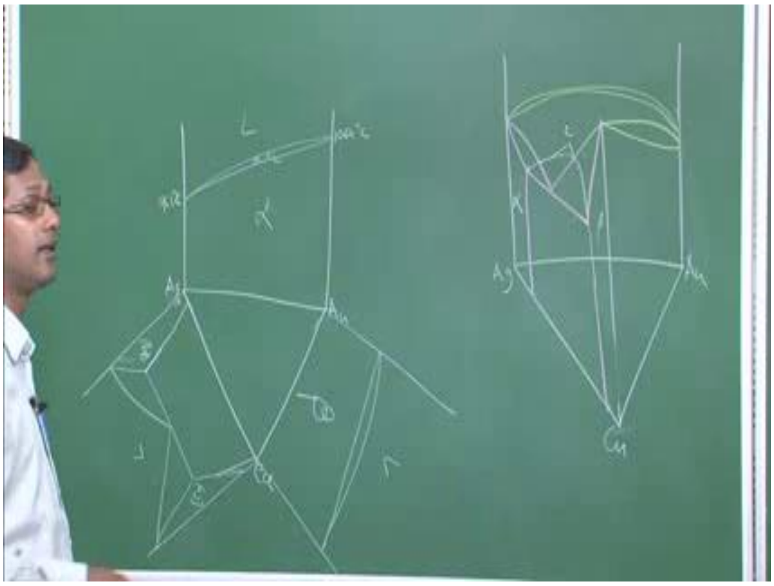

So, gold-silver, gold-palladium and copper; silver, sorry, silver, silver-gold and copper, I am sorry, I made a mistake. So, between silver and gold here you have isomorphous system little bit more. So, between silver and gold you have isomorphous system. You have seen very small gap, 961, 1064 between gold and copper, between gold and copper.

You have again another isomorphous system. As you see, the melting temperature is similar, 1084 for gold, 1064 for the silver; I am not drawing the lower, low, temperature phases. There are low temperature phases we have shown you and between silver and this is silver, right, yes, silver, copper, you have eutectic phase diagram. Silver solid solution, copper solid solution, there is liquid, there is liquid, alpha plus liquid, alpha, beta. Now, we need to built the, sorry, we need to build the phase diagrams of the, in the ternary system.

Well, let us, not difficult, but it is little bit of different from earlier one. So, silver, gold and copper. Silver-copper has this kind of phase diagrams and gold-copper and this one has isomorphous systems. So, and silver gold like that. So, what will happen is this because of presence of this eutectic, the ternary phase diagram will be extended. This, this will increase the miscibility, this will increase the stability of this phase or let us write down this one like this, alpha, beta, alpha, beta, this is beta, this is yeah, that is all.

So, so as you see, this is in a ternary system, this will be like this and then C like that, C will be here, probably you should remember that that because of the presence of the eutectic, the solubility or the presence of this alpha phase will extend beyond even this line little bit instead ahead of the point, ahead of this curve, which is marked by the point C. Here, C is little bit ahead and I discussed you why it should happen. In the class you can go back to my lecture.

So, this is what it will look like. If I remove this part which is not required, then that space model will be like that. Now, what I have shown you, not a very difficult thing to understand, correct, so this, the phase diagram for silver, gold and copper. Now, I am going to show you example of a phase diagram where there are four phase equilibrium exists. This is the three phase equilibria between liquid because this is, reaction is (Refer Time: 15:08) is, liquid going to copper and silver.

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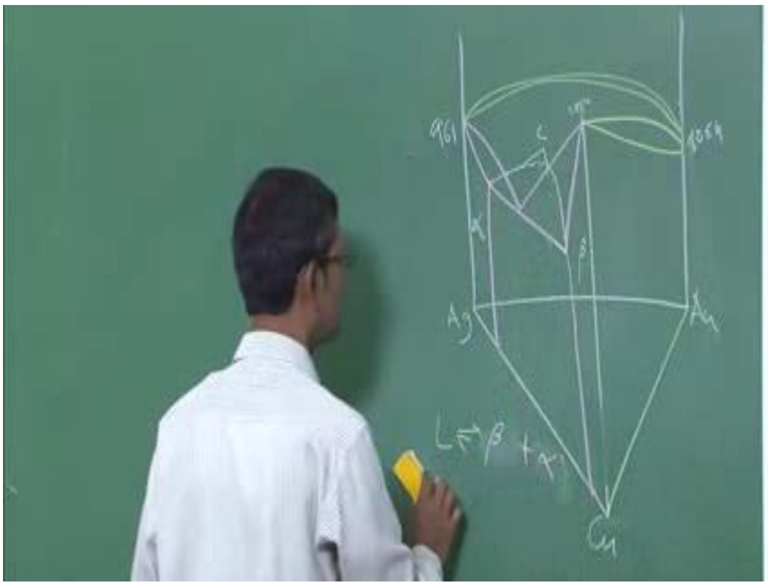

So, therefore, the three phase equilibria exists into the ternary system between solid solutions of copper and silver and I have written this as alpha, this as beta, right. So, that will extend inside the ternary system, that is what is, you should remember. These are the melting temperature, 961, 1064, 1884; that is how it will be.

So, now let me show you the ternary eutectic phase diagrams with example of showing the four phase equilibria I have drawn many, but let me just show you.

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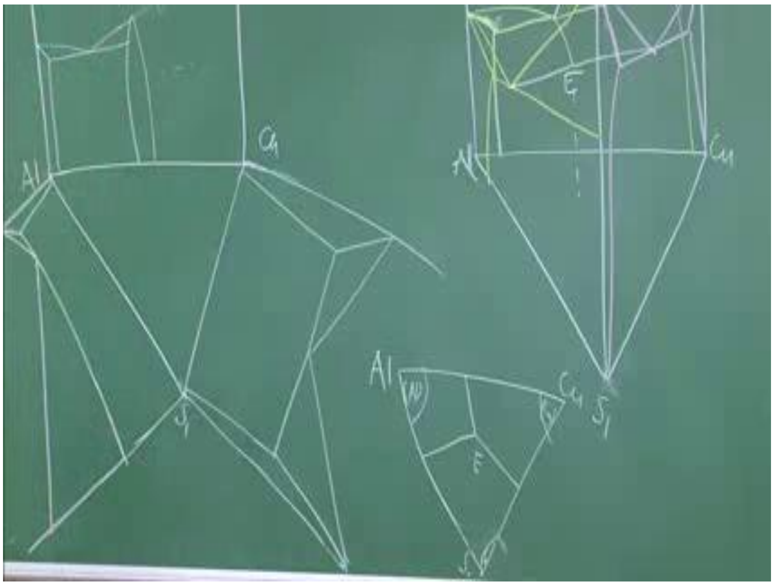

Let me just draw the aluminum, copper and silicon. Aluminum-copper phase diagram is very, very complex and aluminum-silicon is easy. This aluminum-silicon eutectic phase diagram, 660, this will be higher. Aluminum-copper phase diagram is exactly, usually similar with the eutectic, I am not going to draw the, all the other things. This part, there are many intermetallic phases presence, but copper-silicon is also easy, not difficult. Oops, sorry, this will be much above.

So, now basic idea is to, what is the inside thing? How the phase diagram will look like? Well, it is little bit complex than the earlier one, but not a difficult things to do. You remember that I have shown you eutectic between aluminum, silicon and the copper. So, between aluminum and silicon it is easy; copper and silicon is also easy, not difficult; aluminum-copper, oops, it will be lower. So, I am just drawing the half part of the aluminum-copper phase diagram, up to 40 percent.

So, now because of presence of these three eutectic one two and three, we will have a ternary eutectic point existing in this triangle correct. So, if we, if I draw this projection under the ternary triangle, aluminum solid solution, copper, silicon, silicon will not be like this, it will be like that. Aluminum has no solid solution, in silicon this is a ternary eutectic, this is how it will look like. So, you got an fair idea, fair amount of idea how this diagrams to be drawn, correct, and these are all very schematic diagrams, which I have shown you.

Now, let me take, take you, whatever time I have in this lecture for the, aluminium, iron-chromium-nickel system with stainless steel, correct. Stainless steel is basically what? It is a very low carbon steel in which primary (Refer Time: 21:51) elements are chromium and nickel. Classical stainless steel is 18-8, you know, in which you have 18 percent chromium and 8 percent nickel, but concentration of nickel and chromium can very actually, normally, 75 percent is iron and 20, approximately 24.8 percent is your chromium and nickel and rest is carbon, silicon, manganese, carbon, manganese, phosphorus, sulphur all those elements.

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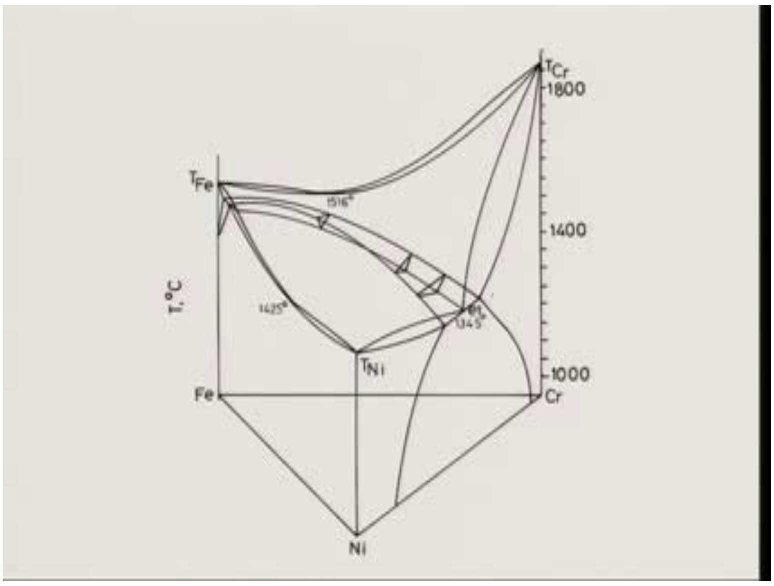

So, first of all what are the binaries phase diagrams between iron and nickel? Your binary phase diagram in which there is a peritectic reaction in the iron end, right. You can see clearly, this is the peritectic reaction. On the other hand, between nickel and chromium, there is a eutectic reaction here, you can see here, above 1345. But between iron and chromium you have isomorphous phase diagrams with a common melting point at 1560, 16 degree Celsius temperature. Remember, chromium melt at a very high temperature, about 1900 plus degree Celsius temperature, correct. Iron melts about 1539 degree Celsius temperature nearly, nickel melts about 1456 degree Celsius temperature.

So, because of this presence of these peritectic on iron and nickel and eutectic on the, iron and, nickel and chromium, you will have a three phase equilibrium existing and that three equilibrium can by generated by drawing the eutectic point to the peritectic point by these kind of constructions along with the solid solubility limits on the both sides, the nickel side and the chromium side with the peritectic isotherm, correct. You could see how this has joined, this point is joined to this way and this way and this point is joined there, little bit different, but you have, must look at that. They are not directly connected from these to these, but this one is connected to the peritectic, you know, solid temperature, solid point and this one is connected to the peritectic. This is the limit of solid solubility iron in nickel and this one is connected to this end liquid composition for the peritectic reaction.

This is the ternary phase model not very complex still understandable important thing is that, so that means, you have a ternary phase, three phase equilibria existing between iron, nickel and chromium. This three phase equilibria is show by triangle, correct.

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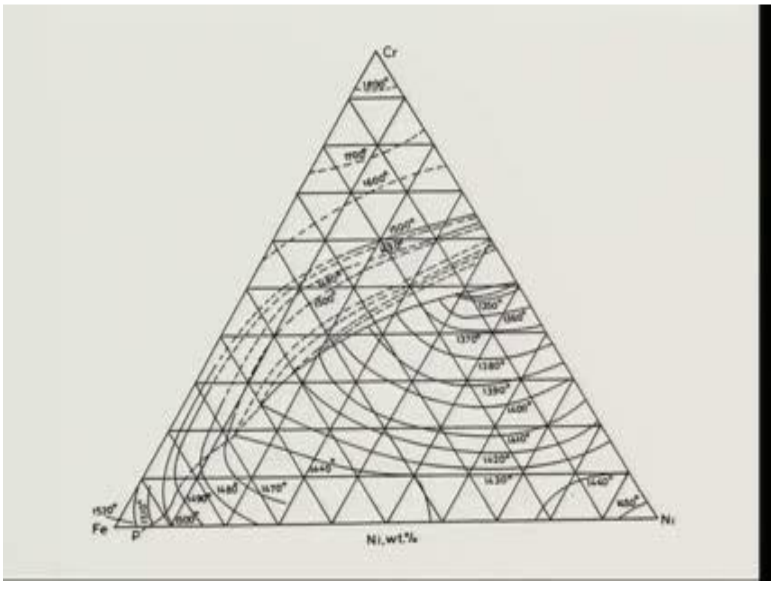

Now, I can project all this things on to the, on to the triangle, on to the Gibbs triangle. This is, you see here, these are, these projections of the liquid is 1450, 1440, 1470, 1480. This is from iron end, so it has to be starting with 1539, 1520, like that. And this is the peritectic point, this one binary peritectic point, correct; shown here. Similarly, on the nickel-chromium side, eutectic point existing where it is about chromium region in between somewhere; this is the eutectic point and there is nothing, there is no (Refer Time: 25:02) system.

So, these are the, these are, these things, this is the binary phase fields of, chrome, nickel solid solution, binary phase of chromium solid solution, binary phase of iron solid solutions and the peritectic reaction is between where is a compound formation in the iron-nickel system.

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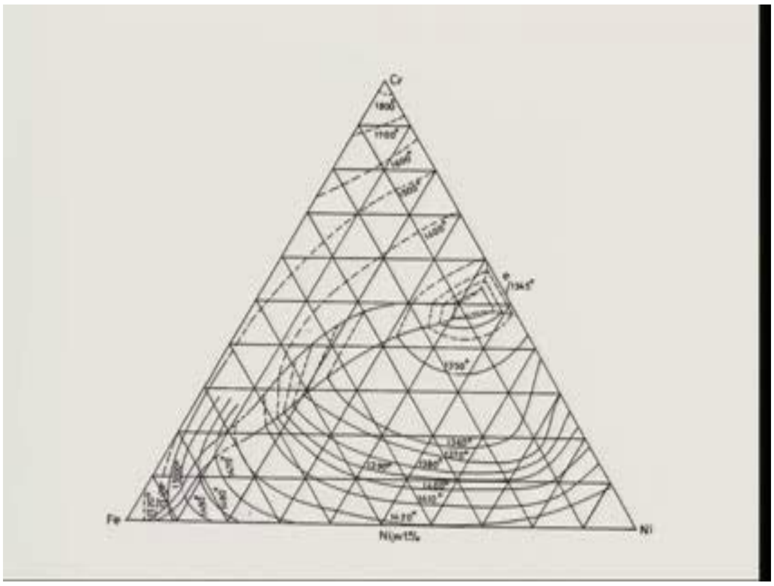

Secondly, well these are all done in different temperature I guess, that is why, anyway. So, you see here, this is a eutectic point here, clear. So, you, peritectic point was, sorry, peritectic point was clear here at 1500, 1539, 30, 10 degree Celsius temperature. Eutectic temperature comes around little lower, 1345 and reaction shows, that these isotherms actually passing the, this eutectic domain.

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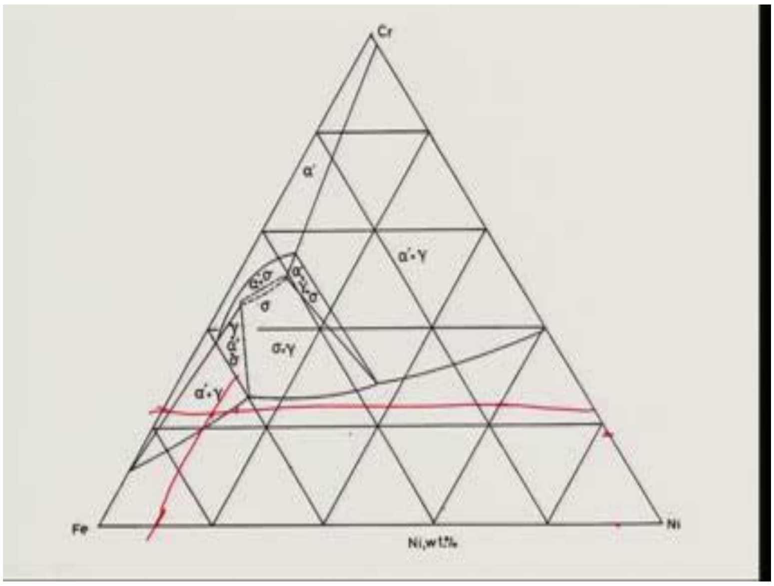

And lastly, at much lower temperature, that is, when everything is solidified, what you have is basically, you see here, this is alpha prime, solid solution of chromium, gamma is a solid solution, (Refer Time: 26:07) solid solution of iron. And what is another important aspect is that iron-chromium system at lower temperature, there is a phase called sigma forms. Sigma is usually intermetallic compound and this sigma actually forms like a, by a monotectoid transformation. It is not easy monotectoid transformation, there is a spiral type of transformation that is why, which is shown between alpha and sigma, alpha plus pi plus sigma, alpha pi gamma plus sigma and sigma plus gamma at different temperatures. So, these are all the phases which are presents.

So, normally the iron concentration is 75 percent here and chromium is 18 percent. So, it will be somewhere like here, chromium, nickel is 8 percent. So, here, and this is 20 suppose, this is, should be 8 percent. So, iron is 75 percent. So, 75 percent iron will be, this is 100 percent somewhere there. So, if, if I connect these three points, nickel, now this is chromium, right, sorry, chromium is here, that is okay, nickel is this, no, nickel is somewhere there, 8 percent, correct. So, if I connect these three, this two are connected, okay, somewhere there. So, that is what actually the normal stainless steel composition. It is a gamma solid solution phase, this is the gamma region and if you want alpha you can actually get alpha also.

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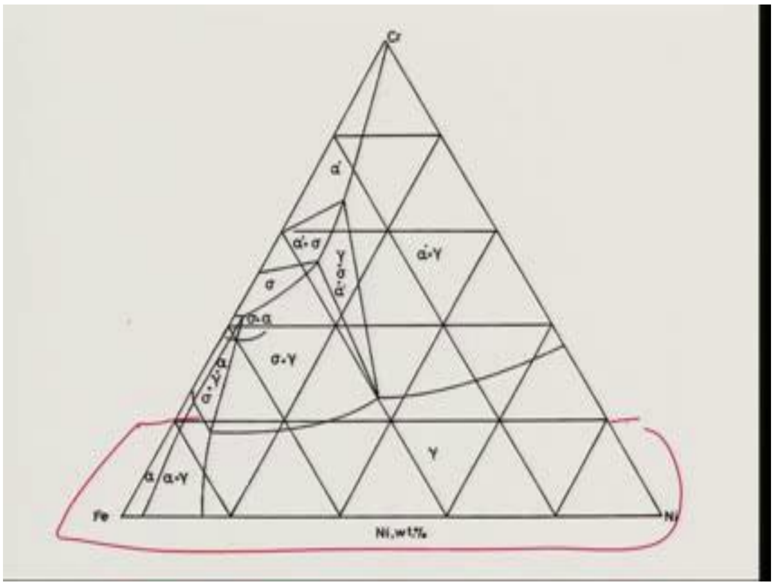

This is at little lower temperatures, only thing expand is, the gamma field is expanding much larger domain, that is what i said. The, this is, this is what this is the stainless steel composition normally looks like, the 18-8, this is gamma. And if your, chromium, nickel composition decreases, then you will have alpha plus gamma and when nickel concentration is very low, you have alpha stainless steel. So, normally you should consider these part of the phase diagram for that, not above that. So, we do not want the sigma face formations or those kinds of things.

But it can happen that compositions with the grain boundaries may change during welding or something, then sigma can precipitate and this is what is known as sensitization of stainless steel, correct.

With this I like to say, that stainless steel phase diagram is much simpler than you think and this can be easily explained using the iron-chromium, iron and nickel binary phase diagrams. So, in the next class I am going to take up the first super alloy phase diagrams are followed by this ceramic phase diagram.

Thank you.