Welding of Advanced High Strength Steels for Automotive Applications

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Lecture - 16
Microstructural Evolution During Welding of Advanced High Strength Steels

So we are looking at the effect of the alloying elements particularly silicon aluminum on the evolution of micro structures.

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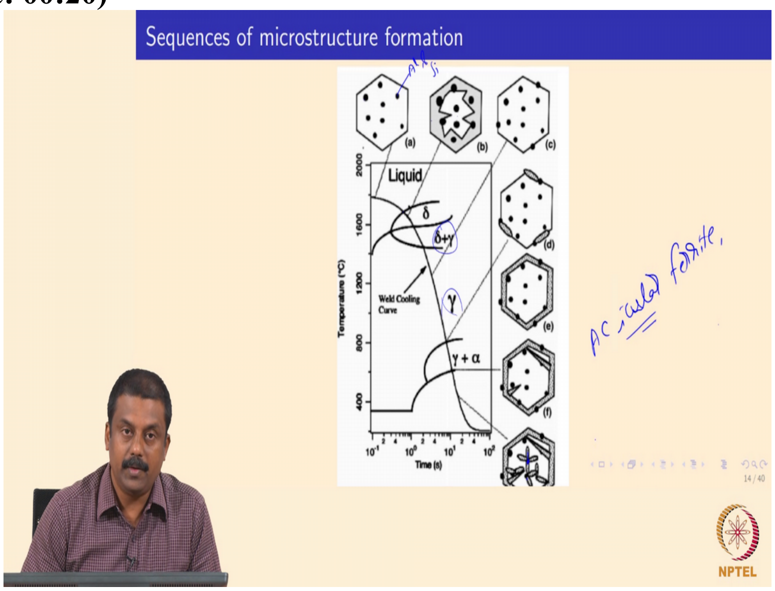

So, if you look at the sequence of micro structure formation in on in steels the first reaction you would expect to see even much before the solidification started seen inclusion formation. So, if you look at the first reaction that happens in and in a microstructure evolution is the inclusion formation and inclusion forms much higher temperature than this solidification in a liquid regions, especially, if you have an oxidizing elements such as in a silicon aluminum, you readily oxidized the these elements in a liquid stage and you form the oxides of aluminum and silicon.

And subsequently when you cool down the upon reaching the solidification start temperatures. So you will nucleate delta ferrite in steels even in advance high strength steels in a convinced advanced high strength steels like in a DP trip when you will solidify first into Delta ferrite and subsequently the alloying elements either can go to liquid or I can even partition towards delta ferrite and especially in aluminium and other elements.

We tried to partition towards liquid and subsequently and solidification completes you know it becomes it undergoes during solidification based on the carbon concentration a protecting reaction and then fully aesthetic microstructure develops and subsequently know your; the best on the cooling rates also austenite can transform into low temperature products or even martensitic based on the cooling rates.

So, in this reaction if you look at it the first rate controlling reaction for subsequent microstructure evolution is the inclusion formation. So inclusion can be engineered to our favour. So, you know, for example, and if you have an size controlled inclusion that are formed and the inclusions are all also act as a potential nucleation sites for these and the subsequent phase transformation from austenite to room temperature.

For example at the acicular ferrite is known to nucleate on the inclusions non-metallic inclusions present in the microstructure. So, if you carefully control the inclusion density in size and volume fraction and we may also promote the nucleation acicular ferrite when the austenite is cooling to room temperature. Then the nucleation of acicular ferrite is seen as advantageous because acicular ferrite gives the best tough and micro structure in terms of properties having an acicular ferrite microstructure is beneficial instead of having an, a fully martensitic microstructure.

So, by carefully manipulating the size and volume fraction and we can also change the microstructure formation and when the austenite it transforms to in any other low-temperature products during cooling. So, the understanding nucleus formation mechanism is very important. We took to control the microstructure at subsequent cooling total temperature.

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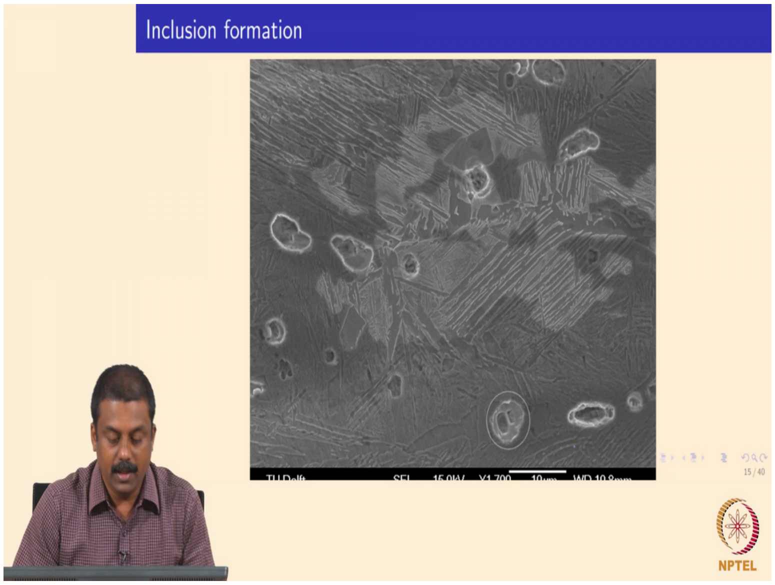

And if you look at an inclusion formation mechanism the as I said in the first reaction that happens when as whirlpool solidifies inclusion formation so inclusion can have can form at very high temperatures so when you expose the liquid pool to atmosphere or the even naturally gas it contains the contamination from oxygen and you the elements like aluminium silicon can readily combine and then form oxides. And these oxides can trap the earlier alloying elements in the liquid onto a surface.

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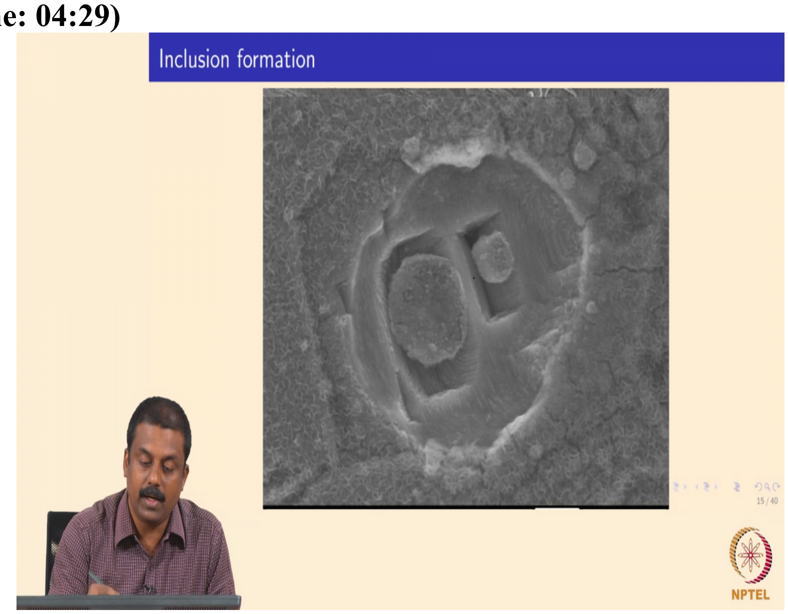

For example if you look at in a typical inclusion in advance iron and steel, what you see over here, is the a globular oxide inclusion in this case. So, this steel, in this case, it is in a silicon based inclusion. So you are taking to be a trip steel and so they say what to silicon oxide for example so once you have an oxide formed the other alloying elements like the manganese and the sulphur they are all getting trapped on the surface of the inclusions, wherein you have an epitaxial enrichment of these alloying elements.

Like for example, manganese silicon would go and enrich these surfaces and we will end up forming the layers of nonmetallic inclusions where the oxides on the center and then because of the a epitaxial enrichment of other alloying elements will end up forming silicon oxide manganese sulphite and so on, so forth in a subsequent cooling.

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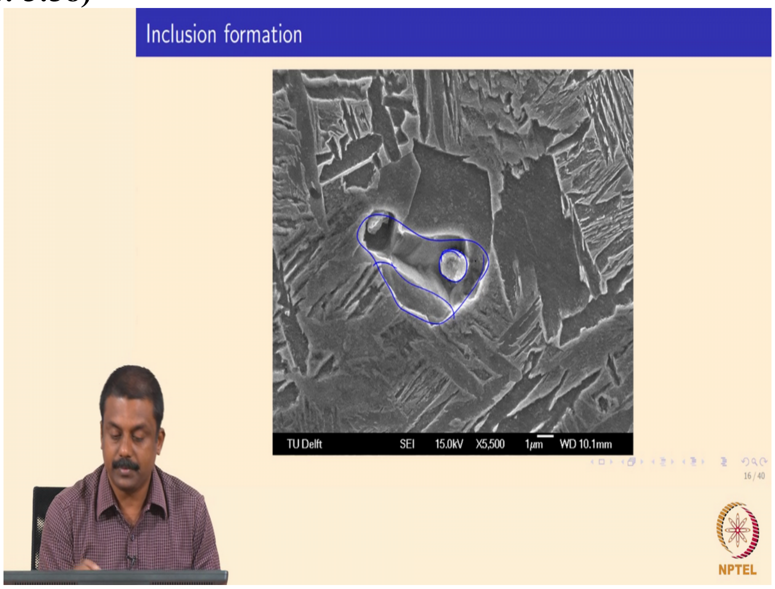

And you see in a various morphologies based on the temperature also forming so you have an invariably at the middle you have oxides of silicon and aluminum and then an epitaxial enrichment of the other inclusions that are formed in and around the oxygen inclusions.

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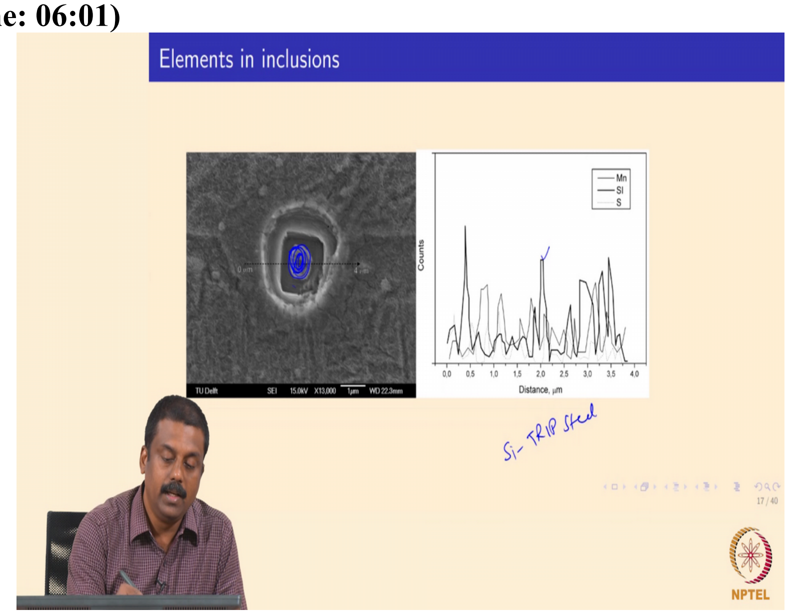

And if you look at the elemental mapping like it can it can be very clear. So, if you look at the distribution of alloying elements in the middle so this is a oxide, so in this case and it is trips silicon based trip steel. In the middle you have an enrichment of silicon and so we will have an silicon peak and subsequently once you have a silicon oxide formed and it traps the elements like manganese and sulphite and then you will have an manganese sulphite forming, surrounding the oxide that forms at high temperature.

And so you will have and a typical non metallic inclusion, containing silicon oxide at the center and then manganese sulphide surrounding the silicon oxide.

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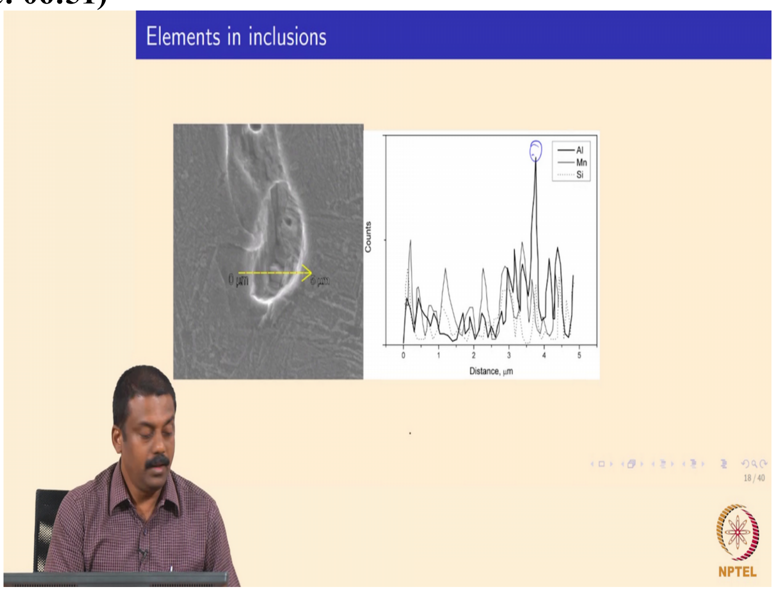

So, same way we find it in aluminum based trip steel as well. Again aluminium oxide forms even higher temperature than silicon oxide and you will have an aluminum oxide formed and subsequently you will have enrichment of silicon and aluminum oxide. And you will have a silicon oxide surrounding the aluminium oxide and subsequently you will have a manganese and sulphur enriching these oxides and forming a complex and on metallic inclusions.

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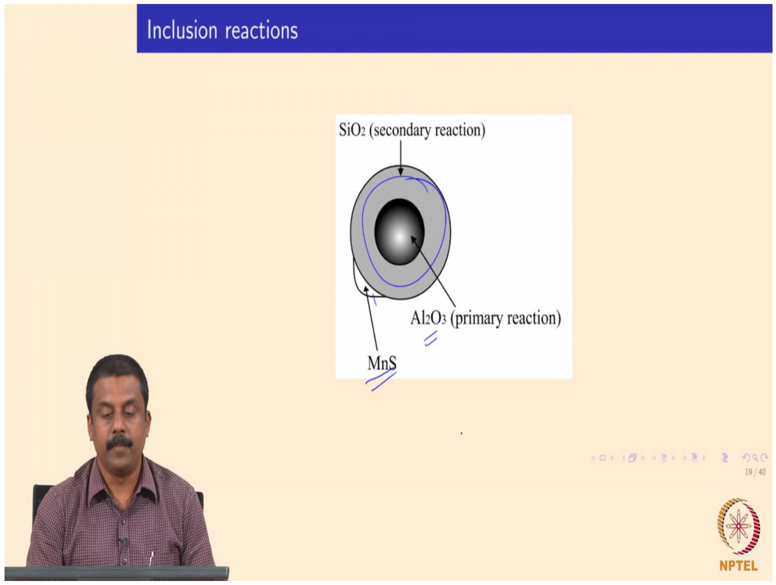

So, the mechanism of inclusion formation in advanced high strength steels welds, it is as in a conventional inclusion formation, you will have an first aluminum oxide formed, so, invariably in the trips steels containing aluminum. So, you first form an the core of aluminum oxide and once you have an aluminium oxide nucleation and then you will have an enrichment of silicon oxide. In this term silicon leading to silicon oxide formation surrounding the aluminum oxide and subsequently manganese, sulphur can also enrich another forming manganese sulphide.

So, the inclusion forming morphology appears complex with the presence of oxide core and then subsequent engagement of manganese, sulphur leading to an a complex nonmetallic inclusion formation in an advanced high strength steels in weld pulls, especially, if you have the highly oxidizing alloying elements like aluminum and silicon.

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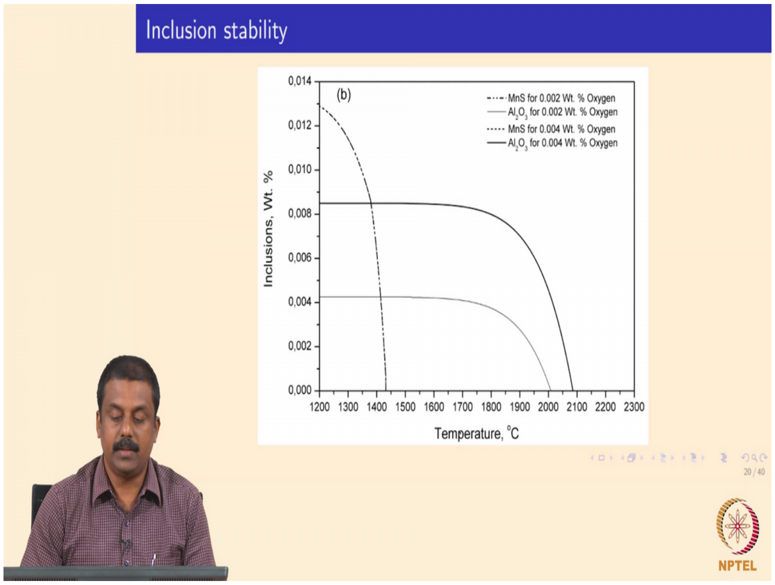

And inclusion stability is also affected by the presence of varying amount of oxygen in the atmosphere. So, if you have shielding gas, when you use a backing gas in a GMAW or if use an sort of a cover the backing gas in SME building the process of oxygen should be controlled significantly and if you change the oxygen concentration in the weld regions. So your, the inclusion information the kinetics of inclusion formation can also be changed significantly.

For example, in this graph, I show and the weight fractions of inclusions that are commonly observed and the weight percentage of inclusions are commonly observed in trip Steels as a function of temperatures with two different oxygen concentration in the whirl pool when you are exposing the whirl pool of aluminum containing trip steel with two different oxygen concentration and you will have sorry this in 20 ppm and 40 ppm of oxygen.

So, in higher oxygen concentration if you have 40 ppm of oxygen, the inclusion formation temperature is about 2100 centigrade and subsequently I know they, say, when you cool down so obviously you tend to form more volume fraction of oxygen inclusions and you end up having and 0.08 percent of inclusions. So, if you if you decrease the oxygen concentration obviously the amount of nonmetallic inclusions you form it also decreases.

And subsequently when you cool down because of an entrapment of manganese and sulphur and the inclusions oxide inclusions you will also have a manganese sulphide form it. And the manganese or formation of manganese sulphide is not influenced by oxygen. So the oxygen would severely affect the volume fraction of oxide inclusions that are present in the whirlpool. Similarly the same behavior can be also be observed in silicon-based trip steel.

So, if you increase the oxygen concentration present in the pool to react with the silicon in the liquid metal and you may also change the inclusion volume fraction as well as the kinetics of inclusion formation. So, if you have a high amount of oxygen you may also have a more volume fraction of in silicon oxide. And now and if you decrease the oxygen concentration the inclusion consolation in the microstructure also decrease significantly.

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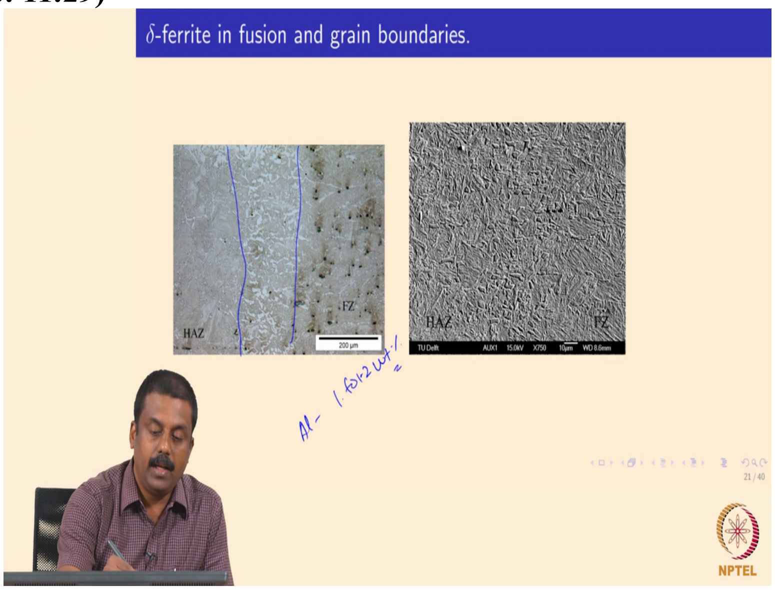

So, the other effect what we generally see in an aluminum based trip steel is the partitioning of aluminium to Delta ferrite. And this can be seen in almost all the welding processes, when you either use a laser resistant spot welding, laser beam welding on or gas metal arc welding and you see an stabilization of Delta ferrite especially if you have an aluminium concentration ranging from say 1 to 1.2 the weight percent.

And you will have a distinctive layer of delta ferrite stabilizer at the fusion boundary as well as along the grain boundaries when you have partitioning of aluminium to delta ferrite. So, how it happens?

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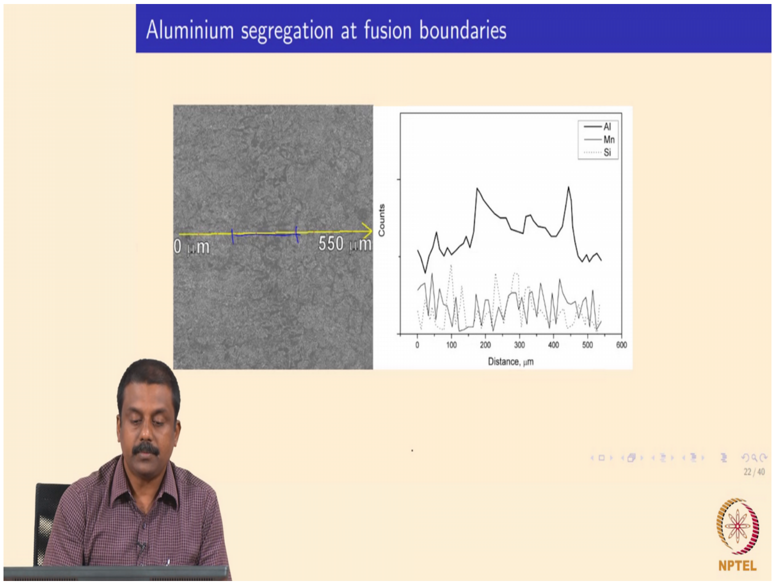

So, this stabilization may be, if we look at an elemental mapping, elemental analysis along the fusion boundary if you look at it in a trip steel containing aluminum, the weld the fusion boundary you would see when you have an a delta ferrite stabilizer at the fusion boundary you will have increase amount of aluminum at those regions. So, what does aluminium do? When aluminium is present in the pool, when solidification happens, so, aluminium is the in this system is only alloying elements which actually partitions to the Delta ferrite during solidification.

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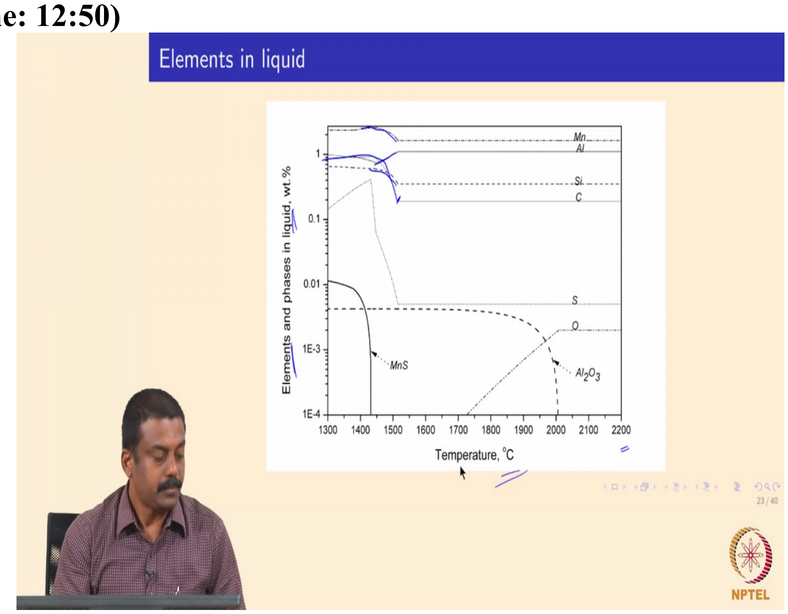

So, if you look at this the graph what I show here the amount of elements present in the liquid entirely amount of elements present in the liquid as function of temperature. So, if you look at carbon it is even starting from the temperature of 200 degree centigrade. The carbon is in the liquid present and the moment you have solidification, then what happens carbon? Carbon tends to go to liquid and segregate liquid.

That means that when you have a delta ferrite solidifying liquid and Delta ferrite sends the carbon or the partitions the carbon to the liquid and because of that you have an enrichment in carbon in liquid right. And similarly the manganese also have a similar partitioning behavior and silicon as well and a partition to liquid; whereas in aluminium it has an opposite partitioning behavior compared to carbon, silicon, manganese.

So, aluminium partitioned towards the Delta ferrite that means that liquid is depleted in aluminium, okay. So, the aluminum is segregates to the Delta ferrite and because of that once you have aluminum concentration into the delta ferrite it increases significantly the Delta ferrite stabilizes to room temperature.

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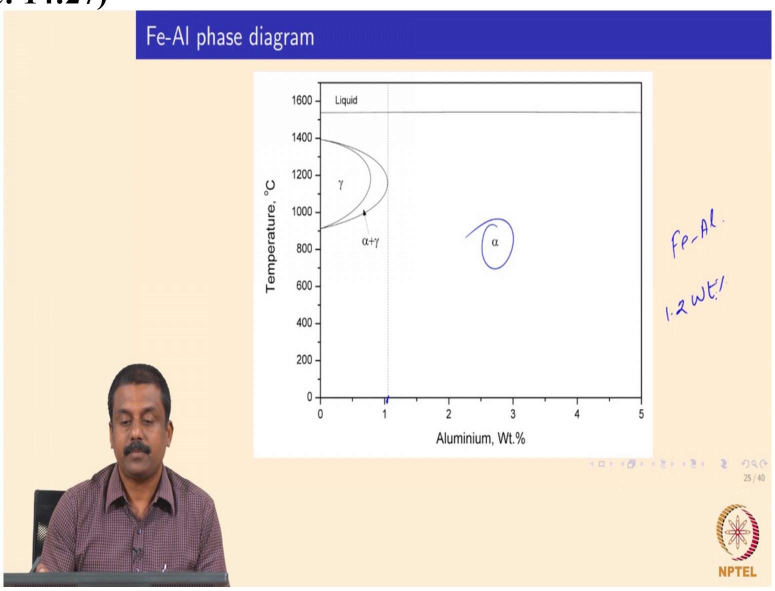

So, for example, if you look at the maximum aluminium concentration in ferrite, so it can go as is say, for a given now, 1.1 bulk aluminum concentration, so when solidification happens and you can go as is 1.2, 1.3 in the Delta ferrite. So, once you have aluminum concentration goes beyond 1.2 if you look at an a conventional and aluminium phase diagram. So, when aluminum concentration in goes above so 1.2 and you stabilize ferrite.

So, because of the partitioning of aluminum to the Delta ferrite when the solidification happens to aluminium based trip steel when the Delta ferrite concentration goes above a critical limit and say in a pure aluminium system, if it goes on more than 1.2 weight percent roughly. And then, the system the microstructure is stabilized to an single phase Delta ferrite. So, that is what you clearly see in the aluminum containing trip steel fusion boundary.

So, when a liquid solidifies in a Delta ferrite, so aluminum partition towards delta ferrite and when the delta ferrite concentration in aluminum reaches beyond 1.2 weight percent and the delta ferrite cannot transform to austenite as for this delta ferrite remains as delta ferrite at room temperature even after cooling to room temperature. So, because of that know we have when a very soft the microstructure in between a martensitic microstructure in the heat affects zone as well as in the in the rest of the fusion boundary.

And leading to an stain partitioning when you are applying to load. We will see in detail how this delta ferrite can change the microstructure, their distribution, especially; the distribution of retained austenite and the mechanical properties of the elements because of these may be the presence of soft delta ferrite in aluminum based trip steel. And this effect is not seen in silicon based trip steel because silicon is not that effective in stabilizing a ferrite or even in stabilizing in the other elements or makers of the phases.

And because of very strong affinity for aluminum to delta ferrite and then the beyond the, say, 1.2 to 2 % 1.28 % aluminum if persent in Delta ferrite and Delta ferrite gets stabilized and then it cannot transform to austenite in subsequent cooling. So, if you look at it now the complexities in maximization development because of these alloying elements so we need to now understand the basics.

And without understanding these basics, we cannot modify the weld thermal cycle. So, I just showed you two examples of the effect of the alloying elements such as silicon aluminum which are very important to stabilize retained austenite and if you have these two alloying elements, you already see a tremendous change in the distribution of microstructure in the fusion boundary in the fusion zone microstructure.

So, we will go in detail how the other alloying elements behave during welding and how the microstructure evolves in the heat affected zone during cooling from high temperatures. We will also see how we can favorably modify the weld thermal cycles or add other alloying elements to our favor so that now we can minimize the damage those these alloying elements do to weld microstructure.