Weldability of Metals
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Lecture-26
Weldability of HTLA Steels-I

Hello, I welcome you all in this presentation related with the subject weldability of metals and now will be starting the weldability of the heat treatable low alloy steel. This is the new type of a steel and as for as the weldability of this steel is concern it is much more lower or much more difficult to weld as compare to the carbon steels or high strength low alloy steels or quenched or tempered steels.

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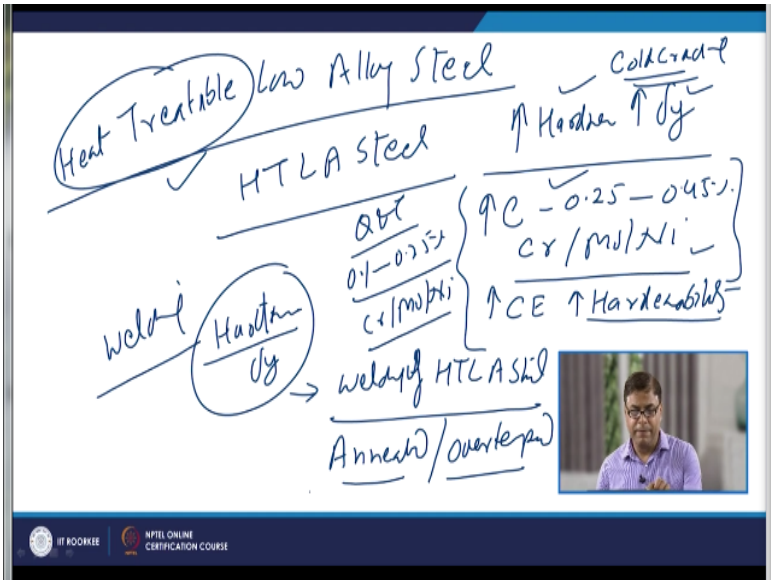

And reason for this is that the heat treatable low alloy steels, in short this is written as HTLA steel. This is these steels have the much higher hardness then the other category of the steels much higher yield strength. And these properties come basically from the higher percentage of the carbon content in these steels which ranges from the 0.25 to 0.45% along with the greater percentage of the chromium molybdenum and nickel.

So, combination of the higher carbon and higher percentage of these elements increases the carbon equivalent of these steels and because of the high carbon equivalent these steels offer

high hardenability. And due to these 2 properties high yield strength and the higher hardness and the third property higher hardenability these steels are very sensitive or cold cracking.

So, cold cracking and the embrittlement of the weld as well as heat affected zone due to the martensite formation, martensite formation are the main issues related with the welding of the heat treatable low alloy steel. If we compare it with the Q and T steels immediately which are heat treated for quenching and then tempering treatment. But the carbon content is lower 0.1 to 0.5% and similarly chromium molybdenum and nickel percentage these steels is also lower as compare to what we have in case of heat treatable low alloy steels.

So, to enhance their response to the heat treatment in these category of the steels the carbon content is increased and alloying concentration is also increased. So, that the response to the heat treatment can be enhanced as for as the welding is concern of these steels because of the excessively high hardness and the high yield strength these are difficult to weld. And that is why their hardness is required to be reduced, yield strength is required to be reduced.

And therefore welding of the heat treatable low alloy steel is normally carried out in annealed condition or over tempered condition. Both these conditions help in reducing the hardness and yield strength of the base metal.

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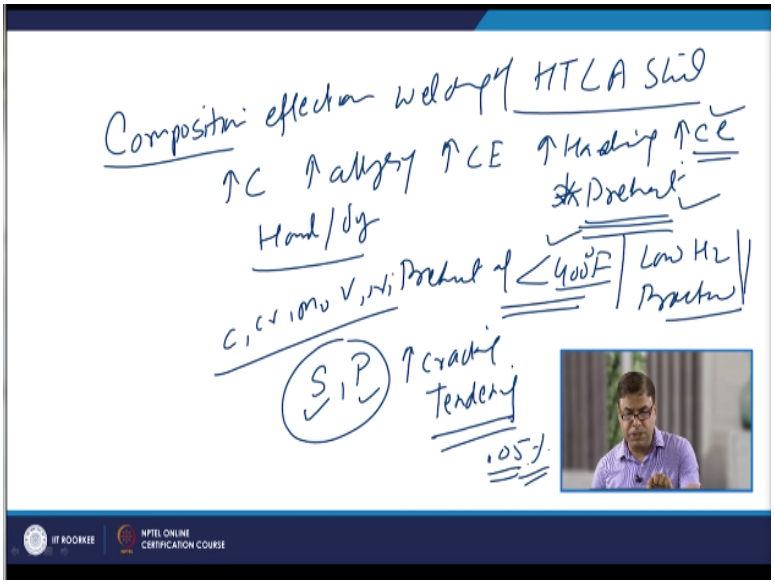

So, that after the welding these do not create much problem related with the residual stresses and the cold cracking tendency. Now apart from these general aspects if we go by the specific composition and it is effect on the welding of the heat treatable low alloy steels. So, as I have said higher carbon and higher alloying concentration leading to the increased carbon equivalent, increased hardenability.

And this in turn increases the cold cracking tendency and therefore preheat in these steels become very crucial means preheating becomes critical in order to lower down the residual stresses and lower down the hardness. So, that the cold cracking tendency can be reduced if the hardness and the yield strengths are extremely high. Then sometimes even preheat of temperature less than 440 degree Fahrenheit does not help much in controlling the cold cracking.

And we need to use the low hydrogen practices for welding, so that the hydrogen content in the weld metal can be reduced. So, for preheat less than 400 degree Fahrenheit low hydrogen control procedures should be used. So, that the hydrogen induced cracking or the delayed cracking or the cold cracking tendency can be reduced. Apart from the normal alloying elements like carbon, chromium, molybdenum, vanadium, nickel in these steels.

The 2 other elements play a very crucial role in these steels that is sulfur and phosphorous both these elements increase the cracking tendency in different ways. And that is why with the heat treatable low alloy steels the maximum limit of the sulfur and phosphorus is less than what is there in for the conventional other steels like 0.05%.

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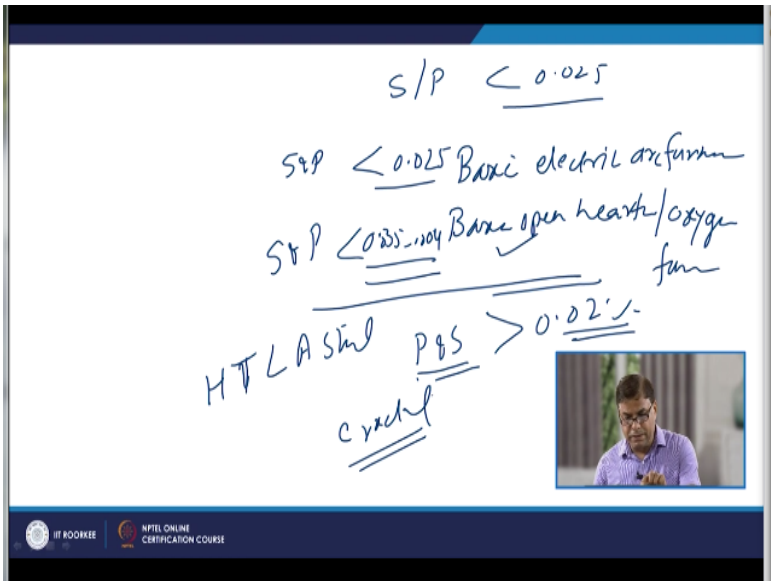

So, the steels which are made by the different processes, maximum allowed limit normally this should be less than 0.025% but for both sulfur and phosphorus. But the steels prepared using the process like the basic electric arc furnace. The maximum the sulfur and phosphorus content should be less than 0.025. While in case of the basic open hearth and oxygen furnaces the maximum allowed limit is less than 0.035 to 0.04.

So, less than 0.04 is the maximum allowed limit for sulfur and phosphorus for the steels made using the basic open hearth or the oxygen furnace. In these steels whenever in these steels means heat treatable low alloy steels whenever the phosphorus and the sulfur concentration is greater than 0.02% singly. Then it increases the cracking tendency and we need to be very careful in order to reduce the adverse effects related with these elements whenever the steel is having the phosphorus and sulfur more than 0.02.

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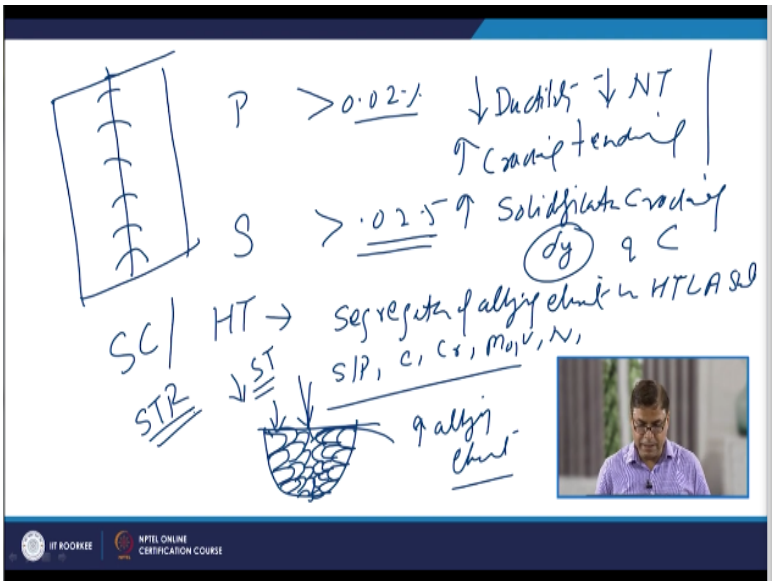

So, the phosphorus whenever it is present in quantity greater than 0.02% in steel it decreases the ductility of steel it decreases the notch toughness of the steel. And because of this the cracking reduced ductility and toughness promotes the cracking tendency of the steel. On the other hand when the sulfur is greater than 0.025% or 0.02% it increases the solidification cracking tendency of the weld metal.

And this increase in solidification cracking tendency in the weld metal is observed especially when the concentration of the sulfur is more and the yield strength of the steel is high carbon is more. And this the solidification cracking SC or hot tearing HEIGHT, hot tearing of the steel is attributed to the segregation of the alloying elements in the heat treatable low alloy steels at the weld center line.

Since the apart from the sulfur and phosphorus these steels have higher carbon and higher percentage of the alloying elements. These elements when the weld joints are made these elements tend to segregate like this is the plate being welded, this is the weld center line. So, when the weld is made like this at particular cross-section of the weld like this, the solidification proceeds from the fusion boundary towards the center like this.

So, solidification proceeds with the solidification of the pure elements and alloying elements are rejected in the molten metal. So, at the end what we have at the center the liquid metal is

enriched with the higher percentage of the alloying element, alloying elements are present more at the center. So, when the liquid metal is having the higher percentage of the alloying elements it reduces the solidification temperature.

And as a result of this 1 zone of the weld metal is solidifying at a higher temperature while other zone will center line zone solidifying at a low temperature because of the segregation of these elements. So, in nutshell our solidification temperature range is enhanced due to this segregation.

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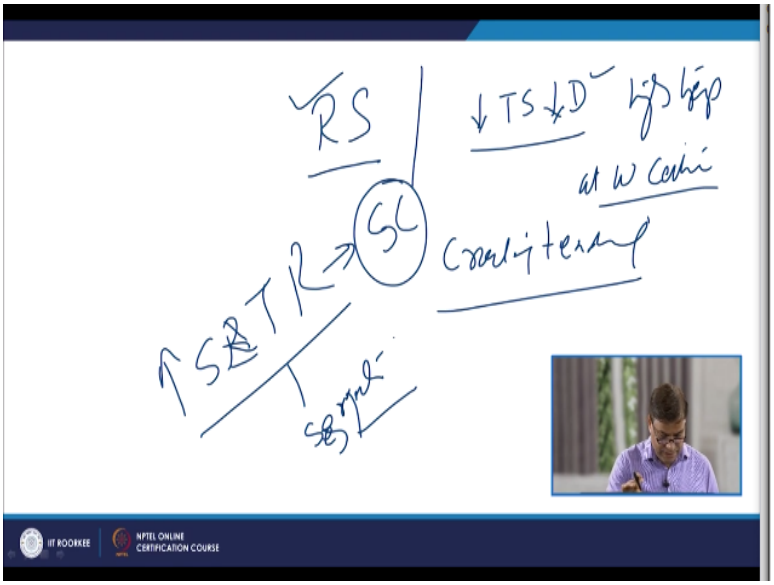

So, a combination of the residual stresses being developed due to the shrinkage of the already solidified metal and the presence of the low tensile strength low ductility metal at a high temperature at the weld center shows the cracking tendency. So, if we see the solidification temperature range is the solidification temperature wider solidification temperature range or increases solidification temperature range is the main cause which is happening due to the segregation of the alloying elements.

So, increases solidification temperature is promoting the solidification cracking that is happening due to the segregation of these alloying elements. So, tensile residual stresses lowest strength and low ductility of the metal at the center line at a high temperature is actually the cause of the cracking of the weld metal along the center line.

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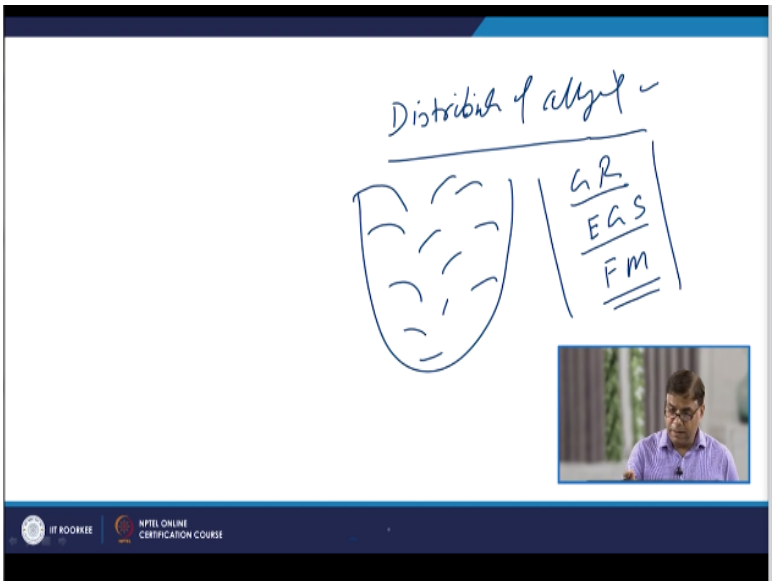

So, in order to control such kind of the cracking it is required that the distribution of the alloying elements is maintained properly and the segregation is avoided. And for that if the molten metal flow in the weld metal is maintained in such a way that the such kind of the segregation tendency is reduced then that will help in controlling the solidification cracking tendency.

Apart from that there are various other approaches like the grain refinement will help in improving the distribution of the alloying elements. And having the grain equiaxed grain structure will also help in reducing the segregation tendency especially at the weld center line improved flow of the molten metal at the weld. Then the change in orientation of the grains during the solidification, reduction in the grain size all these help in reducing the solidification cracking tendency of the weld metal.

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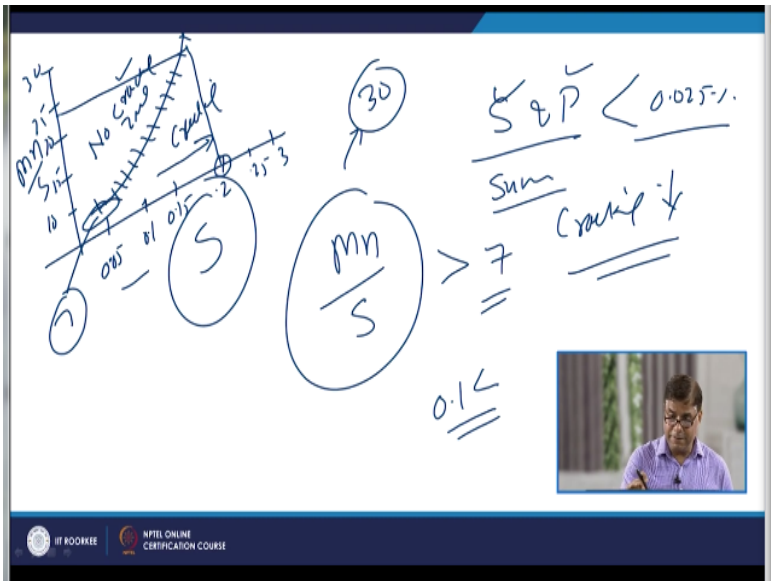

It has been observed in number of the heat treatable low alloy steels if the sulfur and the phosphorus content is less than some of both these elements is less than 0.025% then the cracking tendency is reduced. So, efforts are made that the impurities in form of sulfur and phosphorus which are present in the steel are reduced. And normally if the impurities in are present in form of sulfur then manganese to sulfur ratio is maintained in such a way that this ratio is greater than 7 for the steels having the carbon content less than 0.1.

But for the higher carbon contents this manganese to sulfur ratio can be as high as 30. So, there is a particular diagram which shows the kind of the here carbon content like 0.05, 0.1, 0.15, 2, 0.25, 3 like this. And here we have manganese to sulfur ratio, so manganese to sulfur ratio is like this here 10, 15, 20, 25, 30, so the kind of the ratio which is required to avoid the cracking.

Like this is the no cracking zone and this is the zone where cracking will take place. So, there is very wide band actually for this ratio. So, when the carbon content is very the manganese to sulfur ratio as to be like 7 but as the carbon content in the steel increases the manganese to sulfur ratio which is to be maintained for avoiding the cracking that also increases.

And like say for the carbon content 0.2% carbon content, manganese to sulfur ratio is coming out like 0.25 25 or more. So, the what manganese to sulfur ratio is to be used for avoiding the

solidification cracking or hot tearing tendency that will directly be depending upon the kind of the carbon which is present in given steel.

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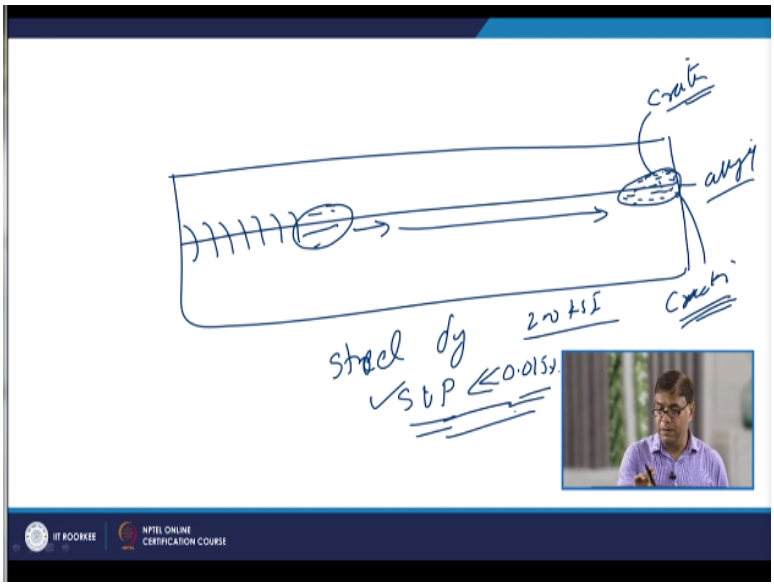

Now we will see that during the welding when the welding is performed so the weld metal is deposited like this and the molten metal pool will be moving in this manner. So, when this portion when the pool reaches means as soon as the welding is completed and we reach at the end of the weld center lines. So, near the end where the weld terminates this zone is the crater where we will see the alloying concentration is high.

So, at this zone where the concentration is high will automatically see number of the crater cracks are present. Cracks in the crater where the weld terminates number of cracks can be seen and those are attributed to the presence of this alloying elements. But when the steel is of the very high yield strength sigma y is of the 200KSI. Then the sulfur and the phosphorus concentration should be maintained less than 0.015.

Because the higher the strength greater will be the cracking tendency and that is why we need to maintain the sulfur and phosphorus content as less as possible.

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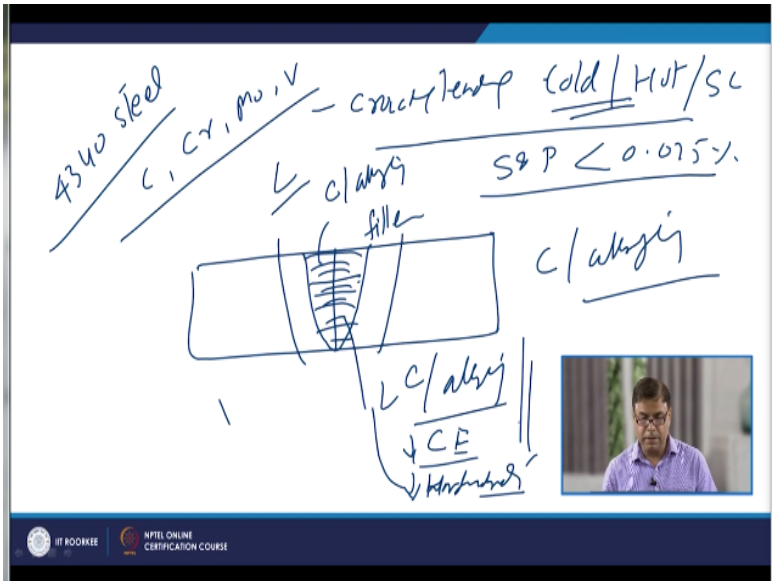

Now we will see there is one typical category of the heat treatable low alloy steel that is 4340 steel. This steel has the higher carbon, higher chromium, molybdenum, vanadium percentage and because of the higher concentration of these alloying elements it shows the cracking tendency. Both cold cracking as well as hot cracking or the solidification cracking tendency.

It has been observed for this steel that if the sulfur and the phosphorus content is less than 0.025 in these steels. Then the such kind of the cracking tendency especially the hot cracking or the solidification cracking tendency of these steel is found to be significantly lower. Since the carbon and the alloying concentration in these steels is high. So, for development of the weld joints which do not show much of the cracking tendency normally the fillers are used which are lower in the carbon and the alloying content.

So, low carbon or low alloying fillers are used, so that whatever weld metal is made that is of the low carbon and the low alloying concentration. And this in turn will be leading to the reduction in the carbon equivalent, reduction in the hardenability. So, reduced hardenability of the weld metal in that case will be leading to the reduced embrittlement tendency of the weld metal because the filler metal will not be doing much or anything with the heat affected zone.

So, Hz properties are not much affected because of this but the weld metal embrittlement and the cracking tendency is reduced when we use the low carbon and the low alloying concentration in the filler during the welding of the heat treatable low alloy steel

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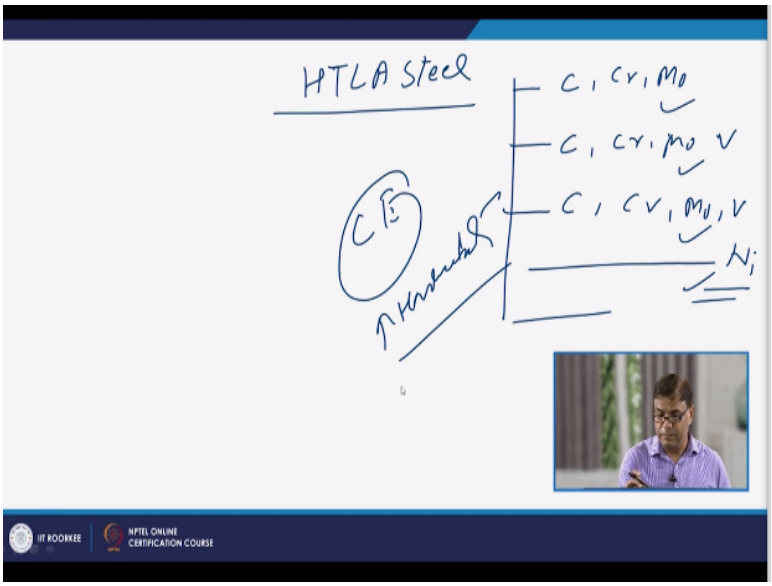

Now we will see the heat treatable low alloy steels significantly differ in terms of the kind of the elements which are present in 8, they are various categories of the Q and T steels few will be having higher carbon, chromium, molybdenum only. While others will have carbon, chromium, molybdenum and vanadium also while there is category of the heat treatable low alloy steels which will have carbon, chromium, molybdenum, vanadium as well as nickel.

So, there are different types of the steels as per the kind of the alloying concentration and their weightages the carbon equivalent will be affected which in turn will be governing the hardenability of the steels and accordingly the response to the heat of the welding will be observed. So, now we will see some of the compositions which are related with the heat treatable low alloy steels.

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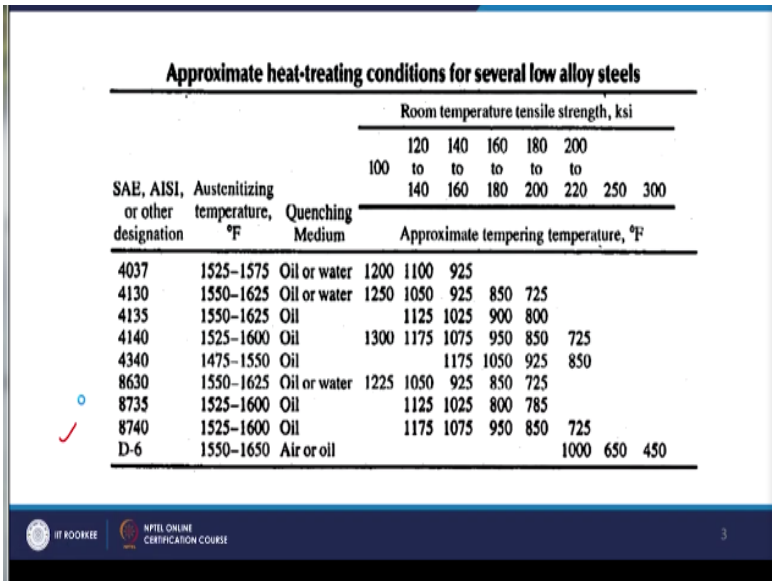

Approximate heat-treating conditions for several low alloy steels

SAE, AISI, or other designation	Austenitizing temperature, °F	Quenching Medium	Room temperature tensile strength, ksi: 100	120 to 140	140 to 160	160 to 180	180 to 200	200 to 220	250	300
			Approximate tempering temperature, °F							
4037	1525–1575	Oil or water	1200	1100	925					
4130	1550–1625	Oil or water	1250	1050	925	850	725			
4135	1550–1625	Oil		1125	1025	900	800			
4140	1525–1600	Oil	1300	1175	1075	950	850	725		
4340	1475–1550	Oil			1175	1050	925	850		
8630	1550–1625	Oil or water	1225	1050	925	850	725			
8735	1525–1600	Oil		1125	1025	800	785			
8740	1525–1600	Oil		1175	1075	950	850	725		
D-6	1550–1650	Air or oil						1000	650	450

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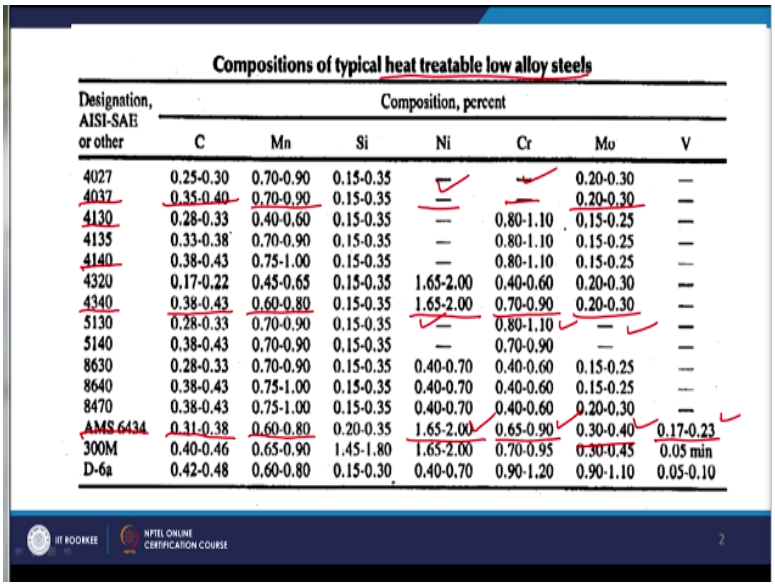

Compositions of typical heat treatable low alloy steels

Designation, AISI-SAE or other	Composition, percent: C	Mn	Si	Ni	Cr	Mo	V
4027	0.25-0.30	0.70-0.90	0.15-0.35	—	—	0.20-0.30	—
4037	0.35-0.40	0.70-0.90	0.15-0.35	—	—	0.20-0.30	—
4130	0.28-0.33	0.40-0.60	0.15-0.35	—	0.80-1.10	0.15-0.25	—
4135	0.33-0.38	0.70-0.90	0.15-0.35	—	0.80-1.10	0.15-0.25	—
4140	0.38-0.43	0.75-1.00	0.15-0.35	—	0.80-1.10	0.15-0.25	—
4320	0.17-0.22	0.45-0.65	0.15-0.35	1.65-2.00	0.40-0.60	0.20-0.30	—
4340	0.38-0.43	0.60-0.80	0.15-0.35	1.65-2.00	0.70-0.90	0.20-0.30	—
5130	0.28-0.33	0.70-0.90	0.15-0.35	—	0.80-1.10	—	—
5140	0.38-0.43	0.70-0.90	0.15-0.35	—	0.70-0.90	—	—
8630	0.28-0.33	0.70-0.90	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	—
8640	0.38-0.43	0.75-1.00	0.15-0.35	0.40-0.70	0.40-0.60	0.15-0.25	—
8470	0.38-0.43	0.75-1.00	0.15-0.35	0.40-0.70	0.40-0.60	0.20-0.30	—
AMS 6434	0.31-0.38	0.60-0.80	0.20-0.35	1.65-2.00	0.65-0.90	0.30-0.40	0.17-0.23
300M	0.40-0.46	0.65-0.90	1.45-1.80	1.65-2.00	0.70-0.95	0.30-0.45	0.05 min
D-6a	0.42-0.48	0.60-0.80	0.15-0.30	0.40-0.70	0.90-1.20	0.90-1.10	0.05-0.10

So, if we see here 4130 and then 4340 these are the few categories of the steels which are extensively commonly used. So, if we take a 4340 steel having the carbon 0.38 to 0.43 manganese 0.6 to 0.8 this is having the nickel of 1.6 to 2%, chromium is 0.7 to 0.9, molybdenum is 0.2 to 0.3. This is one type of the steel there is like 4037 steel having the carbon 0.35 to 0.4, manganese 0.7 to 0.9, there is no nickel, there is no chromium, molybdenum 0.2 to 0.3.

Likewise there is another category of the steel like AST, ASM AMS 3 64 34 and carbon 0.31 to 0.38, molybdenum 0.6 to 0.8. But as per as the nickel is concern 1.65 very high, chromium is

0.65 to 0.9 and molybdenum 0.3 to 0.4 and then additionally vanadium. So, they are different categories, here there is no nickel, no chromium, here we have nickel, chromium, molybdenum.

And in this case we are having nickel, chromium, molybdenum and vanadium all 4 elements. So, the different types of the heat treatable low alloy steels and they will be offering us the different carbon equivalent values and accordingly our the hardenability will be changing. And the response to the heat treatment of the welding will also be changing. And these factors means this compositional variation will directly be affecting the ease of welding or weldability of a steels.

So, welding metrology related aspects will be talking in the next presentation about the heat treatable low alloy steels. So, now I will summarize this presentation, in this presentation basically I have talked about the general properties and the composition of the heat treatable low alloy steels and the way by which the composition can affect the weldability of the steel, thank you for your attention.