Weldability of Metals
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Lecture-28
Weldability of Cr-Mo Steels-I

Hello, I welcome you all in this presentation related with the subject weldability of metals. In the previous presentation we have talked about the general properties of the heat treatable alloy steels and the different types of the heat treatable alloy steels along with their compositions. We know that the composition of the steel significantly affects the weldability because the composition affects the carbon equivalent especially in steels and that in turn affects the weldability.

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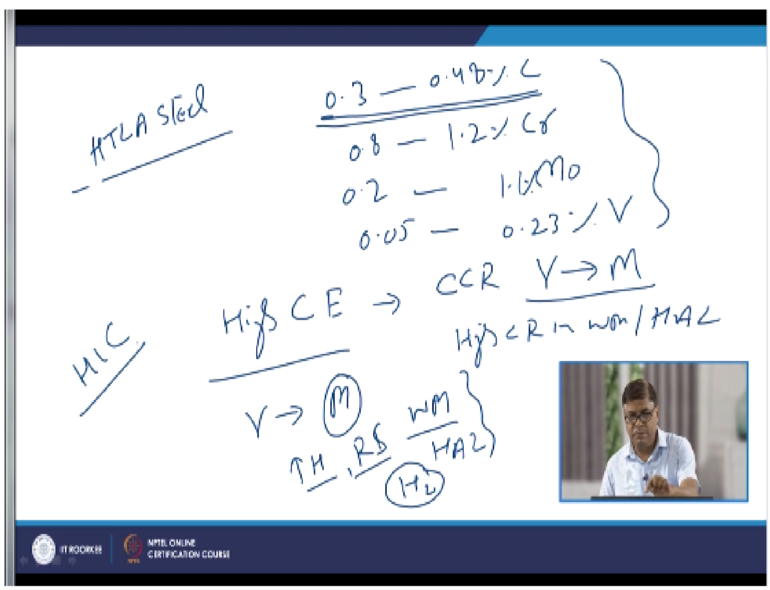

So, since the heat treatable low alloy steels have the quite good percentage of the carbon like high carbon in like 0.3 to say 0.48%. While the little amount of the other alloying elements like 0.8 to 1.2% of the chromium, 0.2 to 1.1% of the molybdenum. And in some of the compositions we have like little amount of the vanadium as well like 0.05 to 2.23% of the vanadium.

So, when these alloying elements are present including the high percentage of the carbon these presence of such kind of the composition in heat treatable alloy steels leads to the high carbon equivalent. And we know that the high carbon equivalent reduces the critical cooling rate for required for transformation of austenite into the martensite. So, since the during the welding frequently we experience the high cooling rates in the weld metal as well as in the heat affected zone.

And therefore in heat treatable alloy steels it is very common that whatever austenite is formed during the welding of the heat treatable alloy steels. These will be leading to the formation of the martensite both in the weld metal and the heat affected zone. Since the martensite formation leads to the significant increase in the hardness residual stress development in the weld and increased embrittling tendency.

So, if there is hydrogen in the weldment then it frequently promotes the hydrogen induced cracking, so as for as the welding metrology is concern of the heat treatable low alloy steel.

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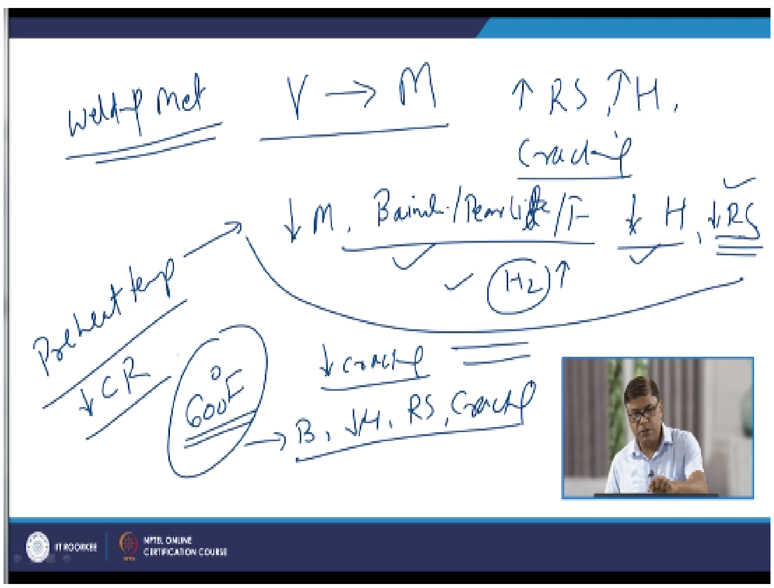

The main concern about the like the welding metrology of the heat treatable low alloy steel is related with the like the transformation of austenite into the martensite increased the residual stress development increased hardness and in presence of the residual stress development and increased hardness, there is increased tendency for cracking. So, we are mainly concern here with the control of cracking, so to control the cracking in case of the heat treatable alloy steel weld joints.

The main we work on the various approaches like somehow if we can reduce the martensite formation and it if it can be replaced with the softer phases like bainide or the pearlite and ferrite. So, if such kind of the phases can be formed which will be offering us the lower hardness. Since these transformations will be taking place at a higher temperature, so the tendency for the residual stress formation is also reduced in the weldment.

At the same time the high temperature transformations will allow the escaping of the hydrogen easily from the weld as well as heat affected zone. And these factors in combination will be reducing the cracking tendency, so the key here is to have the softer phases formation, so that the hardness can be reduced as residual stress tendency, residual stress magnitude can be reduced and escaping of the hydrogen can be facilitated.

There is one simple step for realizing this situation in the heat treatable low alloy steel welding is use of the suitable preheat temperature. We know that increase in preheat temperature will be reducing the cooling rate being experienced by the weld metal as well as the heat affected zone. So, that this kind of the favorable conditions can be facilitated, it is very common that 600 degree Fahrenheit preheat if used during the welding of the heat treatable low alloy steels.

Then it will promote the formation of the bainide, it will be reduce the hardness, it will reduce the residual stress and so these factors in combination will be reducing the cracking tendency. But working or means welding of the heat treatable alloy steels using preheat of higher temperature makes the welding job difficult for the operators.

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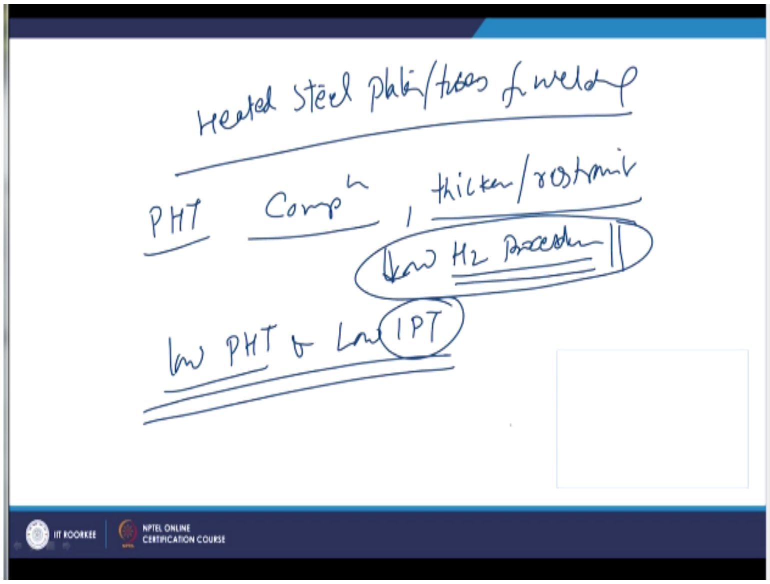

Because now operator will be dealing with the heated steel plates for plates or the tubes or the structures for welding. And so it is not really good or it is not always appreciated to use very high preheat temperature because it makes the job of the welder difficult. So, it is important that the preheat temperature is selected suitably so that the plates can be welded as at the same time the ease of the welding like the cracking tendency is also reduced while there is ease of welding for the operator as well.

So, while choosing the preheat temperature certain points are kept in mind like composition, higher the carbon equivalent in general will be going with the higher preheat temperature. Then thickness of the section or the restrained conditions under which the welding will be performed. So, lower thickness is lesser strain will help us reducing the kind of preheat to be which can be used.

Further if we use the low hydrogen procedure means the welding process is such that the hydrogen in the weld metal and the heat affected zone will be less or the welding consumables are used in such a way, the cleaning of the surface of the plates is done in such a way that the hydrogen content. The possibility for incorporation or inducing the hydrogen in the weld as well as the heat affected zone that is reduced.

So, if we are following the low hydrogen procedures then our requirement for preheat is also reduced. So, that will allow us to use the lower preheat temperature and the lower interpass temperature it is always desired that whatever preheat temperature used is used the interpass temperature similar interpass temperature is also maintained for uniformity of the structure at the different layers. So, that the all zones during the welding in multipass welding will be experiencing similar kind of the metrological transformation.

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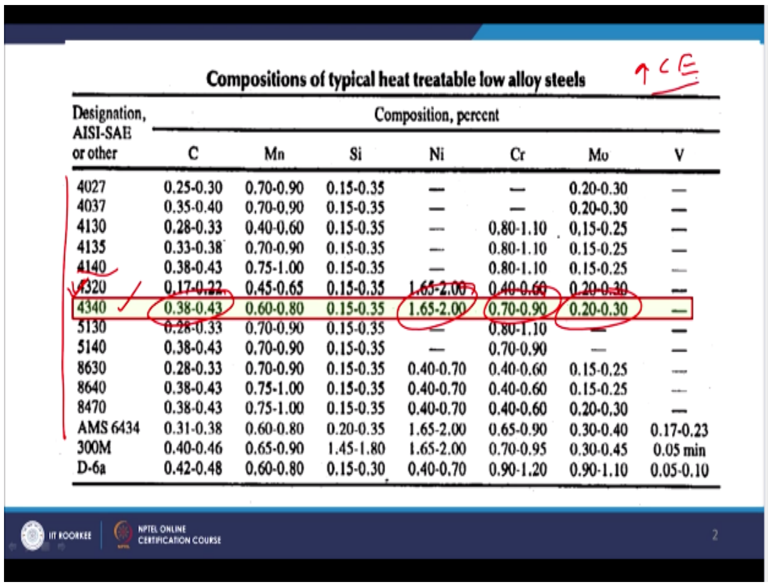

Compositions of typical heat treatable low alloy steels

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

Now we have the way by which preheat is selected so that the martensitic transformation and the cracking tendency is avoided and martensitic transformation is avoided. They are various grades of the heat treatable low alloy steels and this is one of the most commonly used grade like 4140 is also there 4340 is there, these are some of the grades which extensively used.

So, like say 4340 grade of the heat treatable low alloy steels significantly higher percentage of the carbon 0.38 to 0.43, so roughly like 0.4% carbon. Chromium is also like it is 0.8% on an average and 0.25% molybdenum and nickel is also like 1.65 to 2%. So, high concentration of these alloying elements in like say this typical grade of the steel will be leading to the higher carbon equivalent.

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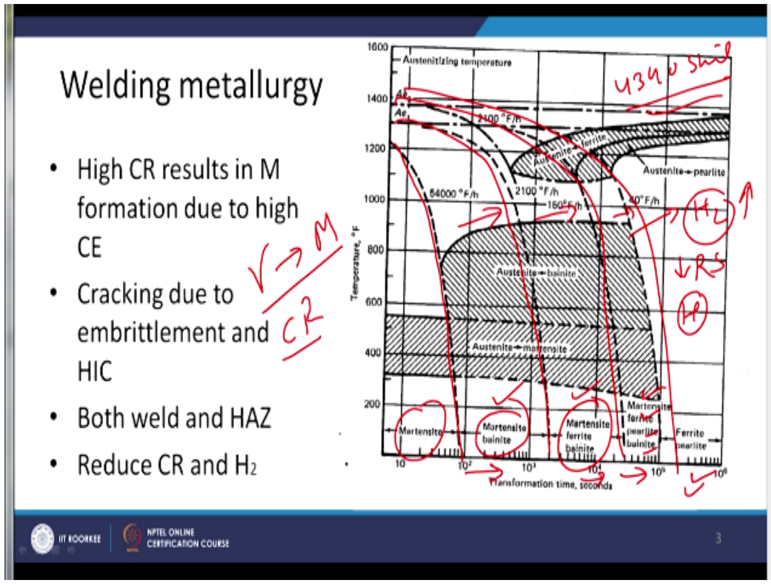

So, increased tendency for the martensitic transformation, as I have said what different phases will be formed during the cooling of the austenite to the room temperature that will depend upon the cooling rate being experienced. If the cooling rates are high then will be having the complete austenite to martensitic transformation. If it is somewhat lower than like this then will be having the phases like martensite and bainide mixture.

If further lower cooling rates using the higher preheat temperature is realized then will have the phases like ferrite, martensite and the bainide. Further lower cooling rates will allow us to have the martensite, ferrite, pearlite, bainide. In this typical 4340 grade steel which is like this is continuous cooling diagram for 4340 which is indicating that how the cooling rate can change the kind of phases which will be formed.

So, higher the preheat temperature, lower will be the cooling rate and accordingly the softer phases will be formed. If the cooling rates are high only martensite otherwise martensite will + bainide, martensite, ferrite, bainide, martensite, ferrite, pearlite bainide and too low cooling rates will be leading to the ferrite and the pearlite only. So, these phases will be determining the hardness and the temperature at which this transformations are taking place will be determining the kind of the possibility for escaping of the hydrogen will be reducing the residual stresses.

Higher the transformation temperature, lower will be the residual stresses that will be induced. So, especially if the martensitic transformation is avoided, so it is always good to have the suitable cooling rate, so that we can have some soft phase formation in the weld as well as heat affected zone. So, that the cracking tendency and the embrittlement tendency of the weld joint can be avoided.

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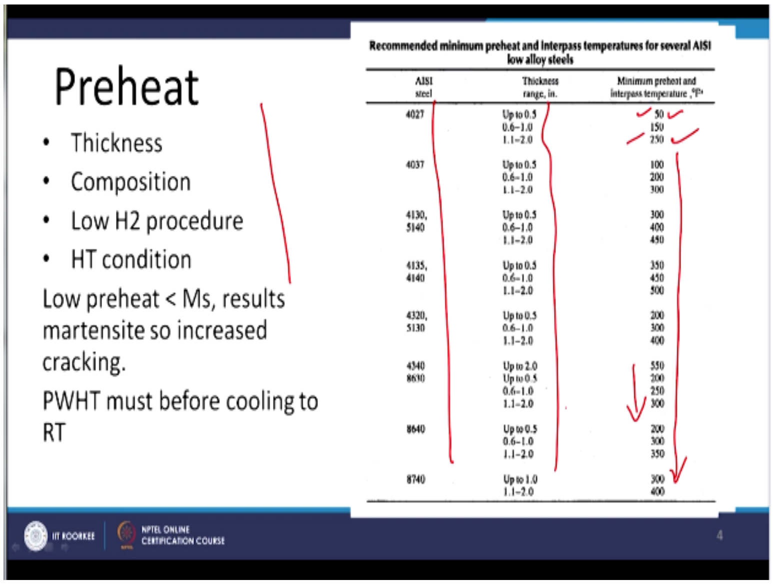

As I have said these are the factors which we need to see while taking decision about the kind of preheat to be used. So, like say for the different grades of the heat treatable alloy steels and for different thicknesses in inch which we know that the higher is the thickness greater will be the preheat temperature that we need to use changing from 50 to 250. And likewise if we see increasing the carbon equivalent will be leading to the use of the higher preheat and interpass temperatures.

So, greater the thickness, greater the preheat temperature, greater the carbon equivalent, higher will be the preheat temperature.

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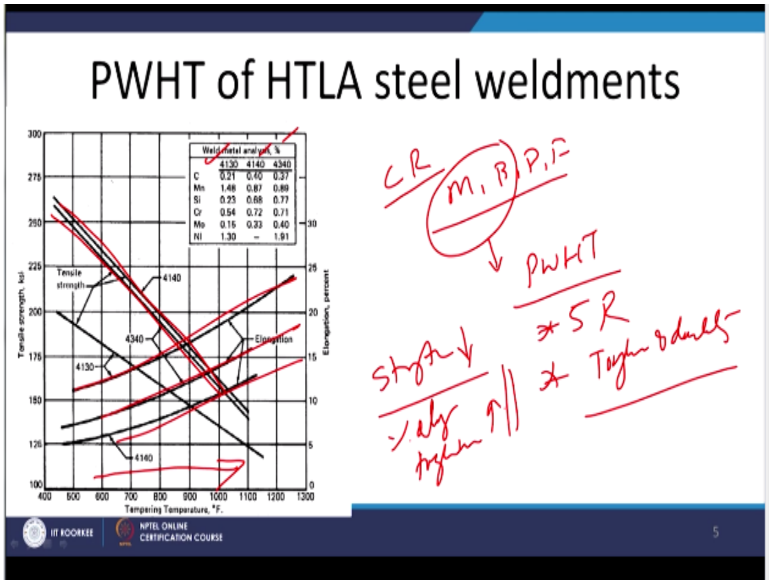

So, this is how we can choose from and we know that the kind of cooling rates the kind of the preheat temperature we have chosen that will be dictating the cooling rate and accordingly will be having the martensite the bainide, pearlite, ferrite in the weld joint. So, especially if the weld joints are having like martensite and the bainide then subsequent post weld heat treatment becomes important for the 2 purposes.

One is to relive the residual stresses if these have been developed in the weld joint and the second is to induce suitable value of the toughness and ductility in the weld joint. So, this post weld heat treatment like if we see this one where tampering is performed of the weld joints. Then increase of the tampering temperature simply reduces the tensile strength of the different grades of the HTLA steels.

On the other hand there is a continuous improvement in the ductility, so in general the strength with increase of tampering temperature, strength decreases percentage elongation and the toughness in general improves with the increase of the tampering temperature.

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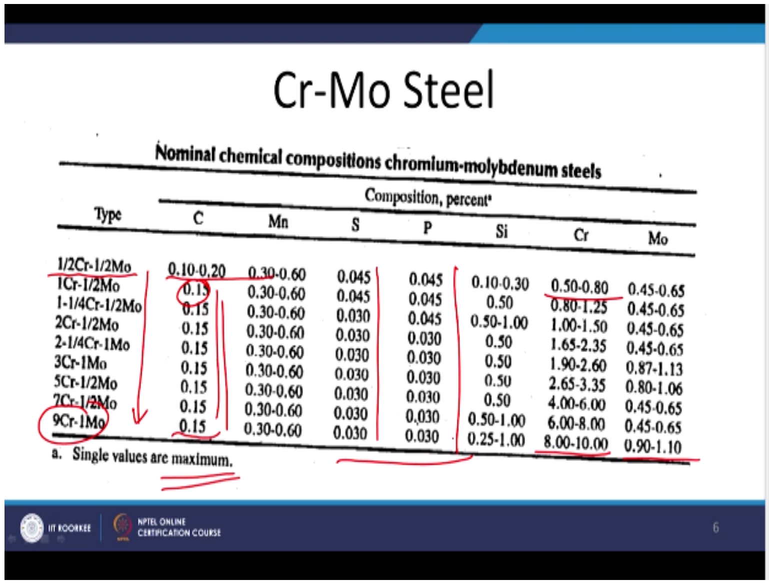

Cr-Mo Steel

Nominal chemical compositions chromium-molybdenum steels

Type	Composition, percent[a] C	Mn	S	P	Si	Cr	Mo
1/2Cr-1/2Mo	0.10-0.20	0.30-0.60	0.045	0.045	0.10-0.30	0.50-0.80	0.45-0.65
1Cr-1/2Mo	0.15	0.30-0.60	0.045	0.045	0.50	0.80-1.25	0.45-0.65
1-1/4Cr-1/2Mo	0.15	0.30-0.60	0.030	0.045	0.50-1.00	1.00-1.50	0.45-0.65
2Cr-1/2Mo	0.15	0.30-0.60	0.030	0.030	0.50	1.65-2.35	0.45-0.65
2-1/4Cr-1Mo	0.15	0.30-0.60	0.030	0.030	0.50	1.90-2.60	0.87-1.13
3Cr-1Mo	0.15	0.30-0.60	0.030	0.030	0.50	2.65-3.35	0.80-1.06
5Cr-1/2Mo	0.15	0.30-0.60	0.030	0.030	0.50	4.00-6.00	0.45-0.65
7Cr-1/2Mo	0.15	0.30-0.60	0.030	0.030	0.50-1.00	6.00-8.00	0.45-0.65
9Cr-1Mo	0.15	0.30-0.60	0.030	0.030	0.25-1.00	8.00-10.00	0.90-1.10

a. Single values are maximum.

Now if we see here like how the preheat temperature is selected and what if the post welding heat treatment is possible immediately after the welding and the situations where it is not possible.

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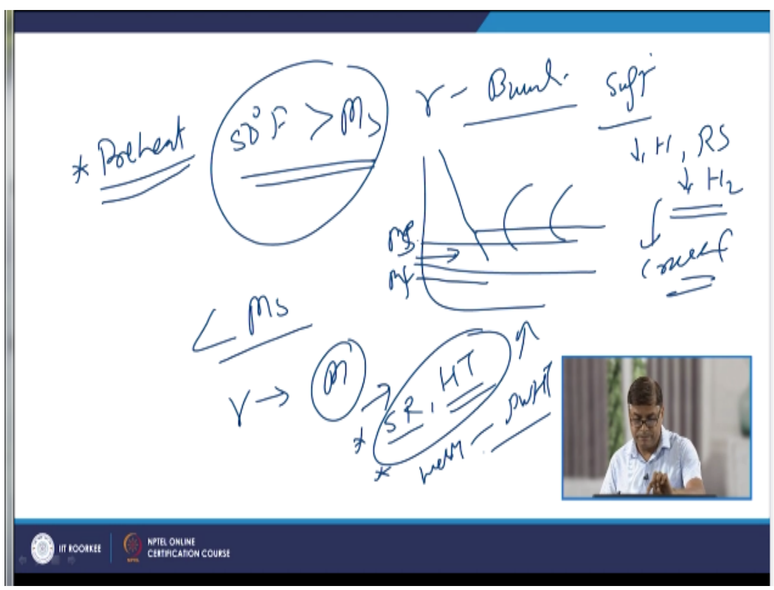

So, like the one case we will take up if the preheat temperature which is possible and being used is preheat temperature is greater than about the 50 degree Fahrenheit above the martensite start transformation temperature. Then we know that since this is above the martensite transformation start temperature, so it will be facilitating the complete austenite to the bainide formation, bainide being competitively softer than the martensite.

It will be reducing the hardness, reducing the residual stresses, reducing the hydrogen content in the weld metal, so it will be simply decreasing the cracking tendency. So, this is one thing that if possible then use a preheat temperature greater than 50 degree Fahrenheit above the Ms temperature that is the martensite start temperature. And if this is not possible like the preheat temperature is less than Ms temperature.

So, in any case the preheat temperature is here, so the preheat if the preheat temperature is less than certainly some of the amount of the austenite will be transforming into the martensite that will depend upon what is the value of preheat. Like if the preheat temperature is below Mf temperature then complete austenite to martensite transformation will be taking place and if the preheat temperature is between the Ms and Mf temperatures.

Then there will be partial transformation of austenite to the martensite and this kind of the transformation will be having the tendency for embrittlement or increased cracking tendency. So, in this situation we do not allow the cooling directly up to the room temperature but we can do the 2 things one is if possible allow the residual stress reliving like stress reliving heat treatment.

So, that the stresses induced in the weld joint can be eliminated and the cracking tendency is reduced. So, if this is possible then we perform the stress reliving heat treatment means this is the situation where immediately stress reliving heat treatment is possible. Then will not allow it to cool it down to the room temperature but stress reliving treatment will be performed.

So, that the joint can sustain the period of the handling from the welding to the post weld heat treatment otherwise the weld joint may get crack immediately. So, if the preheat temperature is less than the martensitic transformation temperature then immediately it is required that immediately a stress reliving temperature is performed.

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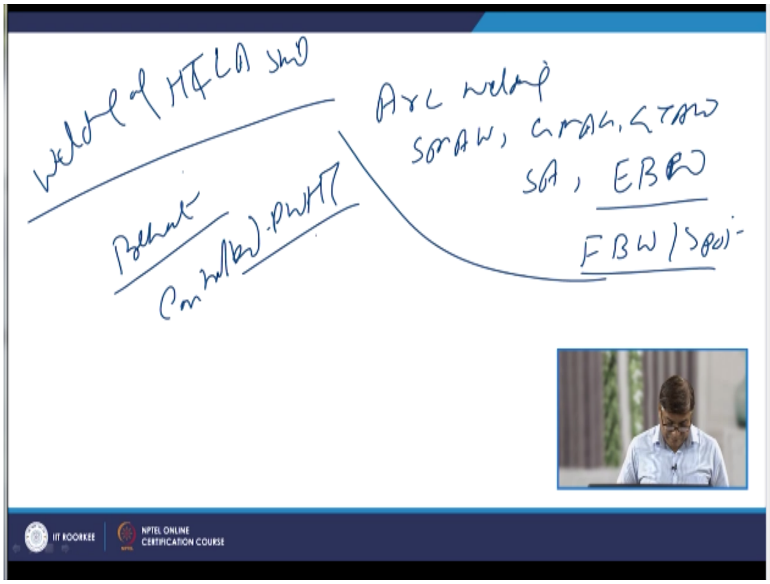

Now we will see the situations when the post weld heat treatment, so now we have to see how about the welding of the heat treatable low alloy steels. Most of the arc welding processes like SMAW, GMAW, GTAW, SAW and like electron beam welding process and in the resistance welding process like flash welding, spot welding.

All these processes can be used but we need to see that the development of the cracks means unnecessary cracking of the weld joints is avoided through the use of the suitable preheat and the controlled post weld heat treatments. So, that unnecessary residual stress development and embrittlement of the weld joints due to the high cooling rates can be avoided.

As for as the post weld heat treatment of the heat treatable low alloy steel weld joint is concern, there are 2 situations when immediate post weld heat treatment is possible.

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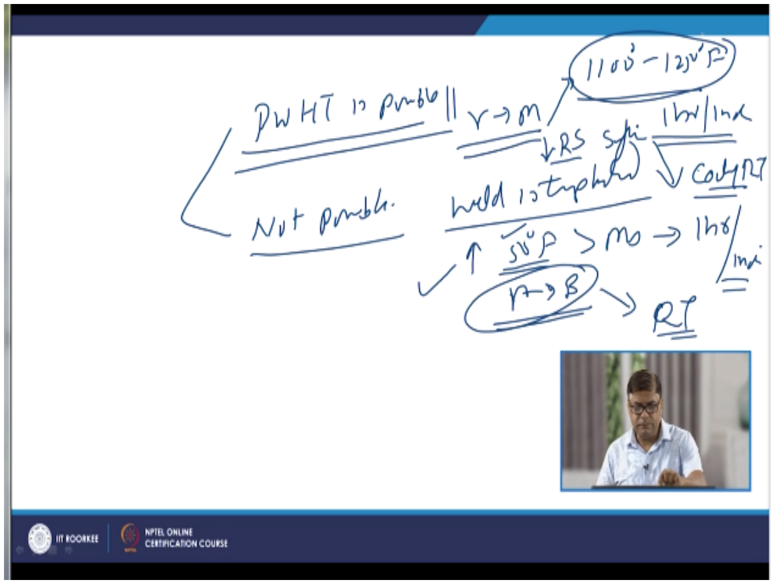

And the second situation is PWHT is possible and when it is not possible, so when it is not possible in this situation what we do as soon as the weld is completed. The joint is temperature of the weld joint is increased about 50 degree Fahrenheit above the Ms temperature and then it is held at for about 1 hour per inch thickness.

So, that complete austenite to the martensitic or bainide formation can be facilitated in order to avoid the cracking tendency and thereafter it can be cool down to the room temperature. So, this is one case when immediately PWHT is not possible. So, the whatever the weld joint was preheated will provide further heat for increasing the temperature about 50 degree Fahrenheit above the Ms temperature.

And then it will held for 1 hour per unit per inch thickness and this will help to facilitate the austenite to bainide formation which will in turn will reduce the hardness will increase the hydrogen diffusion as well as it will reduce the cracking tendency. The another situation when immediate post weld heat treatment is possible, in that case what we do is will allow the weld joint to cool down below Mf temperature.

So, that complete austenite to martensitic transformation is realized and thereafter the weld joint is heated immediately at 1100 degree Fahrenheit to 1250 degree Fahrenheit for 1 hour per inch. And this be leading to the residual stresses will be helping to form the softer phases and thereafter we can allow to cool it down to the cooling to the room temperature. So, these are the 2 kinds of the situations in one case when immediate post weld heat treatment is not possible.

Then after the completion of the weld, weld joint is heated above the Mf temperature of 50 degree centigrade and the second case if the PWHT is possible then will allow the complete martensitic transformation by cooling down below the Mf temperature and then heating at this temperature for 1 hour will help to form the softer phases and relive the residual stresses. Now we will start the another important aspect that is about the chromium molybdenum steels.

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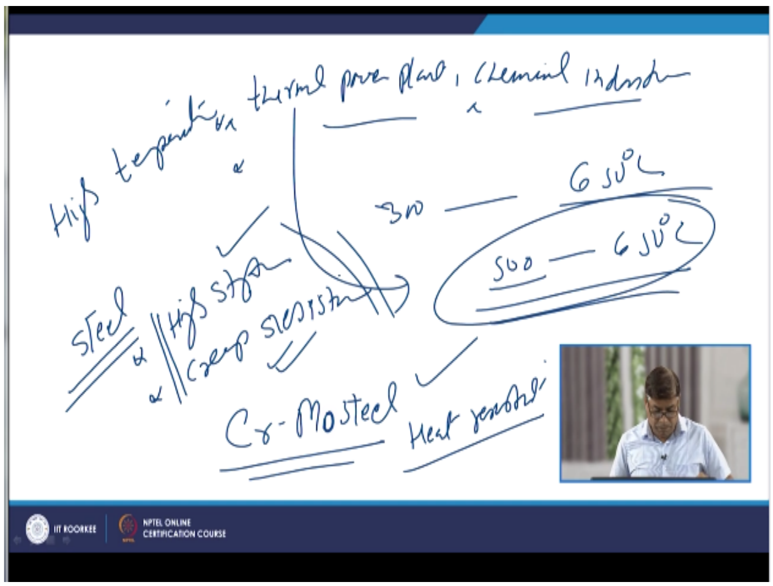

So, in case of the chromium molybdenum steels you know for various high temperature the components which are used at high temperature especially in thermal power plants and number of the chemical industries. And like petrochemical industry and the food processing industries where the components made of the steels are required to work at higher temperature which maybe ranges like say 300 to even 650 degree centigrade.

So, in thermal power plants it is common like 500 to 650 degree centigrade even now-a-days 700 degree centigrade temperature or also used**.** So, the weld joints whatever the weld joints are needed to give the desired size and shape to the various components used in these thermal power plants they must survive at a higher temperature like in the range of 500 to 650 degree centigrade.

And so we try to choose the steels which offer the significant high strength at elevated temperature and they show group creep resistance. So, there is no change in dimensions as a function of time when the component is used at higher temperature. So, high temperature strength and the good creep resistance, these are the 2 important requirements for the components to be used at a higher temperature.

So, in this regard the chromium molybdenum steel is one of the most commonly used heat resistant steel which is used for these applications.

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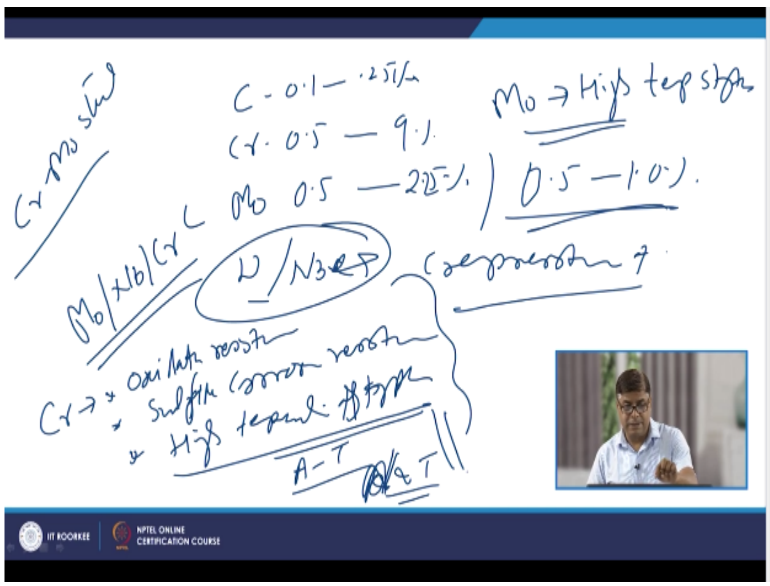

So, in these chromium molybdenum steel we have the carbon normally it is very low like 0.1 to 0.2, 0.25%. And the chromium, in chromium molybdenum steel really dominates it can range from 0.5 to 9% while molybdenum generally is found in the range of like 0.5 to 2.25%. But more commonly it is 0.5 to 1% only apart from this now-a-days even tungsten is also used in improved grades of the steels niobium is also used.

So, that they are not just high temperature strength but also the creep resistance can be enhanced. Here each element plays very specific role like chromium offers the resistance to the oxidation resistance. And then sulfide corrosion resistance is also offered by the chromium and it also helps in increasing the high temperature strength of steel, so these are the 3 important roles which are performed.

On the other hand when molybdenum is used it primarily helps in increasing the high temperature strength of steel. And the similar kind of the role is also performed by the tungsten and the niobium when these elements are present they will be form. Because of their good affinity with a carbon they tends to form their carbides like molybdenum, niobium, chromium etc.

So, some of these carbides are good because they are stable and they do not decompose even at elevated temperature and that is why they help in imparting the good resistance to the creep as well as the high temperature strength. These steels are used in different conditions like this can be annealed and tampered or quenched and tampered condition or the sorry normalized and the tampered conditions and these offer quite good strength and the ductility.

So, now will see the most common grades of the chromium molybdenum steel like the 0.25 chromium 0.25 molybdenum this is the kind of composition having the range of the chromium 0.5 to sorry if the first grade is like 0.5 chromium, 0.5 molybdenum and having the chromium in the range of 0.5 to 0.8 and the molybdenum 0.45 to 0.65.

Likewise the different grades the one of the grade is like 9 chromium, 1 molybdenum having **1.** 0.15 carbon and then we have the chromium in range of 8 to 10% and the molybdenum is 0.9 to 1%. So, and while these the single values shows the maximum possible content of that particular element. So, here in these grades maximum content of the carbon is like say 0.15%.

Wherever the range is given the range will show the kind of the allowable range for that particular value like the maximum allowed value of the sulfur and phosphorus. These are the values like 0.3 or o.45% in order to avoid the kind of solidification, cracking tendency of the weld joints.

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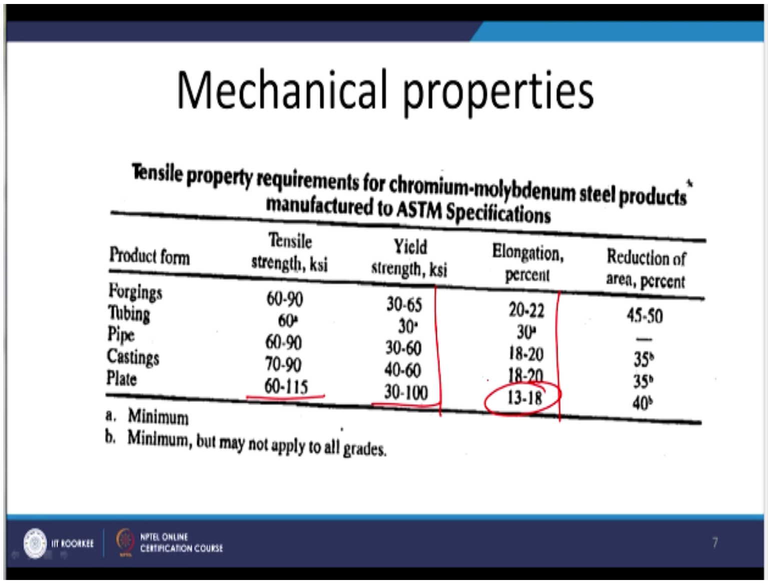

Mechanical properties

Tensile property requirements for chromium-molybdenum steel products manufactured to ASTM Specifications

Product form	Tensile strength, ksi	Yield strength, ksi	Elongation, percent	Reduction of area, percent
Forgings	60-90	30-65	20-22	45-50
Tubing	60[a]	30[a]	30[a]	—
Pipe	60-90	30-60	18-20	35[b]
Castings	70-90	40-60	18-20	35[b]
Plate	60-115	30-100	13-18	40[b]

a. Minimum
b. Minimum, but may not apply to all grades.

Since as I have said these steels are used at a higher temperature and they offer quite ductility and very good strength. So, in the as per the form of the steel we have very wide range. So, here like say these chromium molybdenum steels having the ultimate strength in the range of like say 60 to 115 KSI and in case of the yield strength it is 30 to 100 elongation is 13 to 18 %. So, these are like quite good combination of these have the quite good combination of the strength and ductility.

Now I will summarize this presentation, in this presentation basically I have talked about the welding metrology of the heat treatable low alloy steels and the way by which we choose the preheat and the post weld heat treatment conditions for the heat treatable low alloy steel weld joints. And I have also talked about the composition and the general properties of the chromium molybdenum steel, thank you for your attention.