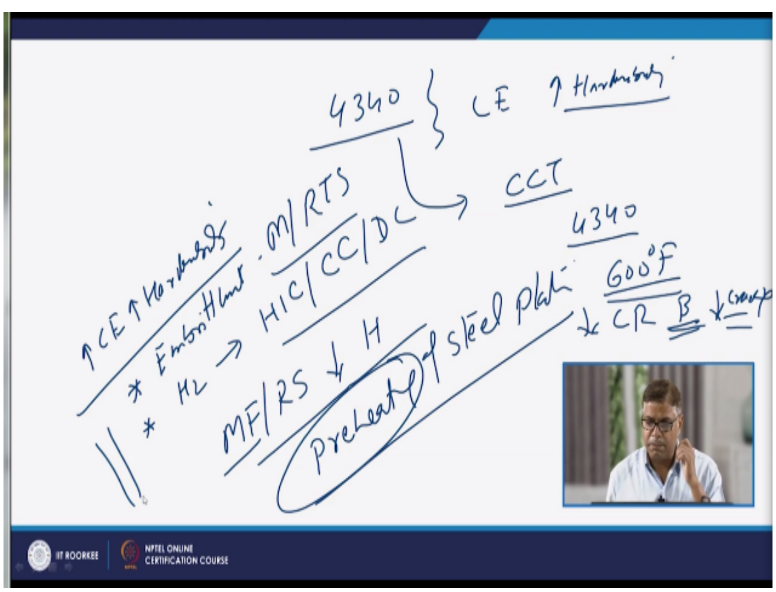
Weldability of Metals
Prof. D K Dwivedi
Department of Mechanical and Industrial Engineering
Indian Institute of Technology-Roorkee

Lecture-27
Weldability of HTLA Steels-II

Hello, I welcome you all in this presentation related with the subject of the weldability of metals. And you know we are talking about the weldability of the heat treatable low alloy steels, these steels in verbally contain higher percentage of the carbon like 0.25 to 0.45 along with the other alloying elements like chromium, molybdenum, vanadium, titanium etc. And due to the presence of these elements in general the carbon equivalent of the heat treatable low alloy steels is generally higher.

And because of the higher carbon equivalent these steels normally offer high hardenability. So, due to the high hardenability these types of steels impose many difficulties related with the welding. And we have also talked about the typical compositions of the various grades of the heat treatable low alloy steels. And one of the typically steels which is extensively used is a 4340 steel which contains higher amount of the chromium, nickel as well as molybdenum.

(Refer Slide Time: 01:37)



And as a result of this leading to the higher carbon equivalent leading to the higher hardenability. So, now in order to understand the relationship between the kind of micro structures which are observed during the welding in heat treatable low alloy steels and there the possible performance or it is effect on the weldability. And that we can understand in much better way using the continuous cooling diagram or CCT diagram.

So, typically we will be going through the CCT diagram for 4340 steel. So, as we know that because of the high carbon equivalent and high hardenability of associated with these steels. These show very much cracking tendency due to the embrittlement and the which is primarily associated with the martensite formation as well as residual tensile stress for development.

At the same time because of the formation of the martensite and presence of the residual tensile stresses. If the hydrogen is present the these steels also impose the problem of the hydrogen induced cracking which is also known as cold cracking or the delayed cracking. So, in order to control such types of the cracking, so that the heat treatable alloy steels can be welded without discontinuities and defects like cracks.

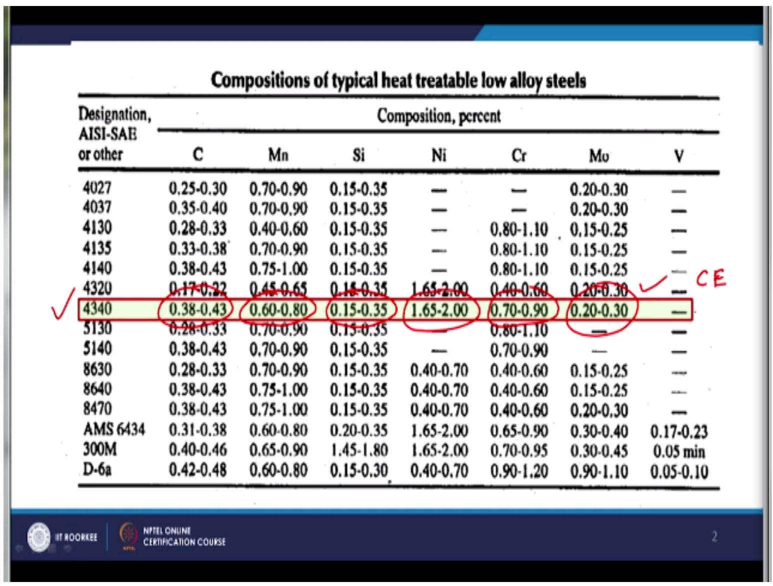
It is required that the formation of the martensite as well as the residual stress, martensite formation as well as the residual stress development both are control. And to control these as well as the hardness is also controlled hardness level is kept at the lower levels. So, for this purpose the main approach which is used is the preheat, preheating of steel plate which is to be welded.

And normally the preheat of the 600 degree Fahrenheit is preferred, so that the cooling rate can be reduced and the formation of the bainide is promoted in order to reduce the related cracking tendency. So, the primary goal is here the formation of the softer phases, so that the unnecessary embrittlement can be reduced and sometime can be given for escaping of the hydrogen.

So, that the hydrogen content in the weld as well as Hz can be reduced and the associated adverse effects on the development of adverse effects in form of development of the weld is continuities as weld cracks or cold cracks in the weld as well as heat affected zone can be reduced. So, the preheating is basically the main thing which is realized how much preheat is to be given and what will be the different phases which will be formed.

If the preheat is given or the preheat is not given, since the preheat directly affects the temperature at which the transformation of austenite into the other phases will be taking place . As well as it will also be affecting the cooling rate which will be experienced by the plates during the transformation of austenite into the other phases. So, it is important to see the what will be the different kind of the phases which will be formed.

(Refer Slide Time: 05:52)

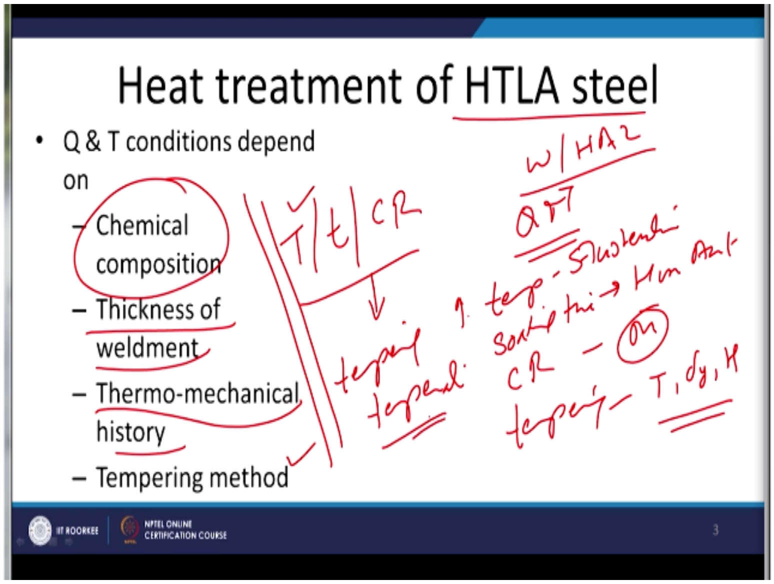


Compositions of typical heat treatable low alloy steels

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

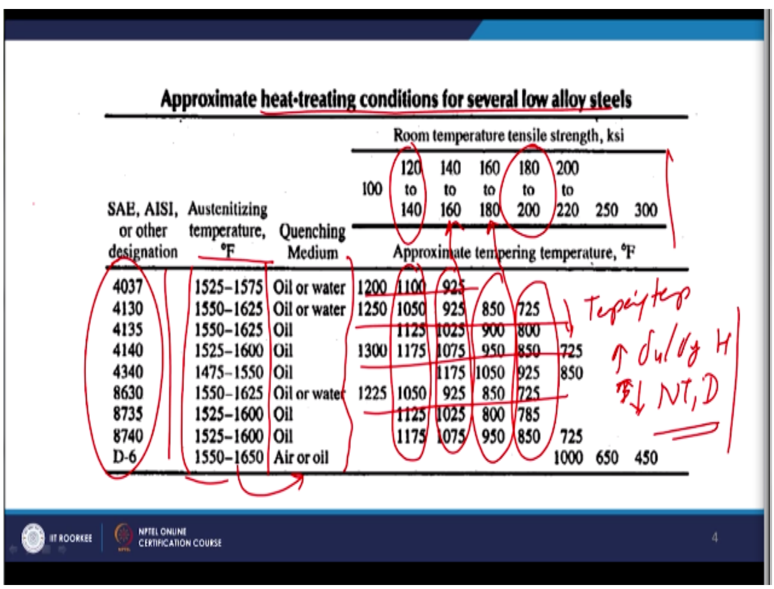
So, will be talking about the continuous cooling diagram of typical steel which is 4340 which contains like 0.43 0.38 to 0.43% of the carbon, manganese, is in the range of 0.6 to 0.8 silicon 0.15 to 0.35. Nickel which is austenite stabilizer is present in the amount of 1.65 to 2% chromium 0.7 to 0.9 and molybdenum 0.2 to 0.3, so because of the presence of these alloying elements in this type of the steel, normally the Ce is high and hardenability is also high.

(Refer Slide Time: 06:37)



Now we will see the kind of the heat treatment which is given to the Q and T steels, so that the properties can be restored that will depend upon the number of these parameters.

(Refer Slide Time: 06:49)



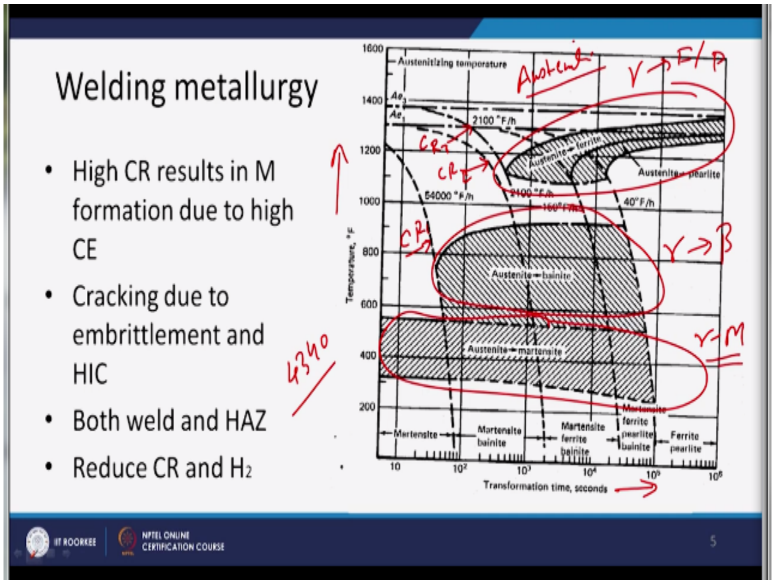
Approximate heat-treating conditions for several low alloy steels

SAE, AISI, or other designation	Austenitizing temperature, °F	Quenching Medium	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

Room temperature tensile strength, ksi

So, the continuous cooling transformation diagram for the 4340 steel is shown in this diagram.

(Refer Slide Time: 06:57)

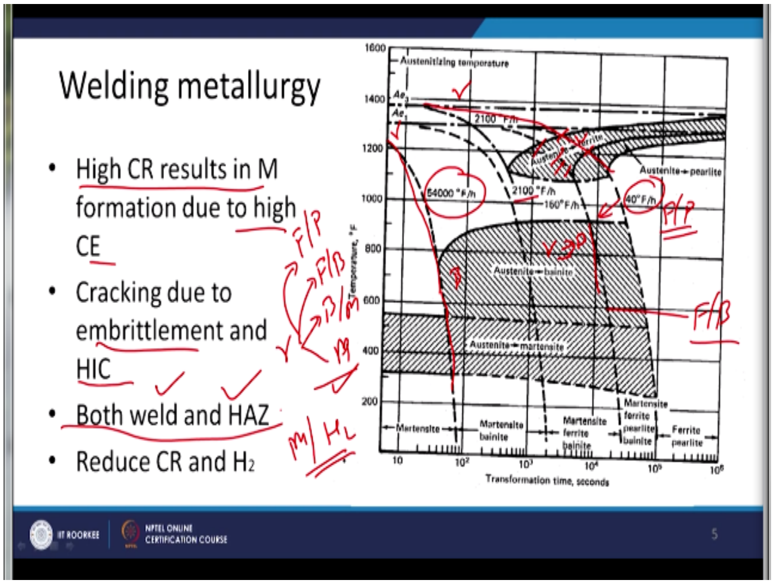


And what we can see when the steel is heated to the high temperature and leading to the formation of the austenite. What happens to the steel when it is cooled at the different rates, what we can see there are 3 zones in this continuous cooling diagram. One zone is this one where the different phases are being formed the cooling rate is low and this zone corresponds to the transformation of the austenite into the ferrite as well as pearlite.

There is another zone that is this zone where as per the cooling rate being imposed the transformation of austenite into the bainide is shown. And the third zone is this one where transformation of austenite into the martensite is exhibited. So, basically this diagram shows the relationship between the cooling rates being imposed on the cooling means the way by which will transforming into the different phases when the different cooling rates are imposed.

So, the temperature verses the time relationship showing the variation in the temperature as a function of time indicating that cooling rate. So, say this is the highest cooling rate shown here somewhat lower cooling rate in this case further lower cooling rate in this case. So, CR1, CR2, CR3 like this we can say and these are the reducing cooling rates.

(Refer Slide Time: 08:49)



So, if we try to understand what happens when the steel is cooled very slowly say that is this case, when the steel is being cooled very slowly leading to the. So, first the austenite transforms into the ferrite in this bend of the time zone and then the remaining austenite transforms into the pearlite. So, in this case primarily will be having the ferrite and the pearlite in the micro structure of steel when it is cooled at like say 40 degree Fahrenheit/hour.

When we use further higher cooling rate say 150 degree Fahrenheit/hour primarily we are getting the ferrite the transformation of the ferrite and then the bainide. So, both the ferrite and the bainide phases are formed when the cooling rate is further higher like say 2100 degree Fahrenheit/hour. In this case basically the soft phase formation like ferrite and pearlite formation is avoided.

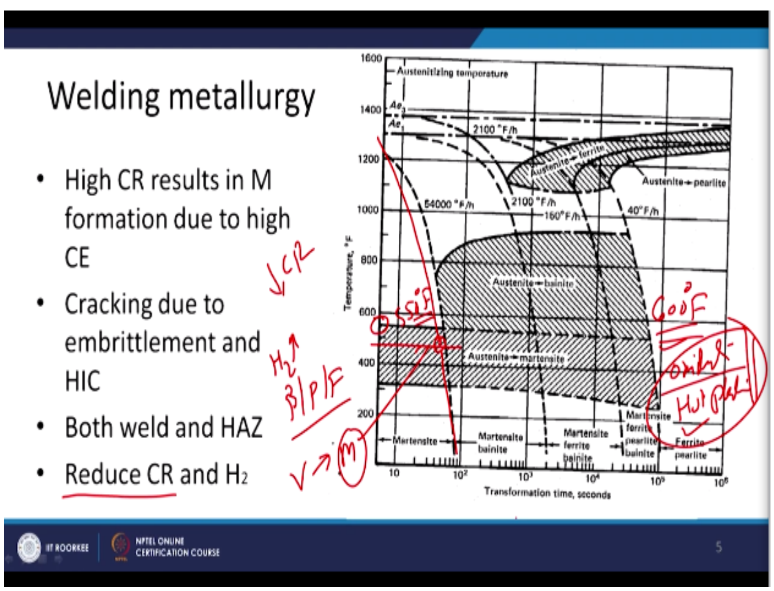
And primarily we get the transformation of austenite into the bainide and this is the zone where will be having the different proportions of the formation of the bainide and the martensite. And this is the critical temperature where we can see 54000 degree Fahrenheit/hour which is indicating that the transformation of austenite into the bainide will be avoided.

And primarily whole of the austenite will be transforming into the martensite, so as per the cooling rate being imposed austenite will be forming into the different phases like ferrite and pearlite then ferrite and bainide then bainide and martensite and the martensite. So, these are the different phases which we can be formed, so higher cooling rate leading to the formation of the martensite and which will be causing the embrittlement of the steel and will be increasing the tendency for the cold cracking.

On the other hand lower cooling rates will be giving the softer phases as well as it will be giving enough time for a hydrogen to diffuse out of the steels from the weld as well as heat affected zone. So, the hydrogen induced cracking tendency is reduced, so what we can see here the high cooling rate results in the martensite formation basically in these steels due to the higher carbon equivalent.

And the formation of the martensite increases the tendency for embrittlement as well as hydrogen induced cracking. And this happens primarily due to the formation of the martensite as well as entrapment of the hydrogen if it is there in the weld as well as the heat affected zone during the welding. And because of the formation of the martensite both in the weld as well as heat affected zone hydrogen induced cracking tendency becomes high and therefore efforts are primarily made.

(Refer Slide Time: 12:21)



Here to reduce the cooling rate, so that the trapped hydrogen can escape out and the formation of the soft phases like bainide, pearlite and the ferrite can be formed instead of the austenite. There is one more thing like that aspect is related to the preheating of the steel we know that in this case the formation of the martensite will start on the rapid cooling at 550 degree Fahrenheit.

So, if we have to give any preheating to the steel so that during the welding the formation of the martensite is avoided. Normally 600 degree Fahrenheit the preheat is preferred but working with the higher degree of the preheat is difficult primarily due to the working with the hot plates as well as the oxidation tendency of the steel. So, working with the hot plates during the welding as well as oxidation tendency these are the 2 adverse effects which are associated with the higher degree of preheat.

Although it will help in reducing the cooling rate and it will also help in reducing the hydrogen content as well as the formation of the martensite will reduce the hydrogen. So, the cracking tendency will be reduced but it will make the welding difficulty due to the dealing with the hot plates as well as the due to the formation of oxides by the steel plates when they are heated to the high temperature during the welding.

So, we need to use the proper degree of the preheat in order to avoid the formation of the martensite and reduce the hydrogen content in the steel plate. Now we will see when the steel is welded it experiences lot of undesirable changes in the weld as well as heat affected zone. And therefore to restore the properties it becomes important to perform the quenched and tempering heat treatment.

And which kind of the quench and the tempering treatment will be carried out means what will be the temperature at which the austenitizing will be carried out, temperature heating temperature basically. And then soaking time how long it will be kept there at a high temperature, so that the homogeneous austenite is formed and then what cooling rate will be adopted.

So, that we can get the required phases that is the martensite and then after that tempering is carried out at particular suitable value of the temperature. So, that the required combination of the toughness, tensile strength and the hardness can be realized. So, the temperature, the time and the cooling rate during the quenching treatment followed by the tempering temperature.

These values will depend upon the chemical composition, the thickness of the weldments, thermo-mechanical history of the plate which is to be processed and the method of tempering which is to be used. So, the quenched and tempering condition to be used for restoring the properties of the HTLA steel weld joints these are the factors which need to be considered while identifying the value of the time, temperature, cooling rates and followed by the tempering temperatures.

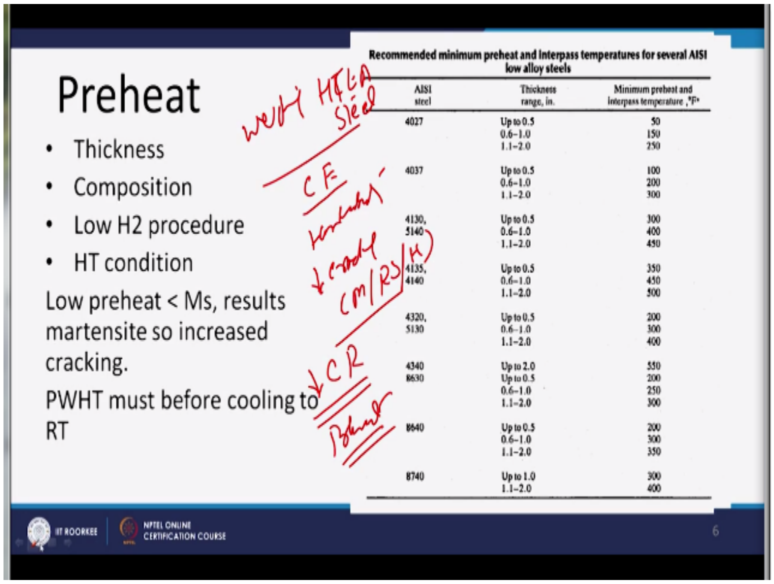
So, this table typically shows the value of the temperatures which is to be used for the different grades of the heat treatable low alloy steels. So, there are various grades of the heat treatable low alloy steels and this column is showing the kind of the temperature which is to be used for austenitizing. And followed by the water or oil quenching, so after austenitizing we need to apply the suitable cooling rate.

So, that the required martensite can be formed and after that the tempering is carried out. So, for the different steels the different tempering temperature are there and their effect on the tensile strength we can see here. So, what we can notice in general when we are using the higher tempering temperatures the strength is low like 120 to 140 KSI. And when lower tempering temperatures are used strength is going higher and higher like this.

So, which means if we use the tempering temperature lower tempering temperature it will be increasing the tensile strength sigma u and sigma y it will be increasing the hardness as well. But at this will be happening at the cost of the notch toughness and the ductility of the steel. So, we need to strike a balance the kind of properties that we should the kind of temperature we should use, so that the required combination of the tensile strength and the notch toughness can be realized.

So, basically in only Q and T steels we do not require post weld heat treatments but heat treatable vice low alloy steels are definitely given the quenched and tempering treatment after the welding properly. So, that the properties which were affected after the welding can be restored .

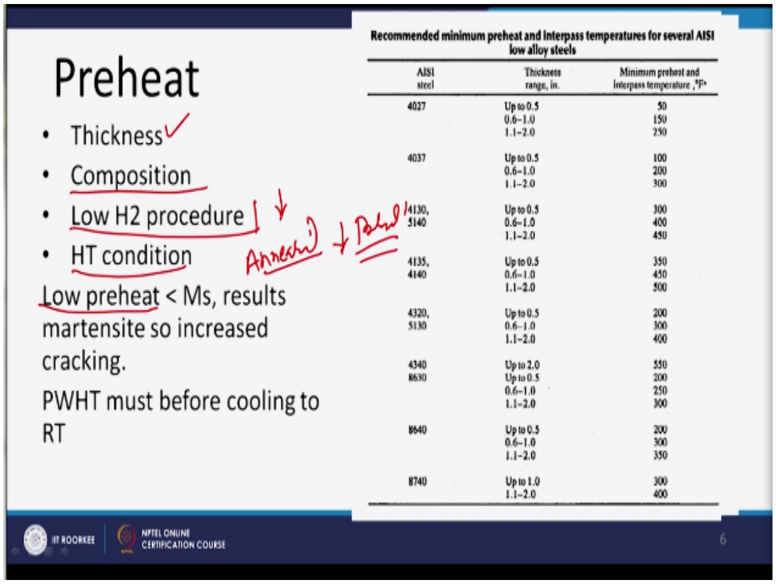
(Refer Slide Time: 18:43)



So, about this the welding metrology related aspects we have already talked about. So, as I have said that the it is the during the welding of the heat treatable low alloy steels. Because of the high carbon equivalent and the high hardenability if at all we have to reduce the in order to reduce the cracking tendency due to the formation of the martensite and the residual stresses and the high hardness.

The cooling rate reducing the cooling rate is the best option and for that we need to use the proper value of the preheat. Normally higher preheat is preferred but too high preheat leads to the oxidation as well as it makes the welding of the plates difficult at a higher temperature. So, the which value of the preheat is to be used that will depend upon these factors.

(Refer Slide Time: 19:37)



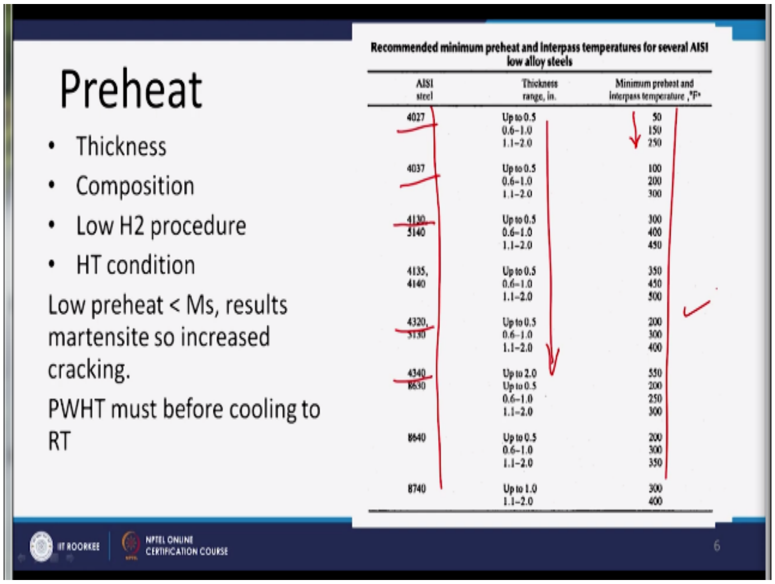
Recommended minimum preheat and interpass temperatures for several AISI low alloy steels

AISI steel	Thickness range, in.	Minimum preheat and interpass temperature ,°F*
4027	Up to 0.5	50
	0.6–1.0	150
	1.1–2.0	250
4037	Up to 0.5	100
	0.6–1.0	200
	1.1–2.0	300
4130, 5140	Up to 0.5	300
	0.6–1.0	400
	1.1–2.0	450
4135, 4140	Up to 0.5	350
	0.6–1.0	450
	1.1–2.0	500
4320, 5130	Up to 0.5	200
	0.6–1.0	300
	1.1–2.0	400
4340	Up to 2.0	550
8630	Up to 0.5	200
	0.6–1.0	250
	1.1–2.0	300
8640	Up to 0.5	200
	0.6–1.0	300
	1.1–2.0	350
8740	Up to 1.0	300
	1.1–2.0	400

Like greater is the thickness of the plate higher will be the preheat to be used, greater is the carbon equivalent, higher will be the preheat is to be used. And if the low hydrogen procedure is used more the hydrogen, more the preheat will be needed and if the low hydrogen procedures. Like low hydrogen electrodes and the in proper inert gases free from moisture, proper cleaning and all those low hydrogen procedures are used then it will be reducing the preheat temperature to be used and the heat treatment condition.

If it is whether it is being welded in anneal condition or in harden condition, so that will also determine the kind of preheat. So, obviously the metal being welded in anneal condition will require lower preheat as compare to the metal say in the hardened condition. So, lower preheat is used so preheat temperature is to be selected properly. So, that we are able to have the required the properties as well as micro structure which will help to reduce the cracking tendency of the weld joint.

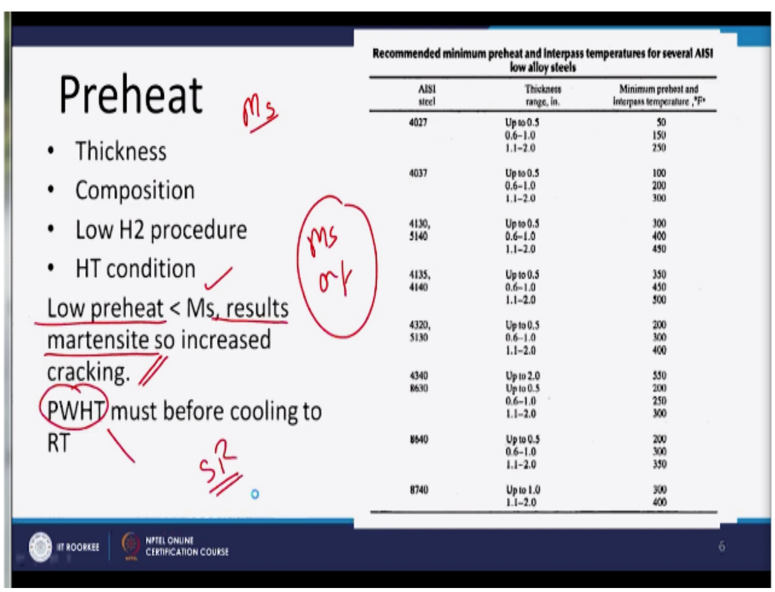
(Refer Slide Time: 20:47)



So, this table shows the various grades of the steels AISI4027, 4037, 4130 and then 4320, 4340. So, they are various grades of the steels and this is like the different thicknesses which and different thicknesses for which the minimum preheat and interpass temperatures has been given here. So, as we can see with the increase in section thickness to be welded in general preheat temperature and interpass temperature increases.

And likewise the steels of the higher carbon equivalent will be needing the higher the value of the preheat and interpass temperatures, so that is what we can see from this table.

(Refer Slide Time: 21:39)



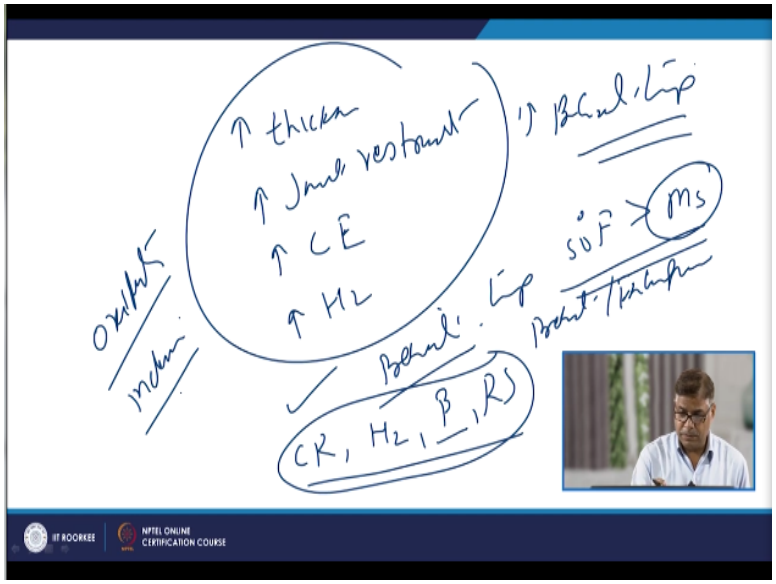
Now there are various other important aspects which are associated with the kind of preheat which is used. And these are like which value of the preheat is to be used like say if the preheat temperature is less than the Ms temperature. So, we can see here that if the preheat temperature is lower than the Ms temperature then what will use, what will happen like steel will be cooled rapidly.

And in this case a little amount of the austenite will be transforming into the martensite. And we should not allow the steel plates to be cool down to the room temperature in that case. Because if the low preheat is used preheat temperature is lower than the Ms temperature then it will be leading to the martensite formation and which will be leading to the increased cracking tendency.

We know that Ms and Mf temperature will be the function of the compositions, so as per the type of the steel to be welded we need to use the suitable preheat temperature. And so in this particular case when the lower preheat is used, preheat temperature is lower than the Ms temperature then the martensite formation will be leading to the increased cracking tendency. So, in this case before the steel weld joint is cool down to the room temperature post weld heat treatment especially for stress reliving is given.

So, that the cracking tendency can be eliminated, now we will see the different aspects related with the kind of the preheat temperatures to be used.

(Refer Slide Time: 23:31)

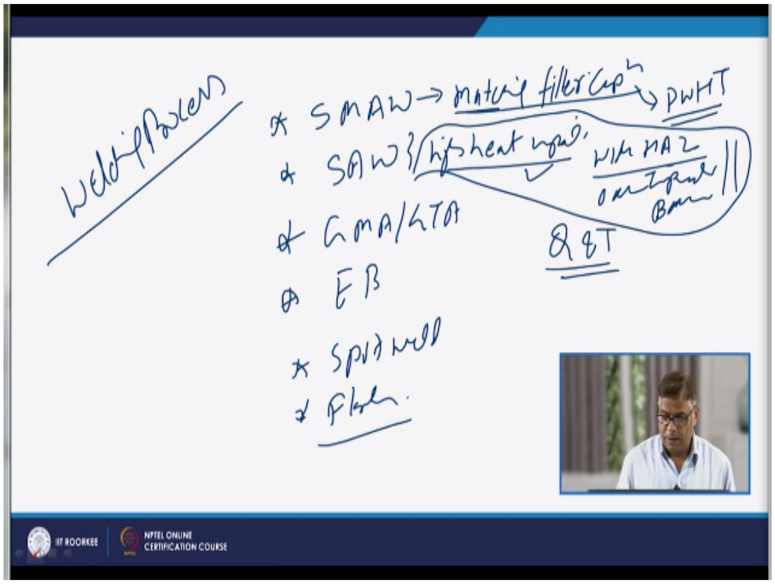


So, in general when we work with the greater thickness of the plate and when the joint restrained, joint restrained conditions when the joint is being made is high. And the carbon equivalent is high, section thickness is high and when the hydrogen content in the weld is high all these will be increasing the preheat temperature requirement. And when it is possible to apply the suitable preheat then preheat temperature selected must be about 50 degree Fahrenheit greater than the Ms temperature.

And once this higher temperature is given not just the preheat temperature but also the interpass greater interpass temperature should be greater than then Ms temperature by 50 degree Fahrenheit. And when the higher temperature is given it will be reducing the cooling rate, it will be allowing the permitting the escaping of the hydrogen it will be permitting the formation of the soft phases like bainide and it will be reducing the residual stresses.

So, the preheat about 50 Fahrenheit greater than the Ms temperature or martensite is start formation temperature will be leading to the all favorable benefits. Otherwise however there is another adverse effect related with the higher preheat that oxidation will be leading to the formation of inclusions in the weld as it is continuity. And dealing with the hot plates will make another the job of the welding difficult to the welder.

(Refer Slide Time: 25:47)

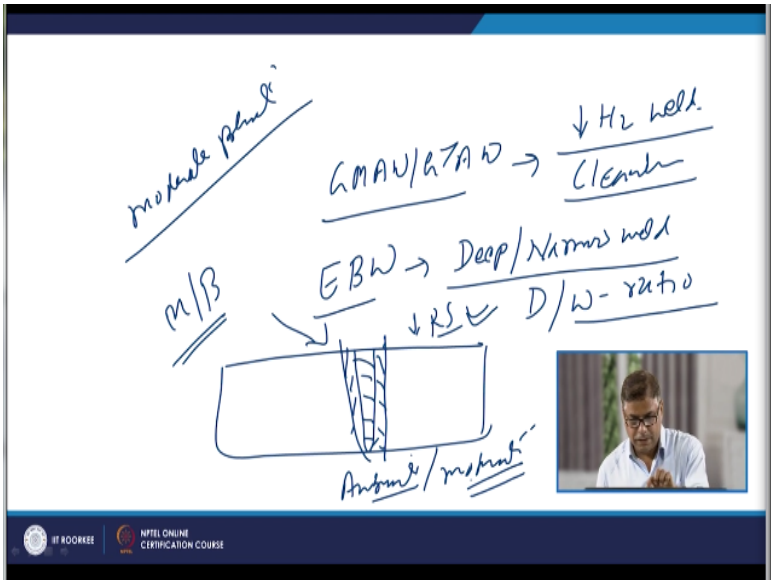


Now will be talking about the welding processes, so we can use the entire range of the common welding processes like shielded metal arc welding process, submerged arc welding process, gas metal and gas tungsten arc welding process electron beam welding process. And the other processes like a spot welding or the flash welding processes, so when we have working with the SMAW normally we choose the matching, filler or electrode composition.

And once we have this the suitable PWHT will help in realizing the joint of the required set of the properties across the plates which are being joined. Submerged arc welding process is known to be of the high heat input process**.** So, this will be causing the greater problems associated with the wider heat affected zone as well as maybe over tempering of the base metal which is being heated due to the high heat input.

So, in order to restore the properties to deal with the issues related with the high heat input sometimes it is required to do the complete quenching and tempering heat treatment of the weldment, so that the properties can be restored.

(Refer Slide Time: 27:31)



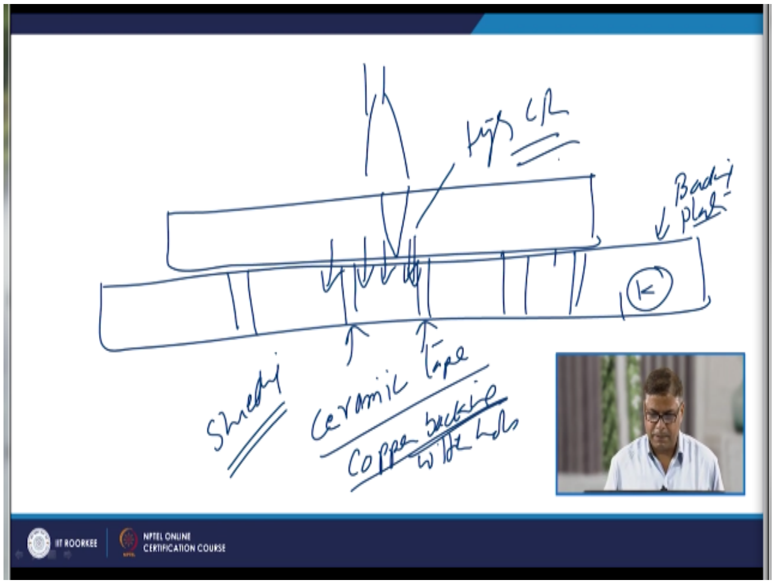
On the other hand like if we are using the processes like GMAW and the GTAW processes both these processes offer low hydrogen weld joints. So, in general the weld is cleaner and we are able to produce the weld joints which will be less prone to have the defects and discontinuities. When the electron beam welding process is used for welding of the heat treatable low alloy steels it is possible to have the very deep penetration and very narrow weld.

And because of this we get very high depth to width ratio weld joints and as a result of this because of the formation of the high depth to width ratio welds the related heat affected zone is very limited. Because we are using very low heat input of the high energy density in form of the electron beams. So, narrow heat affected zone and the less residual stress development.

However high cooling rate may lead to the formation of the martensite or the martensite bainide mixture. So, if we want to avoid normally the cracking tendency is very limited due to the formation of the reduced residual stresses but still due to the formation of the martensite if there is any little bit tendency for the cracking. Then that can reduce by giving the moderate preheat to the steel plates.

So, normally the electron beam welding is applied by the welding of these steels under the ambient conditions otherwise we may use the moderate preheat in order to reduce the cooling rate. So, that the cracking tendency associated with the high cooling rates can be reduced.

(Refer Slide Time: 29:50)



Now we will see the kind of when the plates are welded like this the groove which is being made then proper backing is given. So, for giving various space to provide the backing plate during the welding of the heat treatable low alloy steels. We may use the ceramic tape or we may use the copper backing with the holes from the bottom.

So, the plate having the hole from the bottom side can be used in order to provide the shielding gas, shielding from the bottom side. So, shielding apart from the shielding from the top side, shielding from the bottom side can also be provided through the holes provided in the backing plate. But they are some issues related with the use of the copper backing plate since the copper has the thermal conductivity.

And so when the copper backing plate is used it offers the higher cooling rate extracts the heat rapidly from the weld as well as heat affected zone and imposes the higher cooling rate. So, we normally try to avoid the use of the copper backing plate because the higher cooling rate promotes the martensite formation tendency as well as promotes the embrittlement tendency of the weld as well as the heat affected zone.

So, we try to avoid the use of the copper backing plate but ceramic tapes can be used in order to avoid such kind of cracking tendency associated with the copper backing plate. Now I will summarize this presentation, in this presentation basically I have talked about the way by which the preheat temperature for successful welding of the heat treatable low alloy steel is to be used and in which way the different phases are formed during the welding of the heat treatable low alloy steels when the different cooling rates are exposed or different cooling rates are imposed.

And that is what we have seen with the help of the continuous cooling transformation diagram, thank you for your attention.