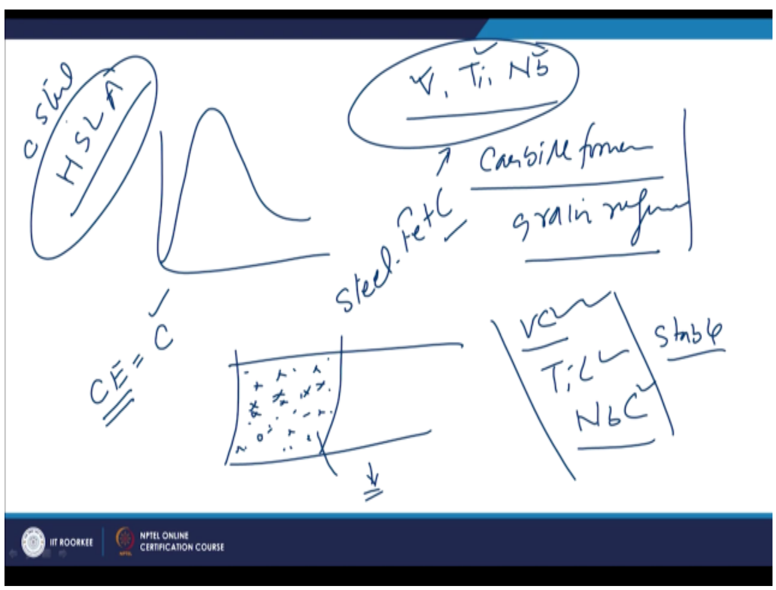
Weldability of Metals

Prof. D. K. Dwivedi
Department of Mechanical And Industrial Engineering
Indian Institute of Technology-Roorkee

Lecture-21
Weldability of High Strength Low Alloy Steels

Hello, I welcome you all in this presentation related to the subject weldability of metals and we are talking about the weldability of the high strength low alloy steels. We have seen in previous presentation that there are 2 broad categories of the high strength low alloy steels that the group A high strength low alloy steels are those which are primarily designed to have the high yield strength while another group which is designed for having the high heeled strength as well as the good corrosion resistance.

(Refer Slide Time: 01:13)



So the steels or HSLAs which are designed for high yield strength they primary contain the elements like vanadium, titanium, niobium, and these acts as a carbide farmers, as well as grain refiners. Since these are very strong carbide farmers so these help in pinning down the grain growth grain bounded movement and that helps in grain refinement, at the same time whenever these elements are present in steel so which is a combination of iron+carbon wherein addition of these elements which are having the high affinity to the carbon.

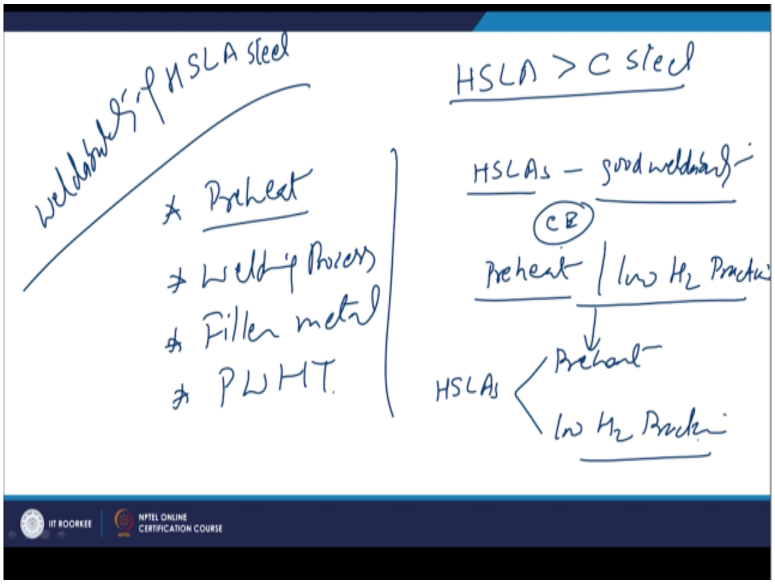
They form their carbides in form of vanadium carbide or titanium carbide or niobium carbide, these carbides are very stable, so they do not decompose easily during the welding under the effect of weld thermal cycle. So these elements these carbides which are present in the matrix these do not dissolve easily during the weld thermal cycle being experienced at different locations.

So because of their good thermal stability and resistance for the thermal decomposition at high temperature unless very long exposure at high temperature is given. As a result of this the carbon is consumed by these carbides so actual carbon content present with the steel is reduced and reduced carbon content in the steel which has not gone into the solution in the austenitic state is not will not be able to contribute the effect on the hardenability.

So the effectiveness of the CE due to this effectiveness of the CE is when all these elements go into the solution and homogenous solid solution of all these elements is formed. But if these elements are formed forming the carbides and compounds and these are not getting dissolved, then their effect on the carbon equivalent will not be that high. Since some of the carbon is being consumed by this carbide so their effectiveness will also be reduced.

So as compared to the carbon steels HSLAs which are forming these carbides and during the welding not getting decomposed these HSLAs offer better weldability as compared to the carbon steels. So with regard to the eligibility of the HSLAs in general HSLAs of a better weldability then the simple or plain carbon steels.

(Refer Slide Time: 04:34)

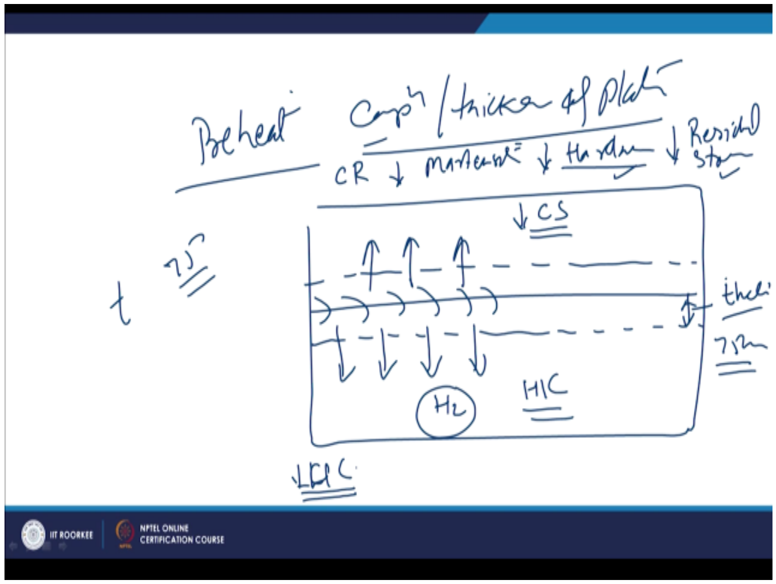


Now if you talk of the typical details related with the weldability of high strength low alloy steels then you need to talk about the 4 different aspects one is like the kind of preheat which is to be used during the welding of the HSLAs then what welding processes can use and what are the issues related with then what kind of the filler metal we can use and what other options available for welding the different category of the or different types of high strength low alloy steels.

And which type of the pores to weld heat treatment is needed and what will be the purpose of the same, in gener4al HSLAs offer very good weldability and can be welded easily using the most of the welding processes. But considering the comparatively high carbon equivalent due to the presence of alloying elements these are it is always preferred it to use suitable preheat and the low hydrogen practices during the welding.

Because whatever weldability whatever hardenability is there due to the presence of alloying elements because of that hardenability efforts are made in order to reduce the unnecessary excessive hardening, embrittlement, cracking tendency and for that purpose only the HSLAs during the welding of the HSLAs will follow proper preheat and the low hydrogen practices what are kind of the welding process is used.

(Refer Slide Time: 06:53)



So whenever we use a preheat of course for the preheat will be the function of the composition and thickness of the plate of the section thickness which is to be welded, whenever we apply preheat it helps to reduce like these are the plates this is the weld centre line. So the preheating is to be done with minimum up to the distance means from the distance up to which preheating should be done will be equal to the thickness of the plate are 75 mm whichever is larger.

So sufficient width of the plate must be heated in order to have the suitable effect of the preheat on the weld thermal cycle of the weld metal as well as heat affected zone, so the preheating of the region equal to the thickness of the plate are 75 mm or 3 inch whichever is a larger that is the distance up from the weld centre Line up to which preheating should be done up to the required temperature.

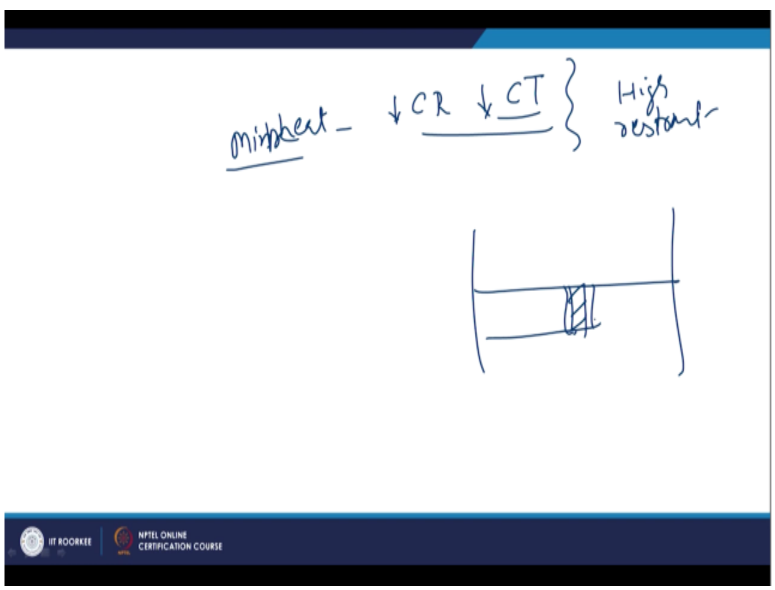
We know that whenever preheating is performed it reduces the rate of heat extraction from the region wherever heat is being applied to the suitable heats source. So because of the preheat the rate of heat transfer away from the weld centre line to the base metal is reduced and as a result of this our cooling rate is reduced, reduced cooling rate in the weld metal and the heat affected zone for the carbon equivalent which are typically available with the HSLA steels.

The martensitic transformation tendency is reduced, so reduction in cooling rate will be reducing the martensitic transformation tendency which in turn will be decreasing the tendency of the weld metal as well as heat affected zone which has been preheating reduced hardness at the same time there it will also reduce the residual stresses being developed in the weld as well as the heat affected zone.

All these things will be favourable with reference to the reducing, cracking sensitivity and cracking tendency of the weld metal. So the preheating will be helpful in controlling the cracking tendency, controlling the embrittlement at the same time since these steels if they are subjected to an appropriate cooling rate leading to the martensitic transformation high hardness, higher tensile residual stresses.

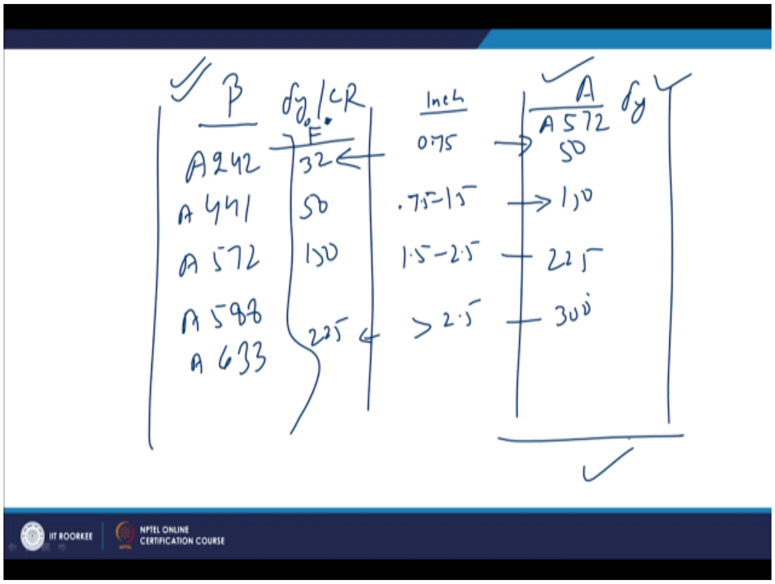
Then in presence of hydrogen these can also lead to the hydrogen assisted cracking, therefore suitable practices like low hydrogen control consumables processes, proper cleaning, proper preparation and all that whichever is needed whatever is needed to have the lower hydrogen concentration in the weld metal is used.

(Refer Slide Time: 10:48)



So there has to be a minimum preheat temperature minimum preheat temperature should be used so that it is able to reduce the cooling rate and it is able to reduce the cracking tendency of the weld as well as heat affected zone and this cracking tendency will be more critical or will be more severe when the weld joint is developed under the highest restrain conditions means the ants are fixed and the joints are being made here.

(Refer Slide Time: 11:41)



So the heat expansion during the heating and subsequent contraction can be more problematic with regard to the cracking tendency. So I have set there are 2 broad groups of the HSLAs the group B is primarily for the high yield strength as well as corrosion resistance and group A is mainly for high yield strength steels like when the plates of the different thicknesses are welded of say up to 0.75 inch.

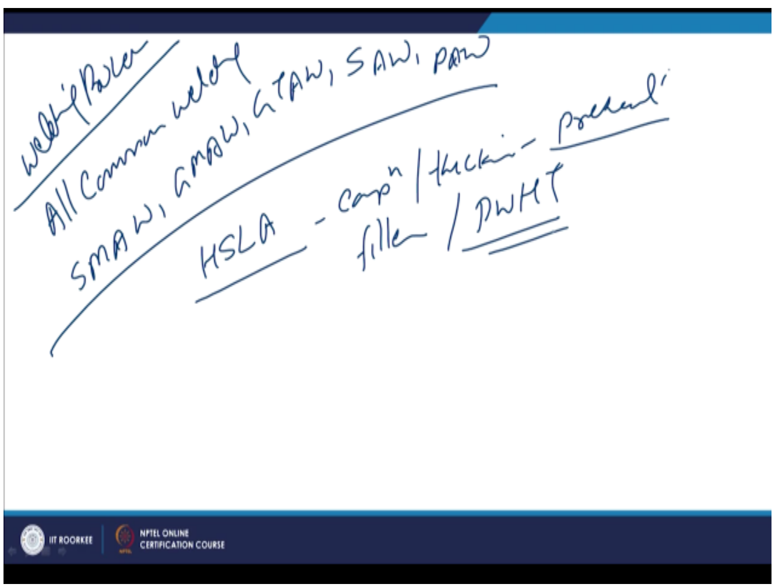
So the plate thickness in inch then 0.75 to 1.5 inch, then 1.5 to 2.5 inch and greater than 2.5 inch, so when the plates of the different thicknesses are to be welded of the group A steel say so that they are different gates of the group B steels like A242 steels, A441 steels, A572 steel, A588 and A633 steels. All these steels when they are used or they need to welded in different thickness then the kind of preheat which is used in Fahrenheit for up to 75 mm thickness.

The temperature pretemperature especially for those conditions those regions where temperature is very low, so the minimum the base plate temperature heat temperature and interpass temperature is to be like 32, when that thickness is in the range of 0.75 to 1.5 mm then it is 50, when the thickness is in the range of 1.5 to 2.5 then it is 150 and for thickness greater than the 2.5 inch it is 225 Fahrenheit.

On the other hand the HSLAs of the group A which are primary design for high heel strength they need much higher temperature like the typical steel of the group A is A572 and the kind of the temperature which is to be used for preheat is 50 degree Fahrenheit of 0.75 then 0.75 to 1.5 inch which is 250 and then for next 1.5 to 2.5 inch thickness it is 2 to 5 and for thickness greater than 2.5 inch it is 300 Fahrenheit.

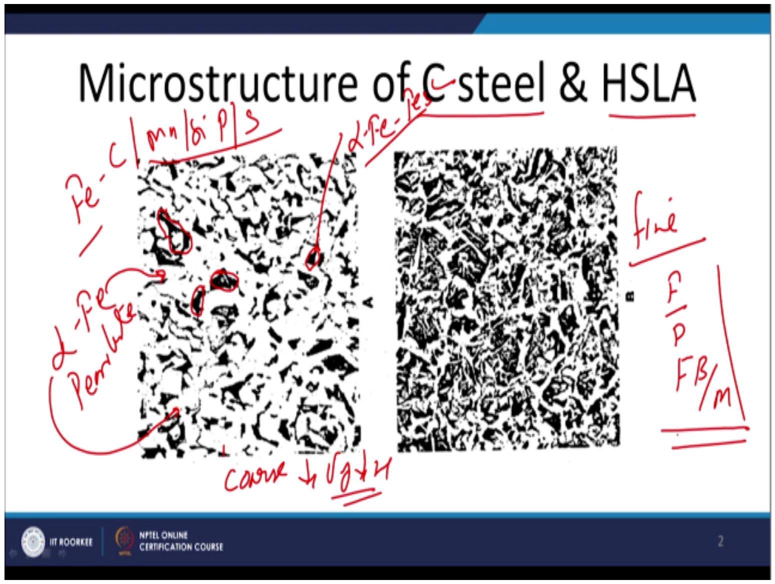
So group A steels need higher there are many for sub classifications in each category if the steels so this is one bigger group A and group B and type of this group B is need higher preheat as compared to that of the group B steels.

(Refer Slide Time: 15:22)



Now coming to the welding processes like all so next is the welding process all common welding processes like shielded metal arc welding, gas metal arc welding, gas tungsten arc welding, submerged arc welding, plasma arc welding. All these can be effectively used for welding of the HSLAs. However as per the composition and the thickness we need proper preheat as well as the suitable filler composition is also to be selected and as per the requirement PWHD is given depending up on the fabrication conditions and the cracking sensitivity of the metal.

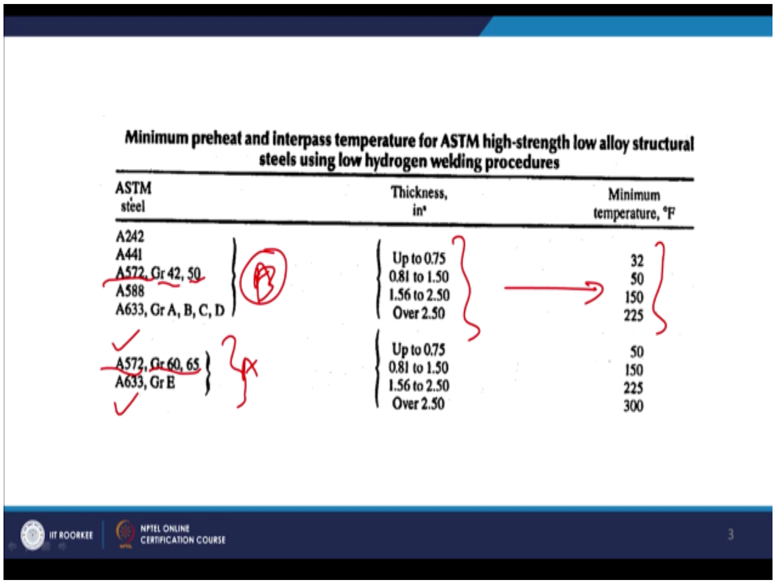
(Refer Slide Time: 16:31)



If we just have a look the typical microstructures of the carbon steel in high strength low alloy steels, carbon steels primarily contain carbon while the magnesium, silicon, phosphorus and sulphur are the residual elements. These will primarily be containing the alpha ferrite and pearlite which is a mixture of the ferrite and cementite. All these white phases are of the ferrite and the dark zones are representing to the pearlite where a pearlite which is the mixture of the alpha ferrite and Fe3C iron carbide that is the cementite.

This is structure is in general course offers the lower yield strength lower hardness as compare to the HSLAs structure we can see is very fine as compared to the carbon steel on the other side it contains fine the ferrite, pearlite may be containing the fine bainide or martensite also depending upon the kind of the thermal and mechanical history of the steel. So these are the common phases which are found.

(Refer Slide Time: 18:11)

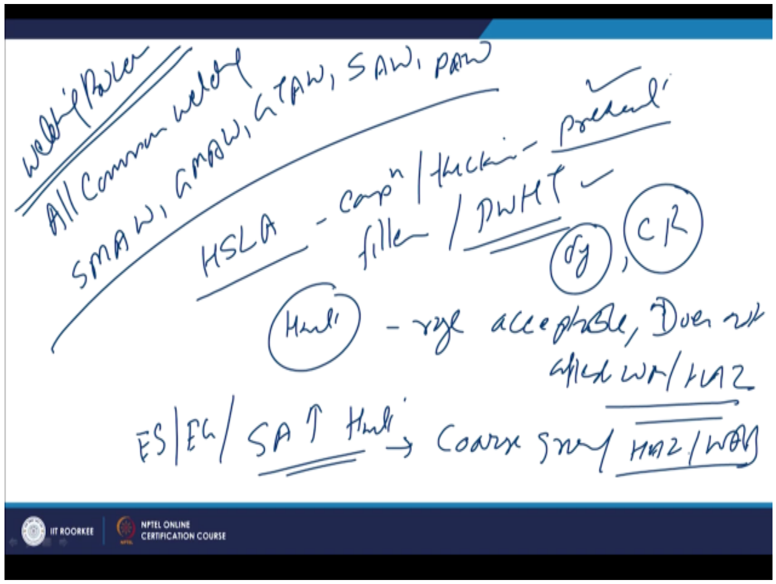


The structure is in general finder for the HSLAs as compared to that of the carbon steel and what this table shows that the kind of the minimum preheat which is to be used as I said this is a group A HSLAs for different thicknesses we need the different magnitude of the preheat ranging from 32 to 25 for sorry for group B steels and for group A steel we are like 572 and 633. The other different sub grades of because we have 572 here and 572 here as well.

So grade 42 and grade 50 it is in a group A and another group B and this is another 572 of grade 60 and 65. So the different grades of the HSLA will be requiring the different magnitude of the preheat. So in any case increase in thickness of the plate we need to increase the kind of preheat which is to be used. So the minimum preheat temperature is increased with the increase of thickness as well as with the change of alloy composition also the preheat is affected.

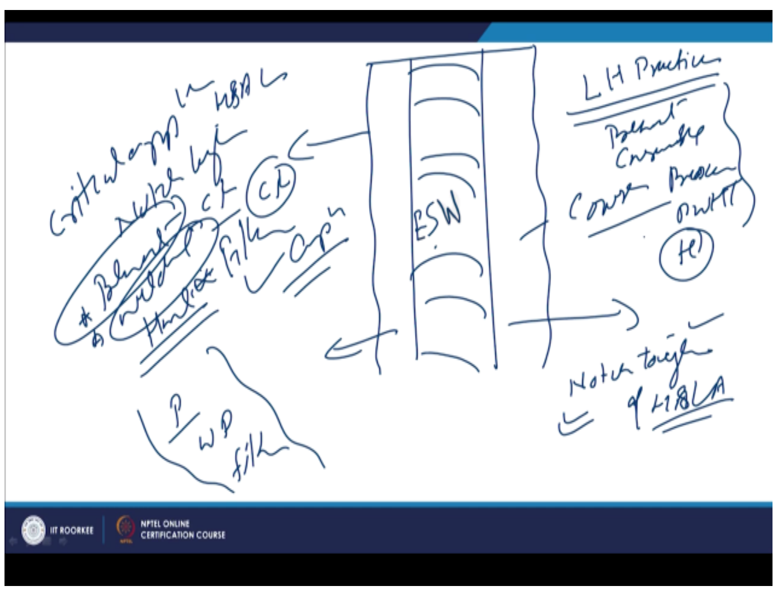
Now you are talking about the welding processes which are used for the welding of the HSLAs, so as I have said most of these welding process can be effectively use this using the suitable combinations of the preheat as well as the filler metal. So that the required tensile strength and the corrosion resistant properties can be realized. So these processes offer the heat input net heat input in a range which is acceptable.

(Refer Slide Time: 19:53)



And does not affect the weld metal as well as Hz properties appreciably, on the other hand there are certain processes like electro slag welding, electrode gas welding or submerged arc welding using performed using extremely high heat input. So in those cases we get very coarse grain structure in Hz as well as in the weld metal. So because of the course grained structure as well as the formation of the unfavourable phase is due to the low cooling rate being experienced.

(Refer Slide Time: 20:40)



Like in electro slag welding, the weld is cool because of the very high heat input weld metal is cooled very slowly as well as the heat affected zone is also cool very slowly. So we get the very coarse pearlitic structure and such kind of the structures reduce the notch toughness of the HSLAs. So for most of the normal applications all common welding processes can be used because the notch toughness the yield strength both are very good which can be realized using most of the common welding processes.

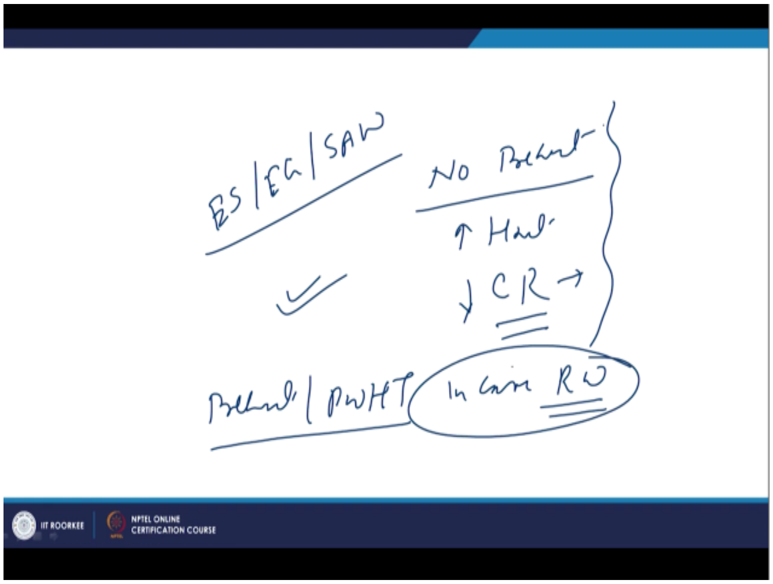
But if the notch toughness is a criteria then we need to be very careful with regard to the H nat, because heat input affects the cooling rate and that in turn affects the grain structure and which can lead to the deterioration in the notch toughness. So all those critical applications of HSLAs where notch toughness is critical, there we must see like the kind of preheat being used, the welding process we used and the kind of the filler metal which will be used.

So these are the things that will be governing the and microstructure in the weld mental as well as heat affected zone, preheating effects the cooling rate welding process affects the heat input and so again the cooling rate and the filler metal affects the composition and which in turn determines the kind of phases which will be up developed for a given set of the cooling conditions.

So we should consider the preheat the welding process as well as the filler metal composition if the notch toughness of the HSLA weld joints is crucial, otherwise the kind of the notch toughness which is offered by these processes and most of the common welding process is acceptable for general applications. Apart from these processes what are process we adopt we must follow the practices for low hydrogen practice.

We must follow the low hydrogen practices so whether it is the preparation or consumable or the process or post weld heat treatment, whatever is needed to control the hydrogen in the weld as well as heat affected zone all those principles must be applied so that the given weld joint of the HSLA when it is developed using a given set of the process is able to develop the weld joint with the required toughness.

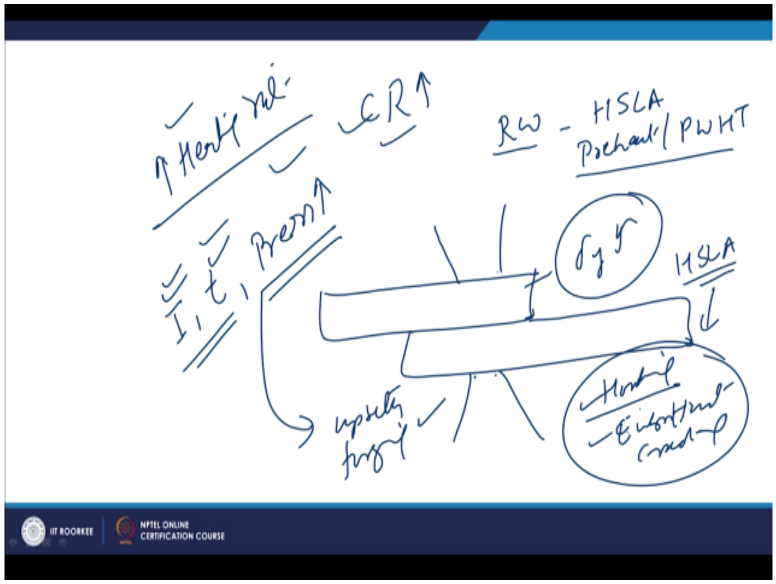
(Refer Slide Time: 23:52)



Now will see that since the electro slag and electro gas and SAW which is performed using very high heat input we do not require any preheat because these processes are of the so high heat input that cooling rate is no enough in order to facilitate the formation of the softer phases and sometimes even the phases are so soft and so course that they deteriorate the notch toughness and the mechanical properties of the metal.

So notch toughness can be one issue especially when the input and the low cooling rates are used that the intern will be leading to the decoration in the notch toughness of the weld joint. So for that purpose we need to control the heat input properly. Now as I have said the preheat and post weld heat treatment cycles in case of the resistance welding processes so with regard to the resistance welding process because in most of these processes the rate of the heating rate is very high.

(Refer Slide Time: 25:20)



And after the heating the force is applied followed by the cooling at a very high rate. So the heating rate and the cooling rates both are high with when the resistance welding processes are used for welding of the HSLAs say resistance welding process like the spot welding or the same welding when it is used so in that case since these are of the high yield strength processes and the resistance for the flow of current is almost same as that of the carbon steels.

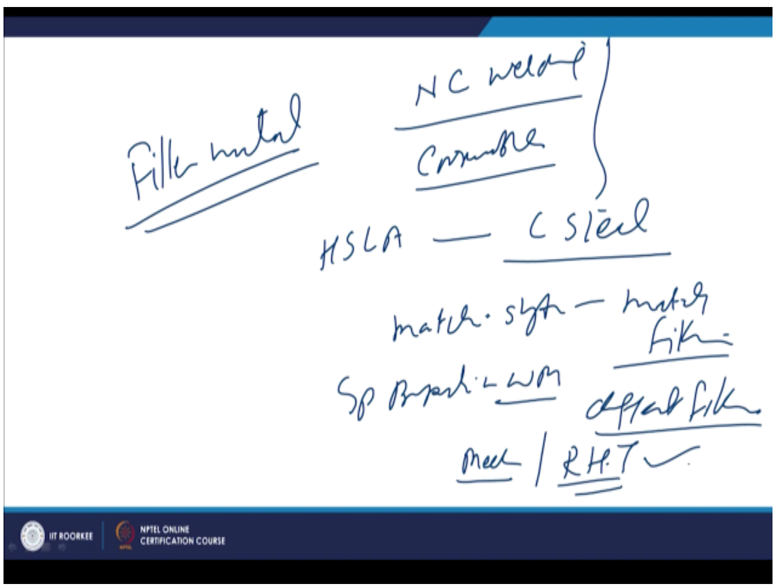
That is why the kind of the current setting and the welding current time of these values are almost same as that for the carbon steels but if we talk of the pressure, the force and pressure or the pressure which is to be used during the spot welding or the same welding so the pressure for the HSLAs is used much higher than what is used in the carbon steels and the reason for this is that high strength steel HSLAs are of the high yield strength in order to facilitate the proper upsetting and forging action during the welding cycle the pressure must be higher than what is used in case of the carbon steels.

So the current and the time settings for its resistance spot welding of the HSLAs are same as that of the carbon steels but the pressure requirement of the load required for realizing the upsetting and forging action during the welding these pressure or the forging upsetting force must be high must be higher than what is used in use case of the carbon steels. So that required upsetting and forging action can be realized for developing the some weld joint.

Apart from this since the heating and cooling rates are very high so in order to avoid the possibility of the excessive hardening and embrittlement and related cracking tenancy if you want to reduce these because the HSLAs have the high carbon equivalent and since the cooling rate and the heating rate and cooling rates are also high, so these will be sensitive for hardening embrittlement and cracking.

So in order to reduce the hardening cracking and embrittlement tendencies like typical preheating and the post weld heat treatment cycles can be incorporated during the resistance welding processes, so that the cooling rates can be reduced and the formation of the softer phases can be facilitated in order to avoid the unnecessary hardening or the embrittlement and cracking tendency of the resistance spot weld joints of HSLAs.

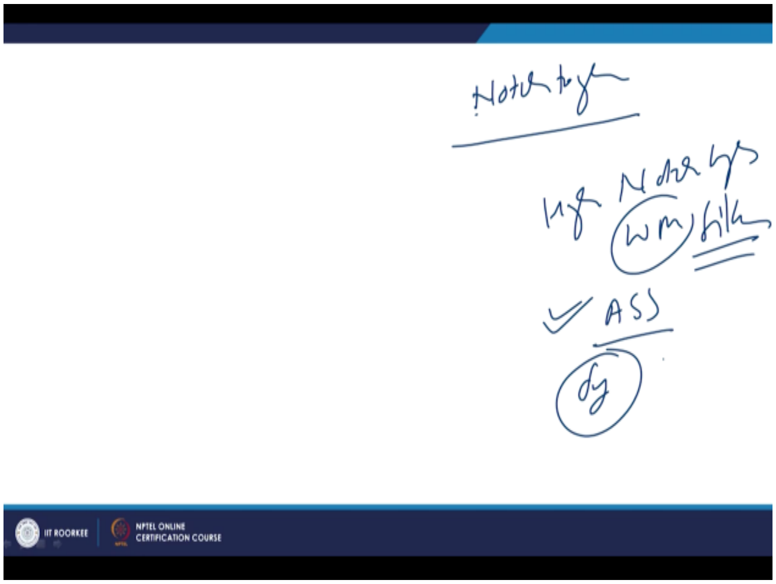
(Refer Slide Time: 28:38)



As far as the filler is concerned filler metal, some of the welding process of the non consumable welding processes and there are few consumable welding processes. So the line are the criteria for selection of the filler metal for HSLAs is similar to that of the carbon steels like for matching strength we choose the matching filler, but if we require some specific property in the weld metal then different filler is chosen.

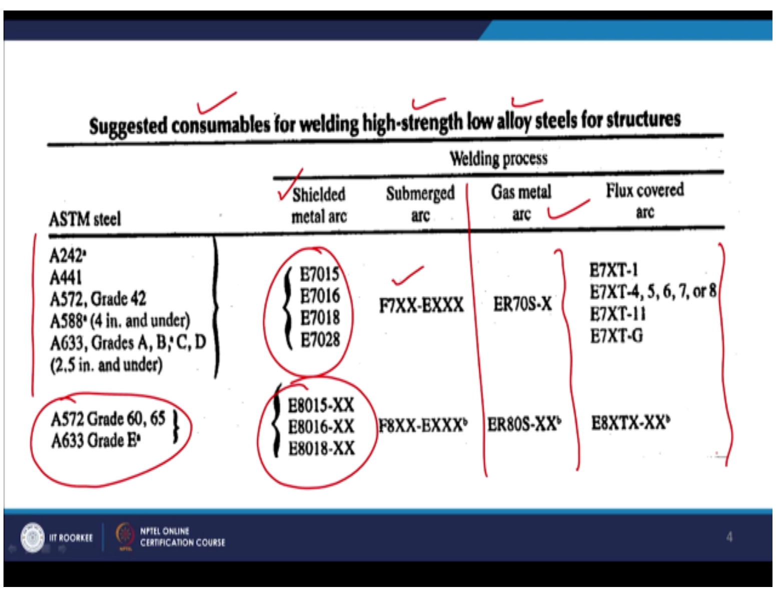
In such a way that is not only provides the required setup mechanical properties but response to the heat treatment is also same as that of the base metal so that the uniformity in the weld as weld metal as well the base metal properties can be realized after the post weld heat treatment and at the same time like I have said that if the notch toughness requirement is crucial for the weld metal.

(Refer Slide Time: 29:58)



Then we may choose the high notch toughness weld metal fillers, the fillers which will provide the higher notch toughness, so like ASS can be used for welding of the HSLAs provided other strength requirements like yield strength requirements are satisfied because this will provide very good the resistance to the a notch toughness .

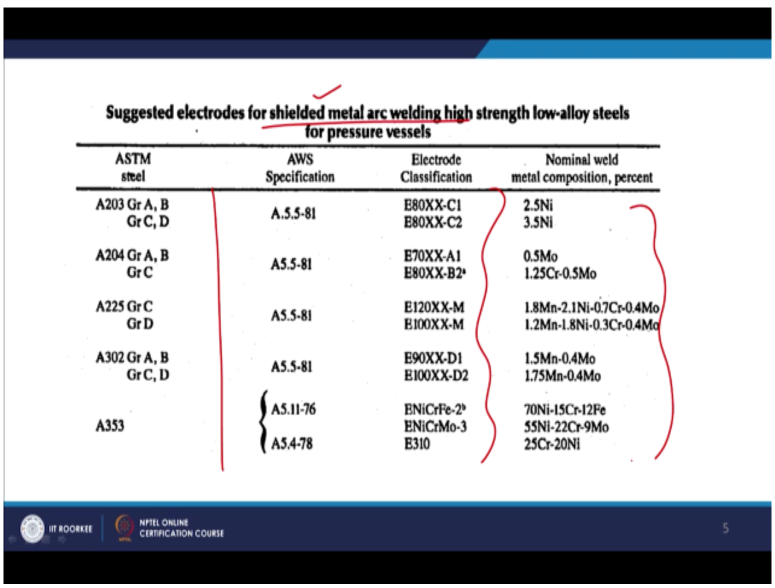
(Refer Slide Time: 30:34)



Now we will see there is a like the different fillers and the consumables which are used for welding of the high strength low alloy steels used for joining of the various structural components. So the different grades of the HSLAs when they are welded using the shielded metal arc welding, these are the set of the electrodes most of these are the low hydrogen electrodes of the 7000 series.

And another category or the group of the HSLAs is like 572 and A663 these grades are welded using these 3 types of the electrodes of the SMAW for SMAW process likewise for submerged arc welding there is a combination of the filler as well as the fluxes which will be able to offer the required set of the properties. These are the typical fillers for the gas metal arc welding and the fillers which are used for the flux code arc welding process are given this table.

(Refer Slide Time: 31:44)

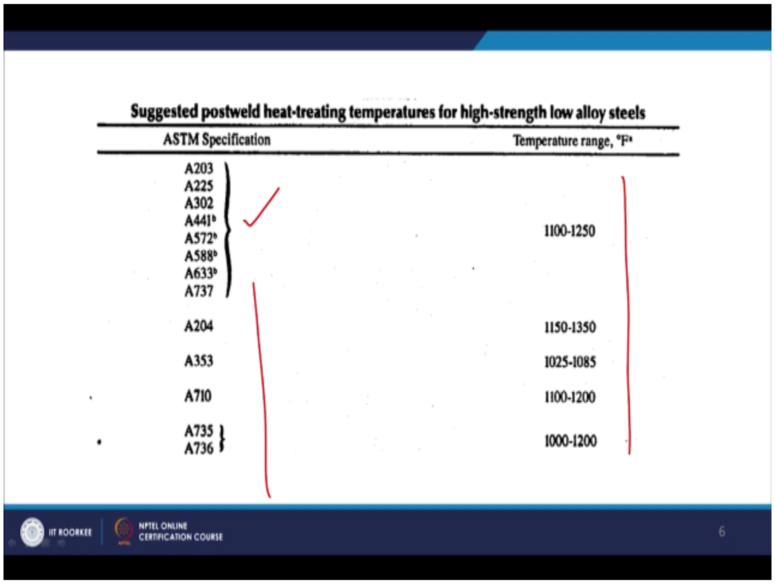


Suggested electrodes for shielded metal arc welding high strength low-alloy steels for pressure vessels

ASTM steel	AWS Specification	Electrode Classification	Nominal weld metal composition, percent
A203 Gr A, B Gr C, D	A.5.5-81	E80XX-C1 E80XX-C2	2.5Ni 3.5Ni
A204 Gr A, B Gr C	A5.5-81	E70XX-A1 E80XX-B2[a]	0.5Mo 1.25Cr-0.5Mo
A225 Gr C Gr D	A5.5-81	E120XX-M E100XX-M	1.8Mn-2.1Ni-0.7Cr-0.4Mo 1.2Mn-1.8Ni-0.3Cr-0.4Mo
A302 Gr A, B Gr C, D	A5.5-81	E90XX-D1 E100XX-D2	1.5Mn-0.4Mo 1.75Mn-0.4Mo
A353	A5.11-76 A5.4-78	ENiCrFe-2[b] ENiCrMo-3 E310	70Ni-15Cr-12Fe 55Ni-22Cr-9Mo 25Cr-20Ni

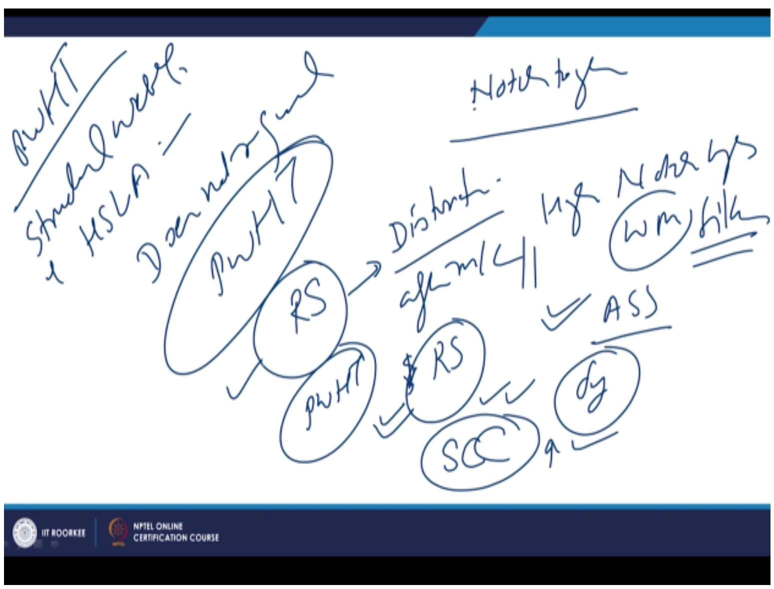
Now these are the typical electrodes which are or the filler metals which are used for the shielded metal arc welding process for the different grades of the HSLAs and these are the different kind of the electrodes which can be used for the welding of the HSLAs by a SMAW process and these are the typical elements which are present in the different grades of the steels.

(Refer Slide Time: 32:14)



Now we will see the kind of the preheat which is post heat treatment which is to be used for the welding.

(Refer Slide Time: 32:27)



And normally in structural welding, so PWHT post weld heat treatment structural welding of HSLAs does not require PWHT post weld heat treatment is normally not required for most of the structural welding of the high strength low alloy steel weld joints. But we know that whenever the steels are welded these invariably developed the residual stresses. So presence of the residual stresses swill be increasing the tendency for distortion especially after machining.

So if we want the dimensional stability of the HSLA weld joints after the machining during machining there is no dimensional change or the shape change then after the welding we must perform the PWHT and this is primary goal of the performing this PWHT is to relieve the residual stresses. So stress relieving is the main target, so that during the machining there is no distortion.

As well as the same time the relieving the residual stresses also helps in reducing the stress corrosion cracking tendency because if the world joint is used in the cross environment and if the tensile residual stresses are present in the weld metal or in the heat affected zone then it will be sensitive for the stress corrosion cracking. So in order to avoid such kind of the possibilities of post weld heat treatment is given to the weld zone.

So main purpose of this is to relieve the residual stresses so that these benefits can be availed for the critical components PWHT must be established so that we can ensure PWHT welding procedure specification should be established it should be tested and then we should follow those are the procedural steps very meticulously and very closely so that the required performance of the weld joint can be realized.

So now I will summarize this presentation, in this presentation basically I have talked about the weldability of the high strength low alloy steels wherein I have talked about the kind of the preheating temperatures to be used and what are the welding processes and it is effect on the properties of the HSLAs weld joints how the fillers are selected and what kind of the post weld heat treatments are given.

As far as the post weld heat treatment is concerned there is one typical the temperature range which is used like the different steels and kind of the post weld heat treatment temperatures which are to be used, so that regular stresses can be released, thank you for your attention