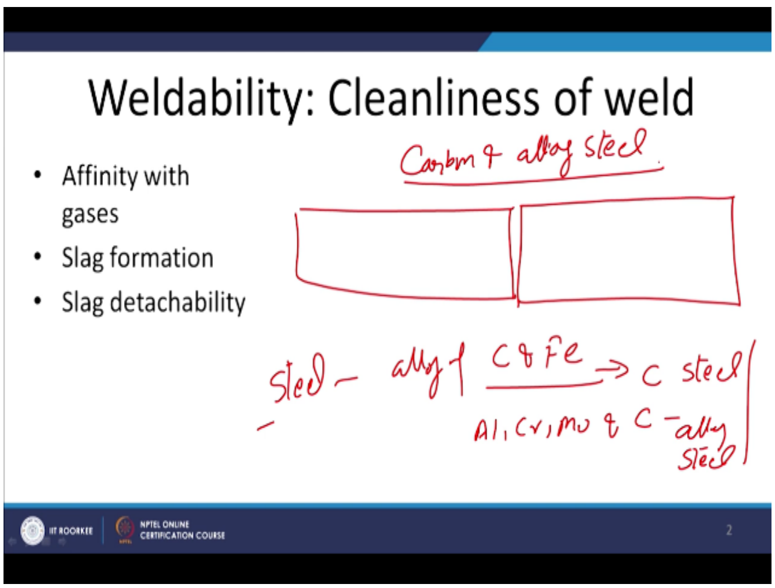
Weldability of metals
Prof. D K. Dwivedi
Department of Mechanical and Industrial Engineering
Indian Institute of Technology-Roorkee

Lecture-12
Weldability of Carbon and Alloy steel–I

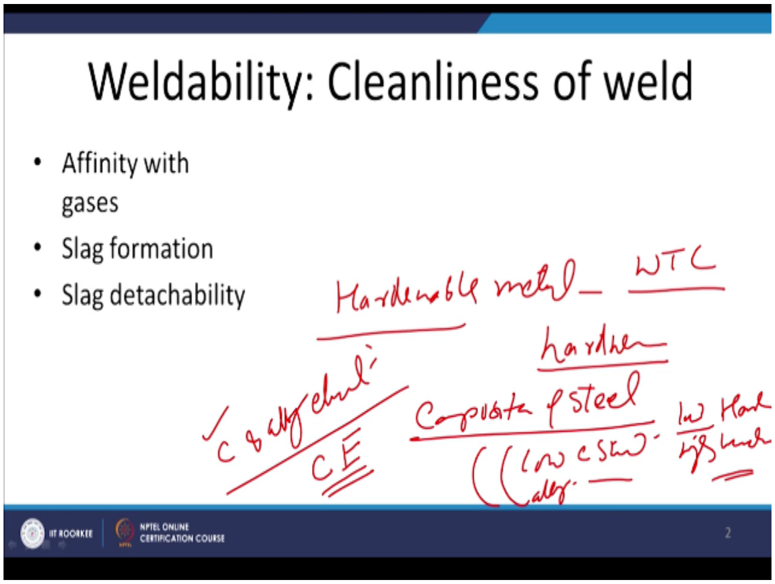
Hello, I welcome you all in this presentation related with the subject weldability of metals and you know we have seen that to look into the weldability aspects of metal we have to see the properties of the weld metal as well as the properties of the heat affected zone to see whether they are sound or not or the kind of properties which are available with the heat affected zone and with the weld metal.

(Refer Slide Time: 00:55)



So like say especially with regard to the steel welding no steels is an alloy of carbon and iron. So when only the carbon content is controlled it is called carbon steel, but when other alloying elements like aluminium, chromium, molybdenum is also added in control way apart from the carbon then it is called alloy steel. So in this topic basically will be initially talking about the weldability of the carbon and carbon steel and alloy steels.

(Refer Slide Time: 01:54)

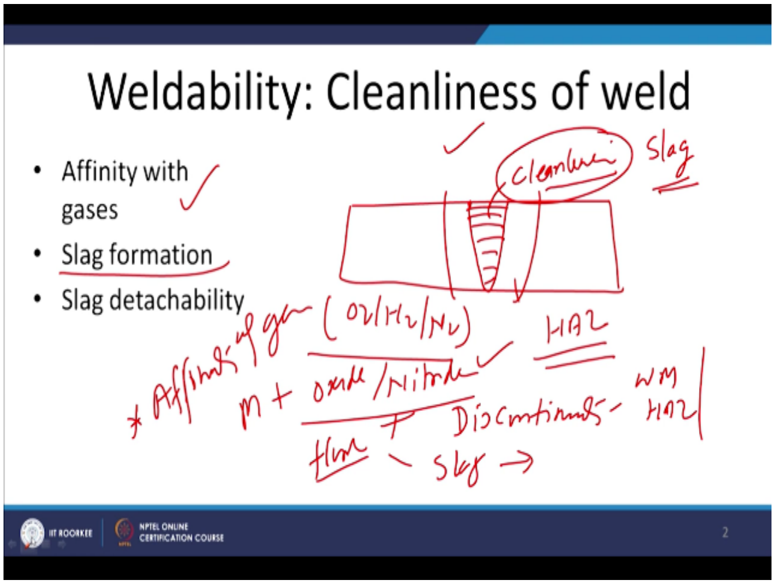


Since both are of the hardenable metal systems means the hardenability means hardenable metals which means when whenever they experience the weld thermal cycle they show such kind of metallurgical transformations where increase in hardness of the metal takes place. So however the hardenability of the metal will depend upon the composition of the steel low carbon steels or of the low hardenability while high carbon steels are of the high hardenability.

Similarly alloy steels are of the higher hardenability then the simple low carbon steels are so to have the combined effect of the carbon as well as alloying elements present in the steel we consider the combined effect of the different alloying elements present in the steel through the carbon equivalent. So carbon equivalent is a factor which includes the effect of the carbon as well as other alloying elements on the hardenable of the steels.

So higher the carbon equivalent greater will be the hardenability, so if the alloying element concentration is less carbon content is less than the hardenability will be low on the other hand if the carbon content is hiring element concentration is also high then it will be leading to the higher hardenability. This is very simplified format of the hardenability.

(Refer Slide Time: 03:35)



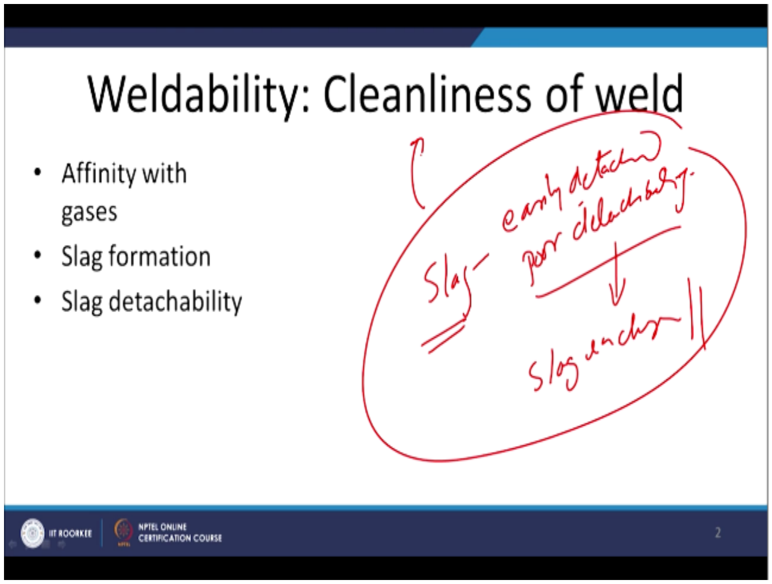
So most of the steels show the carbon and alloy steel show the hardenability and that is why there are 2 important aspects that are looked into to see the weldability of the steel, one is the of the cleanliness of the weld metal which is all about the slag kind of the slag which is present in the weld metal or if it is free from the slag and another one is the kind of the heat affected zone property valuation.

These are the 2 important aspects and in addition to this if the metal is really very sensitive for the defect and discontinuity formation, then we have to see the discontinuities being formed in both in both weld metal as well as heat affected zone. So as far as that weldability of the steel is concerned we will be looking into the cleanliness of the weld metal with regard to the slag inclusion and then the heat affected zone properties.

So the cleanliness of the weld metal depends upon the affinity of the gases atmospheric gases like oxygen, hydrogen, nitrogen etc. these are present during the welding environment and when at high temperature these interact with the metal in molten state they conform their oxides, nitrides, hydrides. So these impurities must be taken care of and for that normally we use fluxes. These fluxes when react with impurities these forms slag.

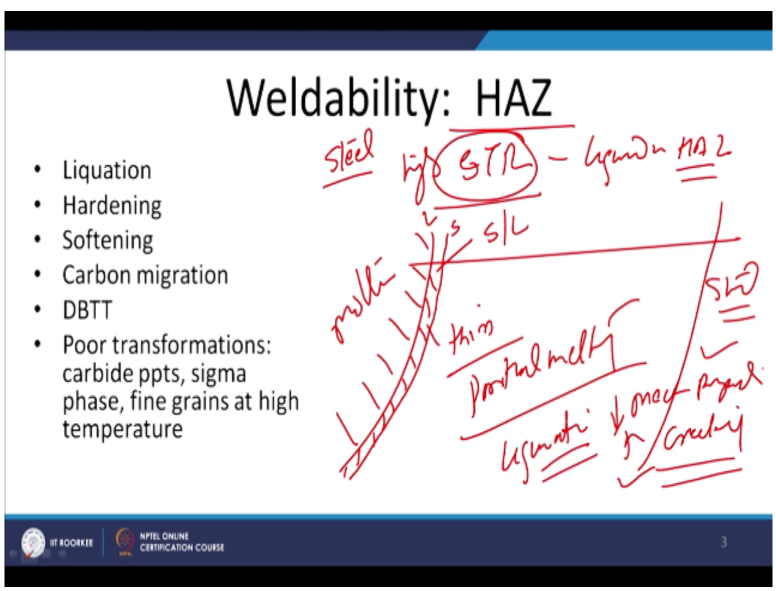
More greater the affinity of these gases so greater with impurities formation it will slag formation, so greater will be the slag inclusions entrapment tendency and which in turn will be reducing the cleanliness of the weld. So greater is the affinity of the gases with the metal in the molten state greater will be the slag formation tendency and so that it will be reducing the cleanliness of the weld metal.

(Refer Slide Time: 05:58)



Some types of the slags which are formed during the welding they can be easily detached but there are few types which show the detachability and when the flag is not detect properly from the weld will then it may remain attached and that can lead to the formation of the slag inclusion. So the slag detachability and amount of the flag which is being formed both affect the cleanliness of the weld metal.

(Refer Slide Time: 06:39)

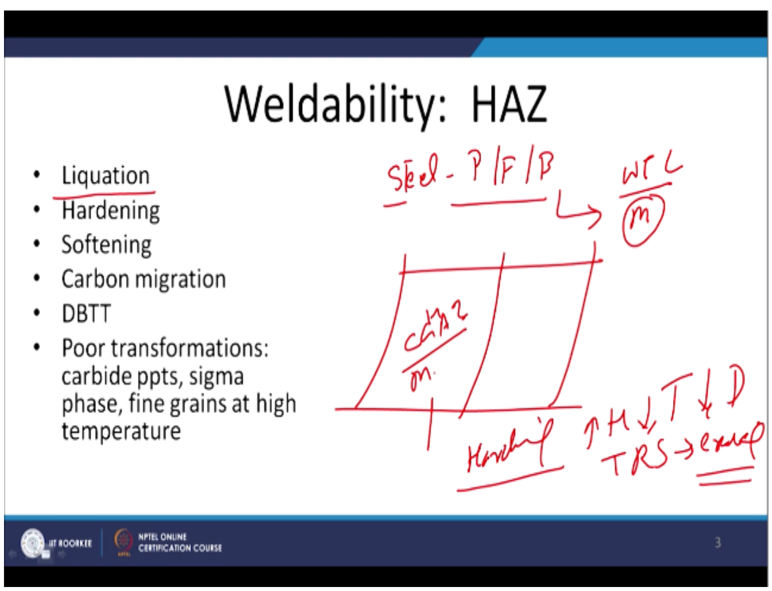


As far as heat affected zone is concerned even in case of the steels which are having the higher solidification temperature range, they show the liquation in the region next to the fusion boundary like this if the we know that if the steel is welded any zone which is heated above the liquidous temperature will be brought to the molten state. But there after there will be a zone which will be (()) (07:14) and that will falling in the solid liquid region .

And thereafter there will be a solidus, so the zone which is falling between the liquidus and solidus will be having the both liquid as well as the solid phases. So the these region which is very thin where partial melting due to the application of the heat takes place is called liquation and this liquation is known to reduce the mechanical properties and increase the cracking tendency of the zone next to the fusion boundary which is partially melting or where liquation is taking place.

So that the deterioration in mechanical properties as well as increase tendency in the region next to the fusion boundary especially in case of the high solidification temperature steels this one is formed apart from the liquation in the region next to the fusion boundary.

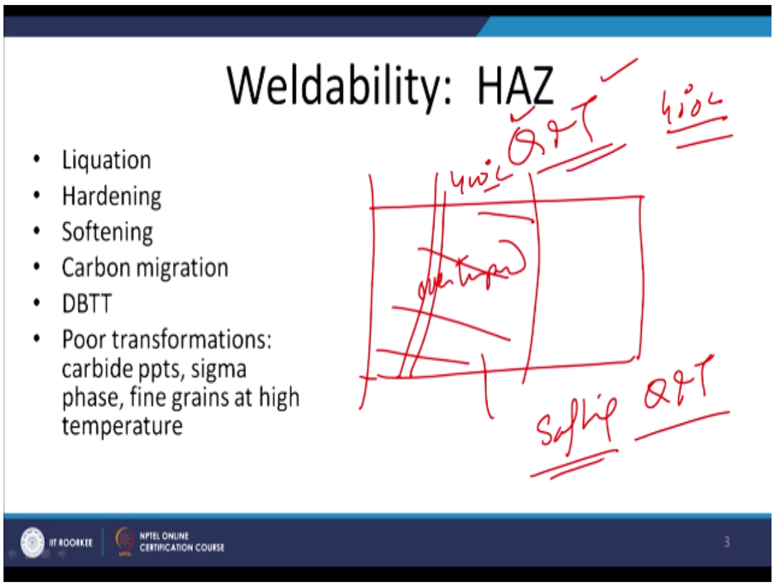
(Refer Slide Time: 08:32)



Whenever steels which commonly only have the pearlite, ferrite, bernide in the phases which are completely soft phases when they are subjected to the unfavourable weld thermal cycler these lead to the formation of the martensite and the formation of the martensite in the heat affected zone coarse grained Hz and the formation of the martensite. This leads to the hardening of the heat affected zone.

Increase the hardness reduces the toughness, reduces the ductility, so h is impact resistance of the heat affected zone is reduced and when the metal is subjected to the heat affected zone is subjected to the tensile residences it shows the great cracking tendency as well some of the metals or some of the steels like steel which is being very welded in quenched and tempered condition.

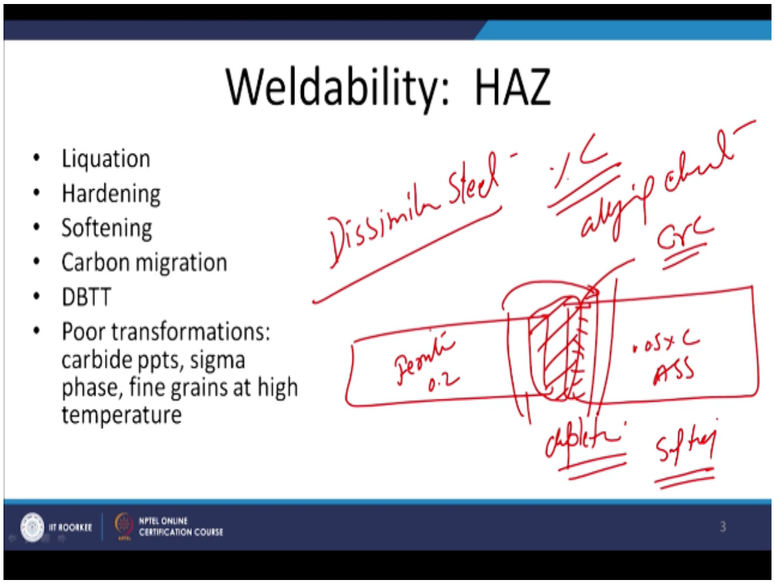
(Refer Slide Time: 09:36)



So obviously it is properties will be corresponding to the quenching and tempering for a corresponding to particular temperature saying steel has been quench and tempered at 400 degree centigrade. So during welding the heat affected zone will be formed and any region which is heated above 400 degree centigrade that will be over tempered and we know that over tampering invariably leads to the softening.

So qnp is steels even in case of the laser welding and other welding processes leads to the softening and this localized softening especially in the region away from the fusion boundary sometimes leads to the weakening of the joint and forms the location of the fracture , in case of the dissimilar metal systems dissimilar steels where there is a great variation in the percentage carbon or percentage of the alloying elements .

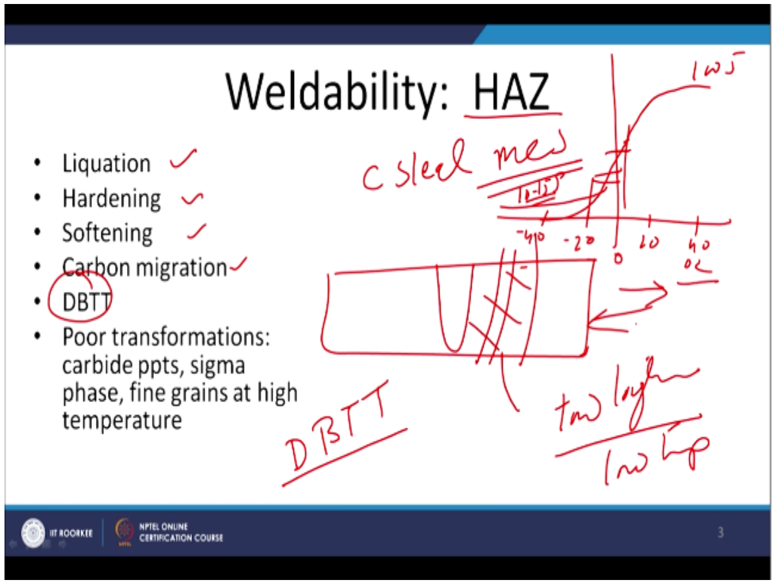
(Refer Slide Time: 10:36)



In that case like one side we are having the very low carbon steel the system like 0.05% carbon in austenitic stainless steel and on the other hand we are having simply ferritic steels having like say 0.2% carbon. So whenever these are the fusion welded what will notice that there is a movement of carbon from the high carbon zone to the low carbon zone due to the concentration gradient.

And this kind of the diffusion of the carbon from the high carbon zone to the low carbon zone leads to the depletion of the carbon, this depletion of deficiency of the carbon leads to the softening of the steel next to the fusion boundary and on the other hand it leads to the enrichment of the carbon on the austenitic stainless steel side and this kind of the enrichment leads to the formation of the unfavourable chromium carbide.

(Refer Slide Time: 12:19)



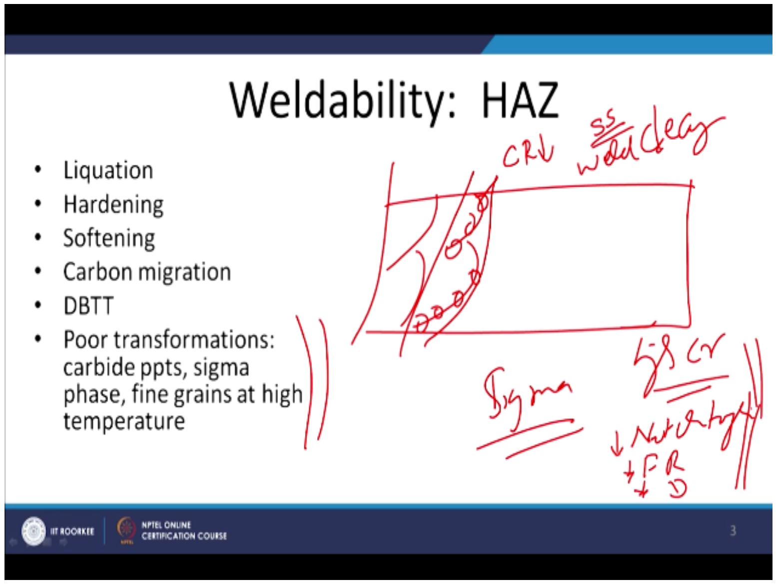
And which in turn reduces the corrosion resistance and sometimes hardening of the steel is also caused due to the localized carbon enrichment apart from these undesirable effects like liquation, hardening, softening, carbon migration. There is another undesirable feature or unexpected behaviour which is shown by the heat affected zone steels in the heat affected zone is the in case of the carbon steels like a medium carbon steel when they are subjected to the welding.

What we notice that the heat affected zone whatever is formed it experiences very low toughness especially under the low temperature conditions. For example if you notice this is the temperature 0 degree centigrade, 20 degree centigrade, 40 degree centigrade and on the other and -20 degree centigrade, -40 degree centigrade and if the toughness are the impact resistance of the heat affected zone of medium carbon steel which has been subjected to the welding.

If it is impact resistance is measured as a function of temperature then we will notice that on reaching to a particular value of the temperature there is very sharp drop in the toughness. So in initially at high temperature toughness maybe of say 100 joule but with the reduction in temperature it may come down to 10 to 15 joules. So such a low level of toughness may lead to the embrittlement, may lead to the fracture under the impact loading.

So this kind of the behaviour is more frequently is shown by the heat affected zone of the steels which show the hardenability and this kind of the drop in the impact resistance at lower temperature is characterized in terms of the ductile to brittle transition temperature, it is always expected that this DBTT will be on the lower side, so that there is no drop in the toughness under the service temperature conditions .

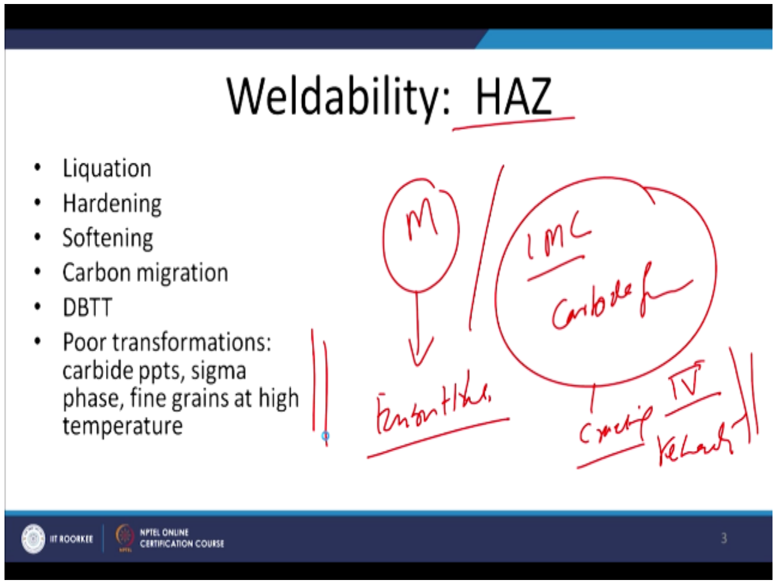
(Refer Slide Time: 14:31)



Then there is like as per the heat affected zone is concern many unfavourable phase transformations in the heat affected zone can take place in the steel and one of them is like in the steels like stainless steel specially the formation of the chromium carbide at the grain boundaries, this kind of the chromium carbide formation lowers the corrosion resistance and this is also called weld decay .

And this leads to the intergranular corrosion and premature fracture due to the localized corrosion taking place along the grain boundary , then another undesirable phase transformation is the formation of the sigma phase, in case of the high chromium systems sigma phase is formed which lowers the notch toughness lowers the fatigue resistance, lowers the ductility of the heat affected zone.

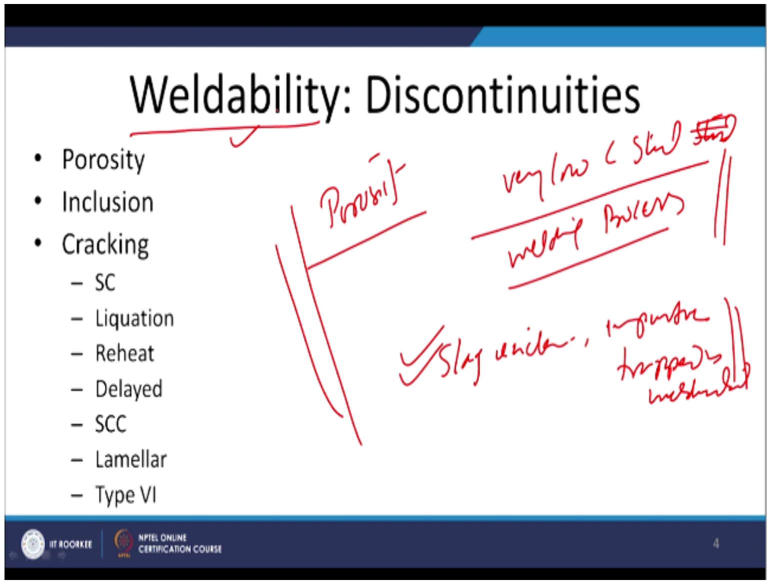
(Refer Slide Time: 16:10)



So formation of such unfavourable phases and intermetallic compounds in the heat affected zone sometimes leads to the reduced performance of the weld joint and reduced ductility, reduce the weldability of the metal due to the unfavourable metallurgical transformations. Apart from these phase transformations there can be formation of the martensite site.

There can be formation of many intermetallic compounds and unfavourable carbide formation. So formation of martensite leads to the embrittlement of the heat affected zone and formation of the intermetallic compounds and the carbides leads to the or it promotes the various kinds of the cracking like typo cracking or the reheat cracking. So all these will be reducing the eligibility of the metal or weldability of the steels if such kind of the unfavourable metallurgical transformations ah take place steel the steel.

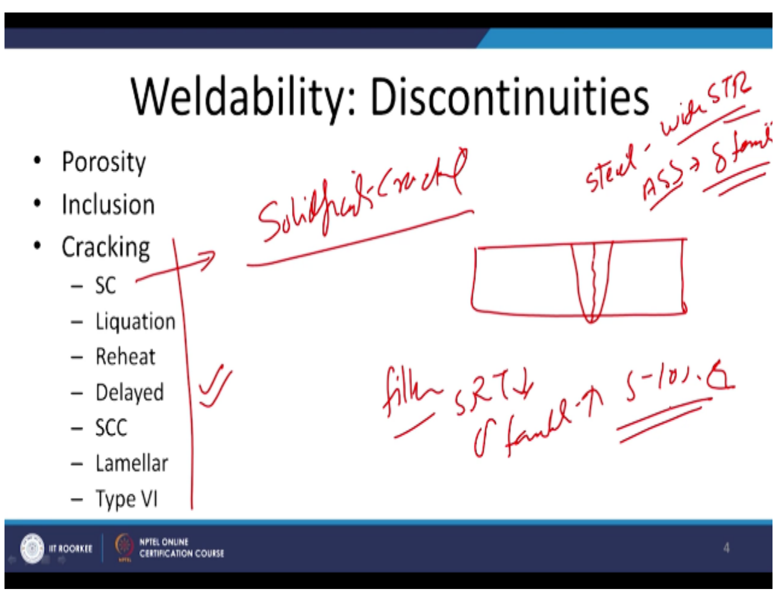
(Refer Slide Time: 17:08)



as far as the discontinuity development is concerned in the steel weld joints of the common the discontinuities which are observed in the steel weld joints and dictate the weldability of the steel is the porosity. Porosity is primarily observed in case of very low carbon steels and those when the welding process is not well controlled.

Then the gaseous packets are formed in the weld metal and thereby this lower the weldability inclusions of the various types like slag inclusions or the impurities trapped in the weld these will be there is a discontinued and may lead to the rejection of the weld metal and once the weld joint developed is rejected then of course the metal will be showing the reduced weldability.

(Refer Slide Time: 18:30)

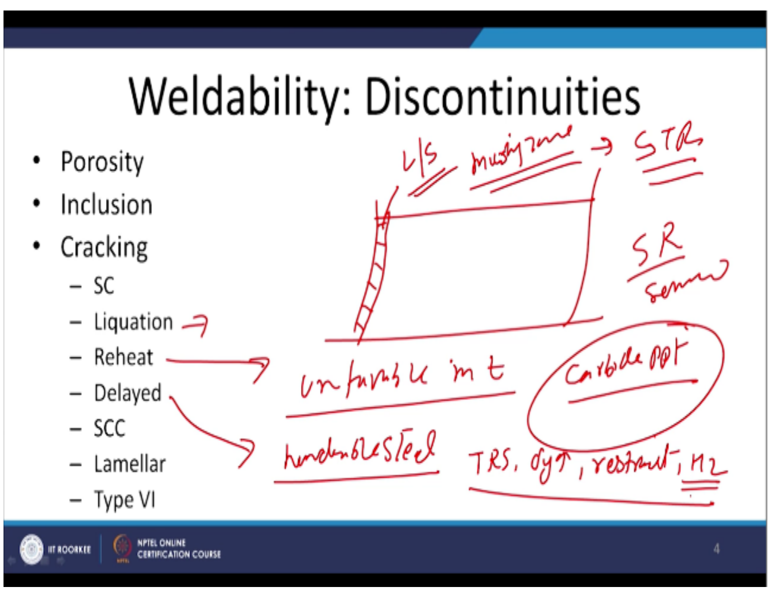


The steel weld joint show various types of the cracking tendencies like the first one is the solidification cracking. Solidification cracking is typically observed in the weld centre line at the weld centre line in the steels which show the wider solidification temperature range in austenitic stainless steel it is observed when the delta ferrite is very limited. So the weld centre line immediately after the building will show the cracks in the weld joint.

And that will lead to the frequently rejection of the welds and that internal will reduces, so all types of the cracking of the steel weld joints will be reducing weldability as it will require the increased precautions during the welding to avoid such kind of cracking. So if the solidification temperature in is very wide or the delta ferrite formation tendency, austenitic stainless steel is very limited.

Then we have to use the suitable filler, so that the STR is reduced or the delta ferrite formation tendency is increased so that we have 5 to 10% delta ferrite in the weld metal in order to avoid the solidification cracking tendency. So we need to take extra care to avoid such kind of the cracking tendency.

(Refer Slide Time: 20:07)

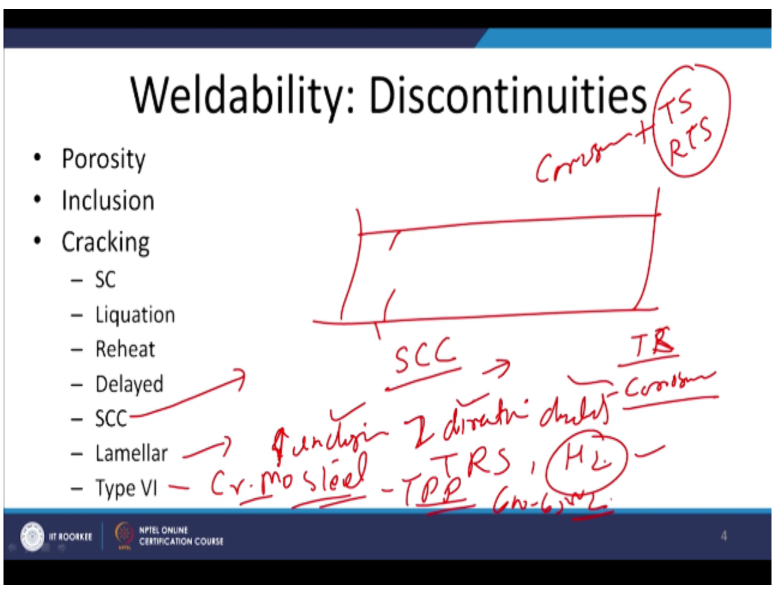


Then the liquation cracking is observed in the region next to the fusion boundary wherever the 2 phase zone is found both solidus as well as both solid and liquid phase are present and this is the basically the (()) (20:25) will be wider in case of the alloys having the wider solidification temperature range , then the reheat cracking is will be occurring due to the unfavourable metallurgical transformation in form of like very fine carbide precipitates along the grain boundary.

And it happens after the welding when the joint is reheated either for the stress relieving or it is heated to the high temperature during the service such kind of the carbide formations lead to the reduced ability of the grain boundaries to sustain the external stresses during the service and which in turn promotes the cracking. Delayed cracking is observed in case of the hardenable steels like all medium carbon steel, high carbon steel.

And alloy steel wherever the tensile residual stresses developed the yield strength is high the welding is being performed under very highest strain conditions and the hydrogen concentration in the weld metal and the heat affected zone is high. Sot hose will be leading to the delayed cracking or the cold cracking.

(Refer Slide Time: 22:01)



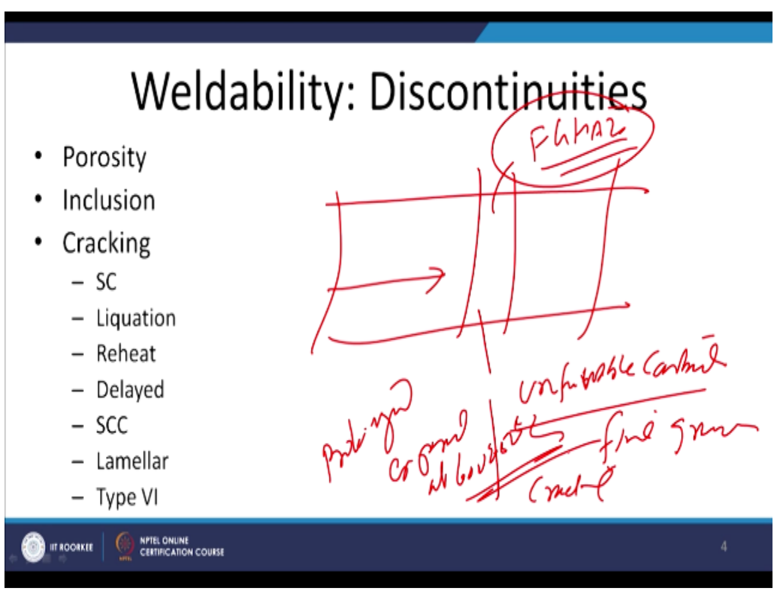
Cracking of the weld joint of the steel is also observed and in the corrosive environment when we either apply the external tensile stresses or the residual tensile stresses developed in the matter. So the metals which are sensitive to the corrosion as well as they are experiencing the tensile stresses or the tensile residual stresses. This show increased cracking tendency along the grain boundaries wherever such kind of the unfavourable metallurgical transformations take place.

So they will be promoting the stress corrosion cracking tendency, to avoid the stress corrosion cracking tenancy basically we have to avoid the tensile stresses we have to avoid the corrosion sensitive media. So that corrosion as well as the cracking tendency can be reduced. The lamellar tearing is basically observed due to the presence of the inclusions in the metal or the steel plate being welded or it is also observed when the Z direction ductility of the steel is limited Z direction.

Ductility of the steel is limited or the weld joint design is unfavourable leading to the development of the tensile residual stresses or it is also having the higher concentration of the hydrogen. So all these 4 factors will be promoting the lamellar tearing and so they will be reducing the weldability. Type 4 cracking is typically observed in the chromium molybdenum steel weld joints .

These are the steel weld joints which are used in the thermal power plants in the temperature range of 600 to 650 degree centigrade. So when such kind of the weld joints of these steels when they are used at high temperature.

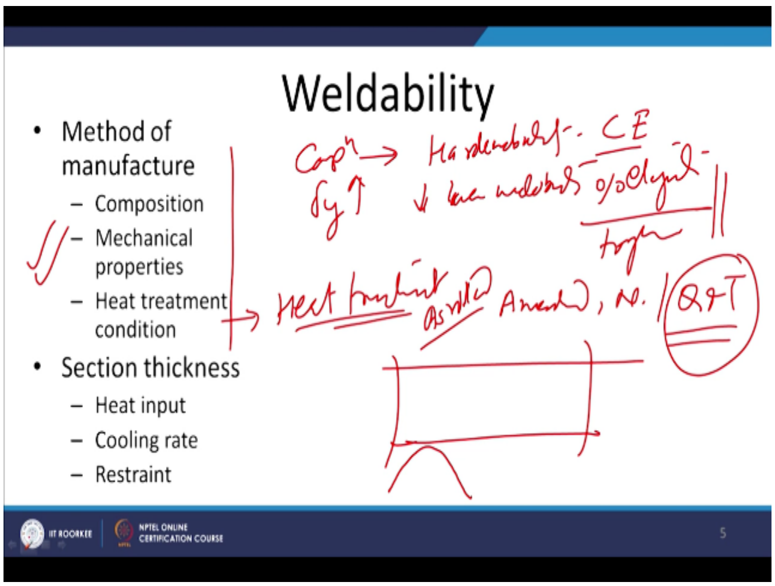
(Refer Slide Time: 24:04)



So a fine grain zone is formed fined grained Hz zone is formed as well as in this region on the prolonged exposure at high temperature formation of the unfavourable carbides at the grain bound at the grain boundaries of the fine grain leads to the promotes the cracking in the region away from the fusion boundary wherever fine grain zone, fine grained heat affected zone is present.

And that cracking occurs after prolonged exposure at high temperature may be 600 to 650 degree centigrade. So this is the type of a type IV cracking, so that different types of the characters will be observed in different types of the steels.

(Refer Slide Time: 25:02)



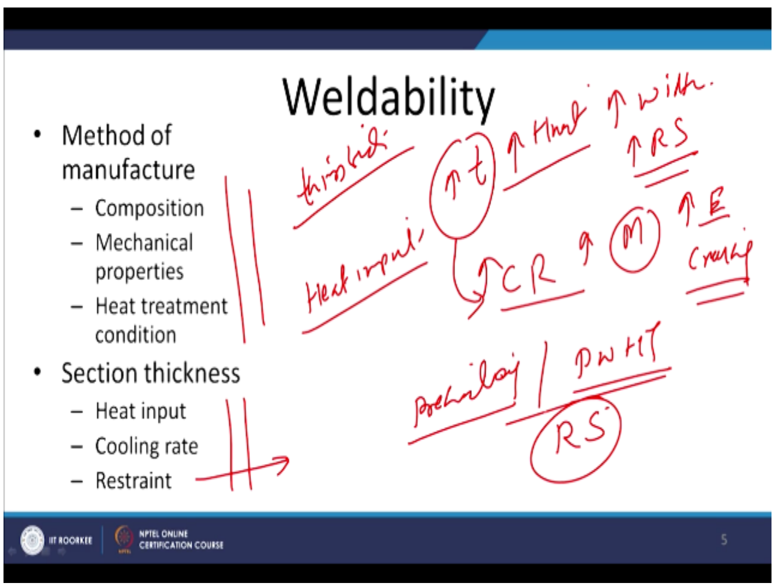
Now we will see that the factors as far as the steel circumstance the factors that affect the weldability like the most important factors that are affecting the weldability of the steel is like composition because it directly affect the hardenability due to the change in the carbon equivalent . Then the mechanical properties in general it is more difficult to weld the metals of the high yield strength.

So higher yield strength will be leading to the lower weldability due to the increased cracking tendency, the steels having the lower yield strength will show the greater tolerance to be discontinuities and defects they will show the greater toughness reduced embrittlement tendency. So it will be easier to weld the lower yield strength is steel size compared to the higher strength.

Apart from the yield strength it is the percentage elongation, the toughness of the steel that will also be affected the weldability, the very important factor that will be affecting the weldability of the steel is the heat treatment condition, so like the steels can be welded in as road condition, annealed condition, normalized condition or quenched and tempered conditions.

So as per the condition of the steel it is properties of the heat affected zone will vary. For example the steel in anneal condition after the welding will show the hardening in the heat affected zone while the qnt steel after the welding in the heat affected zone will show the softening . These are the some of the common factors which will be affecting the weldability of the steel the thin sections.

(Refer Slide Time: 27:10)



But when we talk of the weldability of steels for thick sections we need to consider the additional aspects like heat input like a greater is the section thickness greater will be the net heat input requirement, greater will be the width of the Hz and greater will be the residual stresses. So there will be lot of issues related with the greater heat input when the heaver sections are welded for the section thickness is more it will be extracting the heat more rapidly from the weld metal.

So the cooling rates will be high, so increased cooling rate in case of the heavier sections will be increasing the tendency for the martensite formation increase tendency for the embrittlement, increase tendency for the cracking, for the steel of the given hardenability or of the given composition for the restraint will also be more when the thickness is more, so we need to apply more controlled preheat heating.

And we need to apply the post weld heat treatments in order to take care of the issues related with the residual stresses in case of the heavier sections arising from the heavy restraint conditions. Now here I will summarize this presentation, in this presentation basically I have talked about the way by which the weldability of the steels can be looked into and how the weldability of the steel is affected with this section size and the different factors that we should look into to access the weldability of a steels like composition mechanical properties and the heat treatment condition, thank you for your attention.