Lecture 47 : Weldability of Carbon and Alloy Steel - I

Hello I welcome you all in this presentation 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. So like say especially with regard to the steel welding you know steel 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 controlled way apart from the carbon then it is called carbon. So, in this topic basically we will be initially talking about the weldability of the carbon and carbon steel and alloy steels. Since both are of the hardenable metal systems means the hardenability means hardenable metals, which means 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 temperature. composition of the steel, low carbon steels are of the low hardenability. while high carbon steels are of the high hardenability. Similarly alloy steels are of the higher hardenability than 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 carbon equivalent. So carbon equivalent is a factor which includes the effect of the carbon as well as other alloying elements on the hardenability of the steel. So higher the carbon equivalent greater will be the hardenability. So if the alloying element concentration is less, carbon content is less then the hardenability will be low.

On the other hand if the carbon content is high alloying element concentration is also high then it will lead into the higher hardenability. This is very simplified format of the hardenability. 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. 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 the heat affected zone property variation these are the two 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 weld metal as well as heat affected zone.

So, as far as the weldability of the steel is concerned we will be looking into the cleanliness of the weld metal with regard to the slag inclusions 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, nitrogen, hydrogen etc. these are present during the welding environment and when at high temperature these interact with the metal in molten state they react and form the They are oxides, nitrides, hydrides, so these impurities must be taken care of and for that normally we use fluxes.

These fluxes when react with the impurities these form slag. Greater the affinity of these gases greater will be the impurities formation, greater 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. Some types of the slags which are formed during the welding they can be easily detached, but there are few types which show the poor detachability and when the slag is not detached properly from the weld bead then it may remain attached. And that can lead to the formation of the slag inclusions.

So, the slag detachability and amount of the slag which is being formed both affect the cleanliness of the weld metal. As far as the 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 when the steel is welded any zone which is heated above the liquidus temperature will be brought to the molten state. But thereafter there will be a zone which will be a mushy zone and that will be falling 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, this 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, the deterioration in mechanical properties as well as increased 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 whenever steels which commonly have the pearlite ferrite, bainite in the phases which are completely soft phases when they are subjected to the unfavourable weld thermal cycle, these lead to the formation of the martensite. And the formation of the martensite in the heat affected zone coarse grained HAZ and and the formation of the martensite this leads to the hardening of the heat affected zone. Increased hardness reduces the toughness, reduces the ductility. So, means 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 residual stresses it shows the great cracking tendency as well.

Some of the metals or some of the steels like steel which is being welded in quenched and tempered condition. So, obviously its properties will be corresponding to the quenching and tempering corresponding to particular temperature. Say steel has been quenched and tempered at 400 degree centigrade. So, during the 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 tempering invariably leads to the softening.

So Q and T steels even in case of the laser welding and other welding processes leads to the softening process. 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. In that case like one side we are having the very low carbon steel 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 we 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 or 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 and which in turn reduces the corrosion resistance and sometimes hardening of the steel is also caused due to the localised 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 medium carbon steels 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 we notice this, this is temperature 0 degree centigrade, 20 degree centigrade, 40 degree centigrade and on the other hand minus 20 degree centigrade, minus 40 degree centigrade. And if the toughness or the impact resistance of the heat affected zone of medium carbon steel which has been subjected to the welding, if its impact resistance is measured as a function of temperature then we will notice that on reaching to a particular value of that temperature there is a very sharp drop in the toughness. So initially at a high temperature toughness may be of say 100 joule but with the reduction in temperature it may come down to 10 to 15 joule. So such a load level toughness may lead to the embrittlement, may lead to the fracture under the impact loading.

So, this kind of the behaviour is more frequently shown 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 characterised in terms of the ductile. to brittle transition temperature. It is always expected that this dvtt will be on the lower side, so that there is no drop in the toughness under the service temperature conditions. Then there is like as far as the heat affected zone is concerned 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 steels especially 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 surface. 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 system.

heat affected zone. 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, reduced weldability of the metal due to the unfavourable metallurgical transformations. phase transformations, there can be formation of the martensite, there can be formation of many intermetallic compounds and unfavourable carbide formation. So formation of the 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 typho cracking or the reheat cracking. So, all these will be reducing the weldability of the metal or weldability of the steels if such kind of the unfavourable metallurgical transformations take place.

in the steel. As far as the discontinuity development is concerned in the steel weld joints, 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 when the welding process is not well controlled then the gaseous pockets are formed in the weld metal and thereby these lower the weldability. Inclusions of the various types like slag inclusions or the impurities trapped in the in the weld metal all these lower the, all these will be there as a discontinuity and may lead to the rejection of the weld metal and once the weld joint developed is rejected then of course the weld metal will be showing the reduced weldability. The steel weld joints show various types of the cracking tendencies like the first one is the solidification cracking. Solidification cracking is typically observed 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 welding will show the cracks in the weld joint and that will lead to the frequently rejection of the welds and that internal reducing. So all types of the cracking of the steel weld joints will be reducing the weldability as it will require the increased precautions during the welding to avoid such kind of cracking. So, if the solidification temperature is very wide or the delta ferrite formation tendency in 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.

Then the liquation cracking is observed in the region next to the fusion boundary wherever that two phase zone is found both solid and liquid phases are present and this is the basically the mushy zone which is and this mushy zone 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 steels. Wherever the tensile residual stresses develop, the yield strength is high, the welding is being performed under very high restraint conditions and the hydrogen concentration in the weld metal and the heat affected zone is high, so those will be leading to the delayed cracking or the cold cracking.

Cracking of the weld joint of the steel is also observed in the corrosive environment when we either apply the external tensile stresses or the residual tensile stresses develop in the metal. So the metals which are sensitive to the corrosion as well as they are experiencing the tensile stresses or the tensile residual stresses they 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 tendency 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.

It is also observed when the 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 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 a high temperature. So, a fine grained zone is formed fine grained HAZ zone is formed as well as in this region Carbides at the grain boundaries of the fine grains 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 a prolonged exposure.

at high temperature may be 600 to 650 degree centigrade. So, this is the type of a type 4 cracking. So, the different types of the crackings will be observed in different types of the steels Now we will see that the factors as far as the steels are concerned 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 affects 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 the discontinuities and defects. They will show the greater toughness, reduced embrittlement tendency. So it will be easier to weld the lower yield strength steels as compared to the higher yield strength. Apart from the yield strength it is the percentage elongation. the toughness of the steel that will also be affecting 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 rolled condition, annealed condition, normalized condition or quenched and tempered condition. So, as per the condition of the steel its properties of the heat affected zone will vary. For example, the steel in annealed condition after the welding will show the hardening in the heat affected zone while the Q and T 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 of the thin sections.

But when we talk of the weldability of the steels for thick sections, we need to consider the additional aspects like heat input. like greater is the section thickness, greater will be the net heat input requirement, greater will be the width of the HAZ and greater will be the residual stresses. So there will be lot of issues related with the greater heat input when the heavier sections are welded. Further when 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, increased tendency for the embrittlement, increased tendency for the cracking for the steel of the given material.

hardenability or of the given composition. Further the restraint will also be more when the thickness is more, so we need to apply more controlled preheat, preheating. 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 the section size and the different factors that we should look into to assess the weldability of steels like the composition, mechanical properties and the heat treatment condition. Thank you for your attention.