Lecture 49 : Weldability of Carbon and Alloy Steel - III

Hello I welcome you all in this presentation and we have seen that the weldability of carbon and alloy steel is primarily influenced by the hydrogen induced cracking and the under bead cracking tendency. Now in this presentation we will see that how the what are the different aspects related with the carbon steels which will be affecting the weldability of the alloy. So, we will have to see this what are the various category of the carbon steels. Carbon steel means where primarily the carbon content is controlled and the carbon content can vary from like say up to 1%. while there will be the residual elements like manganese and silicon as per the type of steel. Sulphur and phosphorus are there as impurities, sometimes their concentration is intentionally increased.

So manganese is mostly up to That is the maximum concentration is about 1.65 and this is 1.8 and the concentration of the sulphur and phosphorus is maintained below the less than 0.05%.

So considering this the steel is classified based on the composition or the carbon steels are classified based on the composition and also they are named based on the deoxidation process being used. So based on the deoxidation process depending upon the oxygen concentration there can be rimmed steel capped steel semi-keeled steel or keeled steel. So, these are in reducing concentration of the oxygen and the different elements can be used like manganese kiln, silicon kiln or aluminium kiln. Still since the deoxidation process affects the composition as well as the kind of the elements being used for deoxidation purpose. So alloying elements are also concentration is being affected, so these in turn affect micro structure and so the mechanical properties and combination of both these therefore affects the weldability of the steel.

So, the deoxidation process also affects the weldability of the steel. So the different steels will have the like rimmed to the killed steels will have the different ease of the welding. Similarly with regard to the composition like there is one most common classification 10xx which means there is a maximum manganese content is less than 1%. But there is another 1,5xx category in the carbon steels where maximum manganese content is less than 1.

65%. On the other hand there are 2 more categories 1,1xx this belongs to the category where resulphurization, steel where in the sulphur has been added intentionally in order to improve the machinability and there is one to double x that is re-sulphurized and re-phosphorized. steels where both sulphur and phosphorus concentration has been increased intentionally in order to improve the machinability. But whenever the steel is added with the sulphur and phosphorus intentionally it creates the trouble primarily in form of the increased solidification cracking or hot tearing tendency during the welding. Because these form the low melting point constituents and which facilitates the separation of grains to promote the cracking. Apart from these based on the carbon concentration only the steels are classified as a low carbon steel having the carbon content less than 0.

15%. Then there is a mild steel having the carbon concentration in the range of 0.15 to 0.3%. Then medium carbon steel having the carbon in the range of 0.

3 to 0.5% and high carbon steel where carbon content is greater than 0.5%. And since the carbon content is directly affecting the microstructure increasing tendency for martensite formation, increasing carbon equivalent, increasing hardenability. So it will be reducing the weldability. So with the increase of carbon content in general there is a decreasing weldability of the material.

And if we see the kind of properties which are realised in terms of low carbon steels having the hardness of the order of the 60 HRB is the Rockwell hardness in the B scale. Then the mild steel having the HRB about 90 that is RB. and the hardness on the C scale for the medium carbon steel is around 30 RC and 40 RC is high carbon steels. So, as we can see this low carbon steel offers the excellent weldability, mild steel has a good weldability. Medium carbon steel has a fair weldability where preheat is needed in order to control the cooling rate, avoid the martensitic formation, transformation, reduce the residual stresses so that the cracking tendencies can be reduced and the high carbon steels offer poor weldability which requires low hydrogen process means low hydrogen electrode very close control over the hydrogen concentration in the weld metal during the welding.

And these require preheating and after the welding post weld heat treatment is needed for the welding of the welding. high carbon steel. So the weldability will be minimum for high carbon steel, excellent one is for the low carbon steel, then good for the mild steel, fair for the medium carbon steel and then poor for the high carbon steels and there is a direct since the carbon steel Since the carbon content, carbon percentage in steel directly affects the tendency for the transformation or the transformation characteristics austenite to the other phase transformation characteristic is directly affected by the carbon content. And the alloying elements having the effect similar to that of the carbon content is taken care of through the carbon equivalent. So since in the carbon steels we primarily have the carbon, manganese and silicon, so their effect is also to be taken into account to consider the way by which presence of all these 3 elements The way by which presence of all these 3 elements will be affecting the transformation behaviour and that is taken care of with the help of the carbon equivalent.

Which considers carbon plus manganese plus silicon divided by 4, so here carbon concentration Carbon has the maximum effect on the hardenability and then the lower effects are there of the manganese and silicon. So, accordingly their contribution is taken care of. So, these numbers basically indicate the weight percentage of the different elements present in the process. And the steels have the carbon concentration has the direct effect on the properties of the steels that will be realized and also on the kind of the martensite which is being formed. So the steel like say having the 0.

2% carbon, 0.4, 0.6, 0.8 and 1. So, here percentage of carbon and on the other hand if y axis is showing the hardness variation in terms of the C scale so like 10, 20, 30, 40, 50, 60 and 70 this is RC Rockwell hardness. The high cooling rate which is typically observed during the welding is facilitating the complete martensitic transformation means austenite to martensite transformation is complete means 100% martensite is there in the weld metal.

So, in that case the way by which property variation which is observed in case of the steels goes in like this where this is the property variation means hardness variation when the 100% martensitic transformation is observed. And when the martensitic transformation is 50% then of course there is increase in hardness but the rate of increase in hardness is low. austenite to martensitic transformation is 50%. So, in general if we see this plot the increasing the carbon content increases the hardness and increase in hardness is more effective when the 100% martensitic transformation takes place as compared to the 50% martensitic transformation. So, it is so if we see despite of having the 100% martensitic transformation low carbon steels may have the lower hardnesses and so the reduced cracking tendency and when the carbon content with the steel is high it forms the 100% martensite of the higher hardness.

So, whenever the hardness is high and the martensite is being formed this combination increases the hardness. cracking, tendency and embrittlement of the steel. Now we will see that the way by which carbon steels behave. So, this behaviour of the carbon steel during the welding will be observed in number of ways. One is the way by which micro structural variation which is observed.

And the second one is the way by which the inclusions present in the steel will be responding and then third is the kind of the pores which are formed during the welding of the carbon. So, starting with the structural variation in the weld metal during the welding of the carbon steel. So, we know that whenever the welding or the fusion welding is applied there will be variation in temperature right from the room temperature in which the welding is being performed metal the base metal in its original condition initial stage condition. And on the other hand the weld metal which has been produced after fusion of the base metal will have the highest temperature corresponding to the melting point or more. So if we see one side we have room temperature and another side we have the temperature corresponding corresponding to the melting point of the base metal and in between will have the gradually reducing temperatures.

So the peak temperatures attained by the different locations away from the weld metal will be different and so what we will say that the weld thermal cycle of the different locations will be changing and that weld thermal cycle is measured in terms of the variation as a function of temperature variation as a function of time where we will be seeing the rate at which temperature rises and then how fast it comes down. So basically we have to see the heating rate of a particular location, then the peak temperature heating rate, then the peak temperature attained and then how long that is the soaking is happening and thereafter the kind of cooling rate being experienced in general. The point closer to the fusion boundary heating rate is high, peak temperature is high, so high temperature, soaking at a high temperature is also longer and the cooling rate is high. All these parameters are on the higher side for the regions which are close to the fusion boundary. And on moving away from the fusion boundary the values of all these parameters will be decreasing.

since the different points will be experiencing the different heating rates, different peak temperatures, different soaking time and different cooling rates. So there will be huge heterogeneity in the microstructure. Regions which are very close to the fusion boundary they Since the cooling rate is very high and the high temperature is being retained for longer time, so they will be having the coarse grains plus martensitic or the bainitic. or the pearlitic and the ferritic phases as per the composition of the steel. Mostly the martensite and the ferritic phases are formed in very coarse grain size next to the fusion boundary as per the composition of the base metal.

On moving away from we get the fine grained coarse HAZ then partially refined HAZ and then base metal. So we may have very coarse grain martensite and then fine grain either martensite and the ferrite mixture and then we may have the ferrite and pearlite mixture. So the regions next to the fusion boundary will be having very heterogeneous micro structure and accordingly the properties will be changing significantly very high hardness next to the fusion boundary and then reducing hardnesses away from the fusion boundary. until the base metal. But if we see the weld metal, weld metal experiences the highest cooling rate.

So there will be every tendency for the formation of the martensite and that too of the fine grain structure. if the autogenous welding has been performed. But we may regulate the weld metal composition as well as properties using the suitable filler or the electrode that will help in having the suitable combination of the properties in the weld metal. So we can do a lot for regulating or adjusting or realizing the properties of the weld metal but we have limited things to do for changing the properties of the welding. heat affected zone and that is why especially in case of the steels the property control over the properties of the heat affected zone to a great extent determines the ease of welding.

So, since we get lot of variation in the microstructure starting from the martensite to the martensite and ferrite and then ferrite and the pearlite. So both these structures are very sensitive for cracking especially in case of the high carbon steels. So if the carbon equivalent is high or the carbon content in the steel is high then the formation of the high carbon martensite or high carbon martensite plus ferrite mixture will make the heat affected zone as well as the weld metal sensitive for There is another aspect as I have said the carbon steel carbon equivalent is very important consideration in welding of the carbon steels which is calculated using carbon plus manganese plus silicon divide by 4. So, this will give us the carbon equivalent, so if we take a simple example like very low carbon steel having 0.2% carbon but if the manganese content is very high like 1.

65 and 0.6% of the silicon then this will be leading to the higher concentration of the like this will be leading to the 2.2 divided by 4. So obviously the carbon equivalent it will be leading to the greater than 0.7%. So the carbon equivalent greater than 0.

7% is certainly leading to the problems in form of the cracking due to the high carbon equivalent. In this case especially since the carbon content is low so the martensite even if it is 100% martensite is being formed the hardness of the weld zone as well as heat affected zone will be limited. But if the section thicknesses are high then it will further increase the tendency for So, there is a very useful diagram which is showing the relationship between the carbon equivalent and the various other properties in form of like one side we have the band angle. Like a weld is made like this then notch is made in the weld face side and then controlled bend test is carried out to see the extent up to which bending of the weld joint can be done and then we measure that angle the extent up to which bending can be performed prior to the development of the or the growth of the crack. This directly indicates the notch sensitivity of weld for cracking and that is becomes good indicator of the weldability of the steel apart from that so that bend angle will be indicated here.

like this here we have 10, 20, 30, 40, 50 bend angle in degrees and then we have the hardness hardness in DPH units say 150, 200 to the 550, 450, 350, 300 like this and there is one more scale for the for the hardness value, so the hardness not for the hardness but it is the under bead cracking tendency is this. under weed cracking sensitivity under weed cracking sensitivity UBCS under weed cracking sensitivity 50, 70, 80 and 100. The last scale and if we notice this under weed cracking sensitivity And then if we notice with the increase of the carbon equivalent the bend angle corresponding to the growth of the crack during the notch face bend test that angle will be decreasing like this. which is showing that the bend angle is decreasing means the cracking sensitivity of the weld metal is increasing with the increase of the carbon equivalent for the carbon steel. On the other hand the under bead cracking tendency increases like from 10 to 30, 50 like this.

increase of the carbon equivalent this is for UBCS under weed cracking sensitivity and this is the bend angle. Bend angle is decreasing and under weed cracking sensitivity is increasing with the carbon content. Then we have the hardness variation, so hardness will continuously be increasing with the increase of the carbon equivalent like this. So what it shows with the increase of carbon equivalent weldability in terms of the crack sensitivity, under width cracking sensitivity as well as the bend angle in the notch face bend test that is also indicating the weldability all those will be decreasing while the hardness will be increasing and this is primarily attributed to the formation of the high carbon martensite, increased martensitic transformation tendency of the higher carbon content.

Then another aspect is the inclusions. As I have said the carbon steel sometimes intentionally added means re-sulphurized or re-phosphorized or sometimes they are intentionally added with the lead content. So these additions are primarily done to make the steel free machining type. So, these will be there as inclusions and will promote the discontinuous chips and reduce the cutting forces required for the machining purpose. So, the free machining steels are made with the addition of the sulphur, phosphorus and lead. When the sulphur and phosphorus are present in the higher percentage in the steel, these low melting point constituents in the weld metal and these low melting point constituents in the weld metal when they come across the tensile residual stresses they promote the of the grains from the grain boundaries which appears in form of hot tearing or the solidification cracking.

So, both sulphur and phosphorus because of the formation of the low melting point phases sets under the influence of the tensile residual stresses being set in the weld metal promotes the separation of the grains along the grain boundary and which appears eventually in form of the solidification cracks along the weld centre line. On the other hand the lead when it is added in higher percentage in order to facilitate the machining, machinability of the steel or easy machining of the steels it will be there as inclusion. Because it does not get dissolved so it will there as inclusion since it has a very low melting point even under the high intense heat of the welding it may evaporate. Evaporation since the lead fumes are toxic, so we need very good ventilation. And even the evaporation of this can lead to the development of pores in the weld metal.

So, the cracking due to the melting as well as pores formation due to the evaporation and good ventilation requirement for due to the high toxicity of this. gases will be increasing the troubles associated with the welding especially with regard to the porosity and the cracking tendency of the steel. So, what to do if at all in any case if the high sulphur, high phosphorus and high lead steels need to be welded then the best way is to reduce the heat input as much as possible, low heat input so that the extent of fusion of these undesirable constituents can be reduced. So, reducing the extent of sulphur, phosphorus and lead content in the weld metal by reduced melting of the base metals with the help of low heat input basically will be leading to the control of the dilution. Control of the dilution will help in reducing the sulphur and phosphorus content in the weld metal and thereby it will help in reducing the problems associated with the sulphur and phosphorus and the lead, so these are the things which can be done in order to overcome the issues related with the welding of the carbon steels.

Now I will summarize this presentation. In this presentation I have talked about the various categories of the carbon steels and what are the common issues which are encountered during the welding of the carbon steels and what can be done in order to overcome those issues. Thank you for your attention.