Weldability of Metals

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

Lecture-14

Weldability of Carbon and Alloy Steel-III

Hello I welcome you all in this presentation related with the subjects weldability of metals and we have seen that the weldability of carbon and alloy steel is primarily influenced by the hydrogen induced cracking and the underwear cracking tendency. Now in this presentation will see that how the what are the different aspects related with the carbon steels which will be affecting the weldability of the carbon steel.

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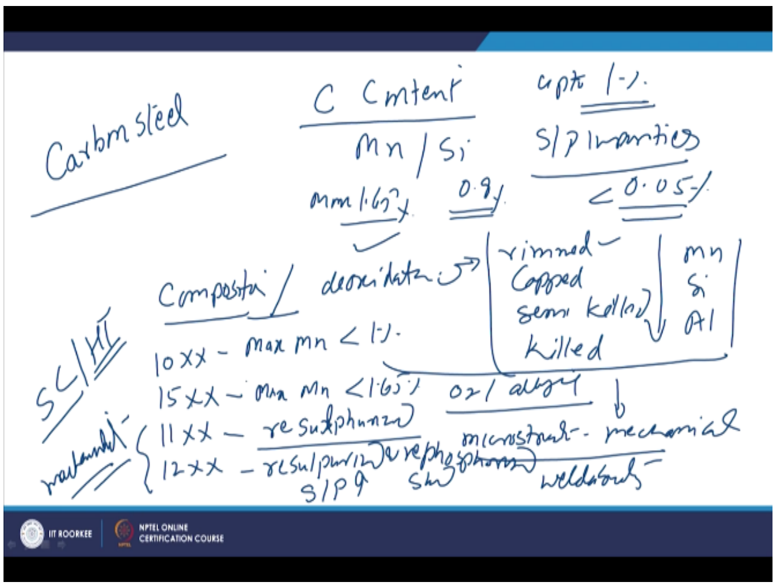

So will have to see this what are the various category of the carbon steels. Carbon steel means where primarily the carbon content is controlled and the carbon content can vary from like say up to 1% while there will be the residual elements like manganese and silicon as per the type of steel sulphur 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 **1.** 0.8 and the concentration of the sulphur and phosphorus is maintained below 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 de-oxidation process being used.

So based on the deoxidation process depending upon the oxygen concentration there can be rimed steel, capped steel, semi killed steel or killed steel.

So these are in reducing concentration of the oxygen and the different elements can be used like Manganese killed, silicon killed or aluminium killed steel, 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 interns affect the microstructure and so the mechanical properties and combination of both these therefore affects the weldability of the steel.

So that the deoxidation process also affects the weldability of the steel , so the different steels will have the like a rimed 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 there is a maximum manganese content is less than 1%, but there is another file XX category in the carbon steels where maximum manganese content is less than 1.65%.

On the other hand there are 2 more categories 11XX this belongs to the category where resulfurization, resulfurized steel where in the sulphur has been added intentionally in order to improve the machinability and there is 12XX that is resulfurized sulfurized and rephosphorized 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 primary inform of the increased solidification cracking or hot tearing tendency during the welding because these are formed the low melting point constituents and which facilitates the separation of grains to promote the cracking.

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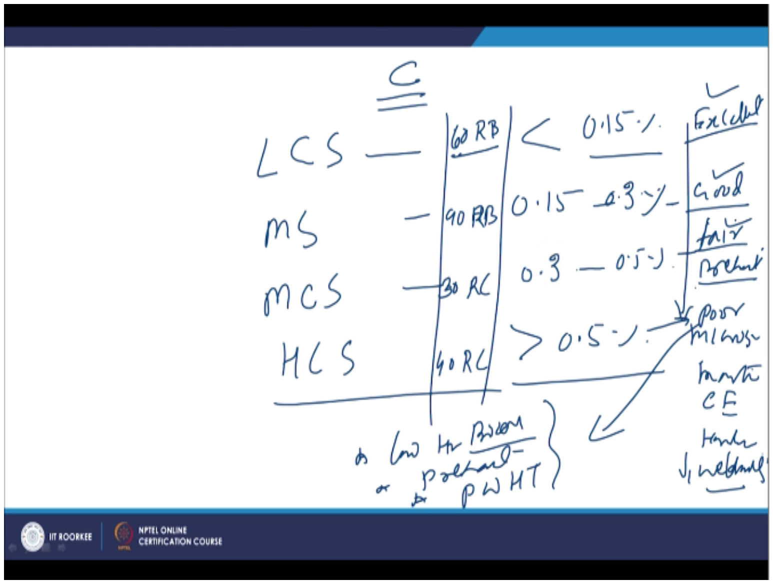

Apart from these based on the carbon concentration only the steels are classified as a low carbon steel having the carbon content less than 0.15%. Then there is a mild steel having the carbon concentration in the range of. 152.3 percent then medium carbon steel having the carbon in the carbon concentration in the range of 0.15, 2.3% 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 equal and 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 metals and if we see the kind of properties which are realized in terms 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 for the high carbon steels.

So as we can see this the low carbon steel offers the excellent weldability medium 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 molten state formation, transformation reduce the residual stresses. So that the cracking tendencies can be reduced and the high carbon steels of a poor weldability which requires low hydrogen process is 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 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.

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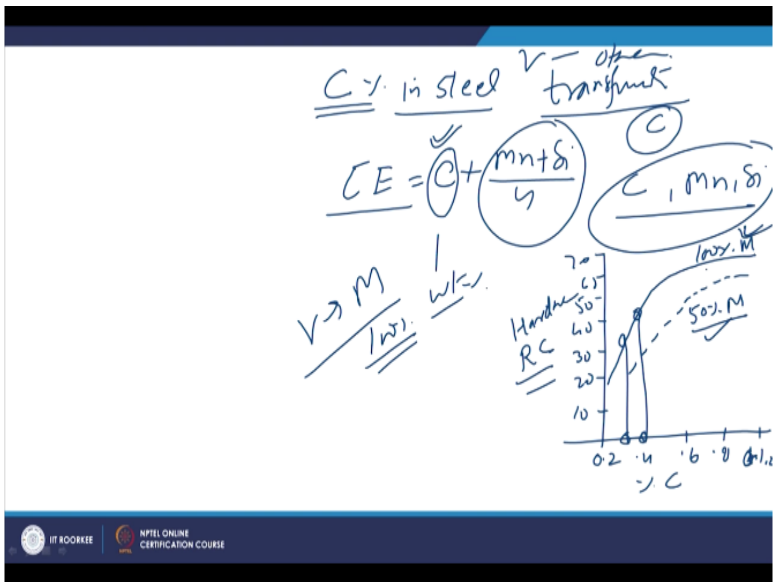

And there is a direct since the carbon steel since the carbon content carbon percentage in steel directly affects the tendency for the transformation or the transformation characteristics of the austenite to the other phase transformation characteristic is directly fitted by the carbon content and the alloying elements having the effects similar to that of the carbon content is taking care of to the carbon equivalent.

So since in 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 the 3 elements will be effect in the transformation behaviour and that is taking care of a with the help of the carbon equivalent which considers carbon+magnesium+silicate/4.

So here carbon concentration as 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 values these numbers will indicate the weight percentage of the different elements present in the steels 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 1.0, 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. So when the high cooling rate which is typically observed during the welding is a facilitating the complete martensitic transformation is austenite to martensite transformation is complete is 100% martensite is there in the weld metal.

In that case the way by which property variation which is observed in case of the steel goes like this, where this is the property variation is hardness variation when the 100% martensitic transformation is observed and when the martensite transformation is 50% then the of course there is increase in hardness but the rate of increase in hardness is low when the austenite to martensite 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 compare to the 50% martensitic transformation. So it is so it is so if we see despite of having the 100% martensitic transformation low carbon steels may have the lower hardness and so the reduced cracking tendency.

And when the carbon content with the steel is high it forms a 100% martensite of the higher hardness. So whenever the hardness is high and the martensite is being formed this combination increases the cracking tendency and embrittlement of the steel.

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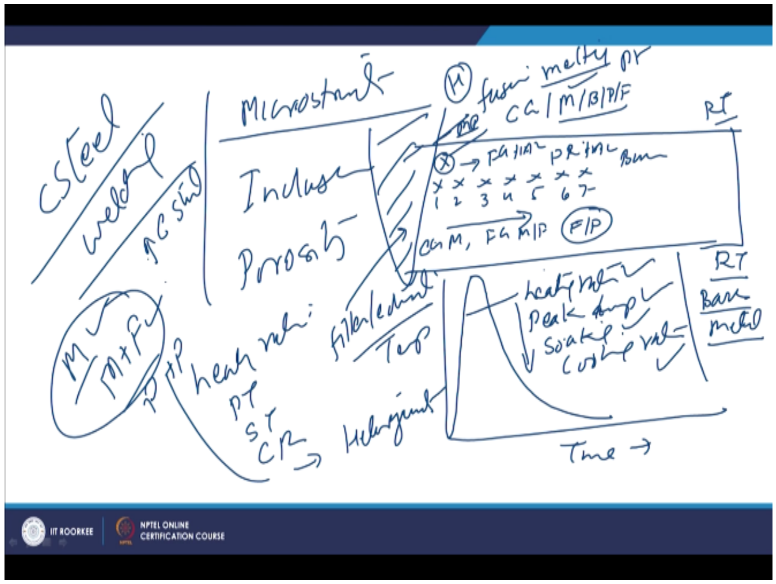

Now we will see that the way by which carbon steels behave, so ah this behaviour of the carbon steel during the welding will be observed in number of ways one is the way by which microstructural variation which is observed and the second one is the way by which the inclusions present in the steel will be responding and then third is the kind of the pores which are formed during the welding of the carbon steel.

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 been 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 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 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 temperature variation as a function of time where 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 there after 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 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.

So 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 or as the cooling rate is very high and the temperature is being retained for longer time.

So they will be having the coarse grains+martensitic or the banide, or the pearlite 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 Hz then partially refined Hz and then base metal.

So we may have very course green martensite and then fine grain either martensite and the ferrite mixture and then we may have the ferrite and pearlite mixture. So the region next to the fusion boundary will be having very heterogeneous microstructure and accordingly the properties will be a changing significantly very high hardness next to the fusion boundary and then reducing hardness away from the fusion boundary until the base metal.

But if we see the weld metal experiences the highest cooling rate so there will be every tendency for the formation of the martensite and that was 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 metals but we have limited things to do for changing the properties of the heat affected zone and that is why is 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 steel, so if the carbon equivalent is high or the carbon content in steel is high then the formation of the high carbon martensite or high carbon martensite+pearlite mixture will make the heat affected zone as well as the weld metal sensitive for cracking.

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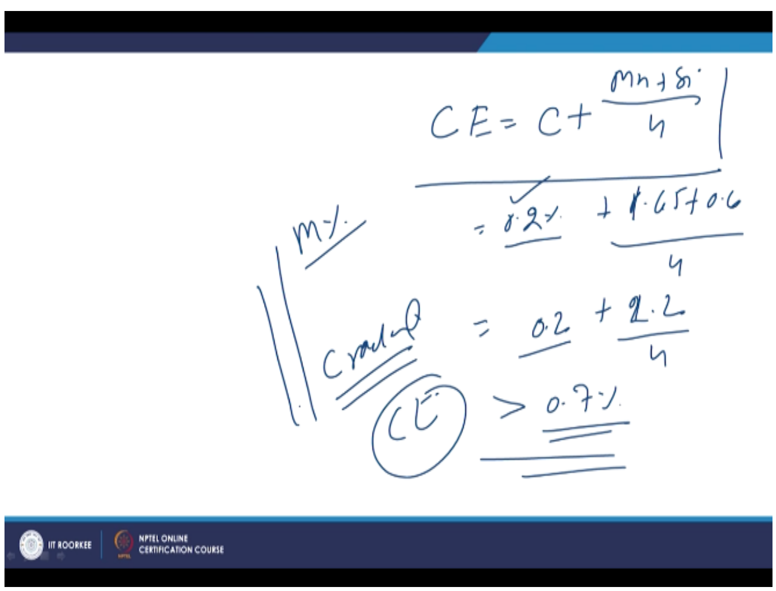

There is another aspect as I have said the carbon steel carbon equivalent is very important consideration in welding of the carbon steels which is calculated using carbon+manganese+silicone/4. So this will give us the carbon equivalent, so if we take and simple example like very low carbon steel having 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 2.2/4, 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 is the carbon content is low so the martensite even if it is 100% martensite is being formed the hardness of the weld known as well as heat affected zone will be limited.

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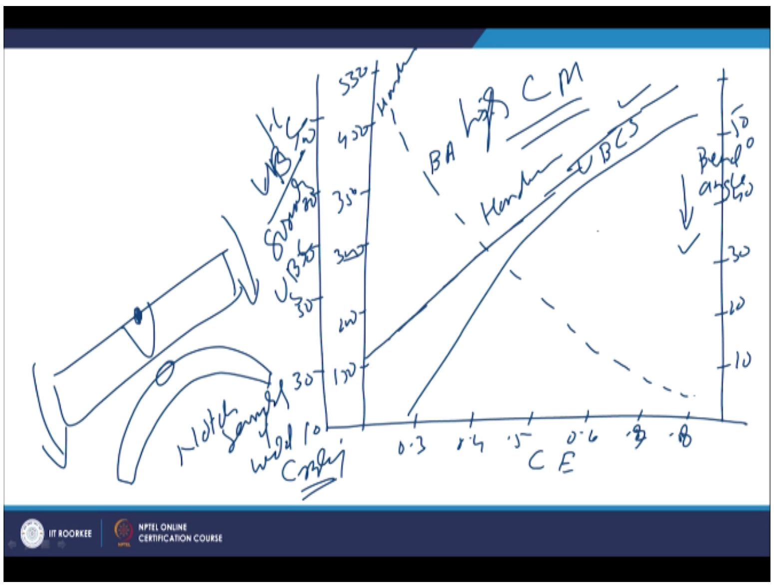

But it will in if the section thickness is are high then it will further increase the tendency for the cracking. So there is very useful diagram which is showing the relationship between the carbon equivalent and the various other properties in form of like one side we have the bend angle a well is made like this, then notch is made in the weld phase side and then controlled bend test is carried out to see the extent of twitch 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 growth of the crack, this directly indicates the notch sensitivity of weld for cracking and that is becomes a good indicator of the weldability of the steel. Apart from that so that banned angle will be indicated here like this we have 10, 20, 30, 40, 50 band angle in degrees.

And then we have the hardness in BPH unit say 150, 200 to 550 450, 350, 300, like this and there is one more scale for the hardness value, so the hardness not for the hardness but it is the underweight cracking tendency is this underweight cracking sensitivity UBCS underweight cracking sensitivity 0, 30, 50, 70, 80 and 100.

The last scale and if we notice this underweight cracking sensitivity will be for the various carbon equivalent values and say 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and then if we notice with the increase of the carbon equivalent the band 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 band 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 other hand the underweight cracking tendency increases like from 10 to 30, 50 like this so it will be increasing with the increase of the carbon equivalent, this is for you UBCS underweight cracking sensitivity and this is the band angle band angle is decreasing and underweight cracking sensitivity is increasing with the carbon content, then we have the hardness variation.

So hardness will continuously increasing with the increase of the carbon equivalent like this, so what it shows with the increase of carbon excellent weldability in terms of the crack sensitivity underweight cracking sensitivity as well as the band angle in the notch phase band test interest 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.

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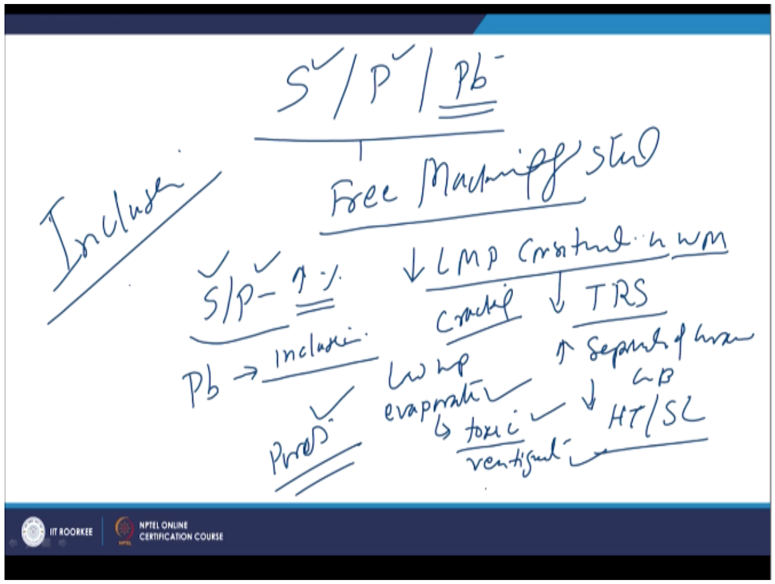

Increase martensite transformation tendency of the higher carbon content, then the another aspect is the inclusions that said the carbon steel sometimes intentionally added in resulfurized or rephosphorized or sometimes they are intentionally added with the lead content. So these are these editions are primarily done to make the steel free machining type. So these will be there as inclusions and will promote the discontinuous steps and reduce the cutting forces required for the machining purpose.

So the free machining steels are made by with the addition of the sulphur, phosphorus and lead. When the sulphur and phosphorus are present in the higher percentage in the steel these promote the low melting point constituents in the weld metal and this low melting point constituents in the weld metal when they come across the tensile residual stresses they promoter the separation 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 in under the influence of the tensile as well as 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 lin . On the other hand the lead when it is added in higher percentage in order to facilitate the machining machinability of steels or easy machining of the steels it will be there as inclusion.

Because it does not get dissolve so it will there is inclusion since it has 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 set 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 may due to the high toxicity of these gases ah will be increasing the troubles associated with the welding especially with regard to the porosity and the cracking tendency of the steel.

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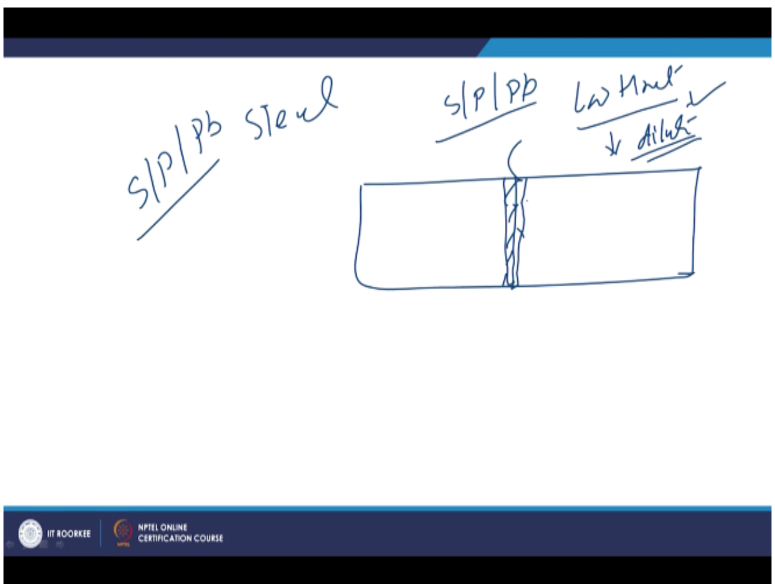

So what to do if at all in any case if the high sulphur, high phosphorus and high lead steels need to be welded the then the best way is to reduce the heat input as much as possible low heat input so that the extent of fusion of the these undesirable consequences can be reduced. So reducing the so reducing the extent of sulphur, phosphorus and lead content in the weld metal by reduce the 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 various categories of the carbon steels and what are the common issues which are during the welding of the carbon steels and what can be done in order to overcome those issues thank you for your attention.