Welding Metallurgy
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Lecture - 09
Carbon, Equivalent Schaeffler Diagrams

Welcome to the lecture on Carbon, Equivalent and Schaeffler Diagrams. So we will be talking about the relevance of the carbon equivalent values and the Schaeffler in welding processes.

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Carbon Equivalent Value

- The carbon equivalent content concept is used on ferrous materials, typically steel and cast iron to determine various properties of the alloy.
- The idea is to convert the percentage of alloying elements other than carbon to the equivalent carbon percentage
- This concept is used in welding, heat treating and in casting of cast iron.

So coming to the carbon equivalent value. So carbon equivalent value or carbon equivalent content this is very much used on ferrous materials, typically steel and cast iron to determine the various properties of the alloy. So normally as we know that in the case of steel or cast iron so you have carbon as one of the alloying element and apart from that we have also different alloying elements are added so that you can get the desired properties.

But then these elements they affect some of the properties of the materials especially when you are trying to cast it or when you are trying to weld it. So during the welding basically for finding the weld ability of the materials typically in the area when you have the material which is prone to cracking you know or I mean to avoid cracking sometimes you need to have preheating of the material.

So these carbon equivalent value concept is you know useful in those cases. So idea is to convert this percentage of alloying elements other than carbon to the equivalent carbon percentage. So basically many alloying elements they supplement their roles as far as in the same direction as the carbon does it. So as we know that when we talk about cast iron. So in that case we are talking about, you know, the eutectic composition.

So we will talk that how even in **cast iron** so while casting the carbon equivalent value is coming into picture or even in welding. So this concept is used in welding, heat treating and in casting of cast iron. So basically while talking about the casting of the cast iron components this carbon equivalent value that has lot of significance. So if you come to the cast iron.

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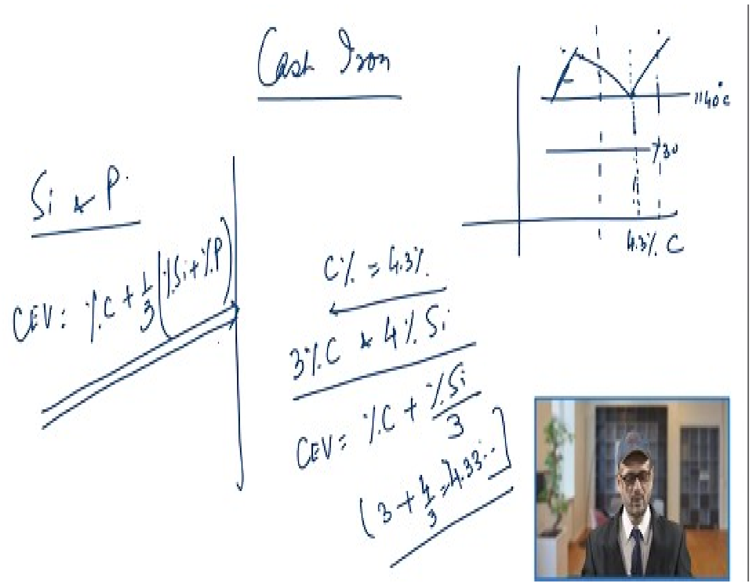

So we know that you know in case of cast iron when you look at the phase diagrams we know that you have one is 1135 °C this line is there. So on this line you have this, this is the eutectic composition that is 4.3% carbon. So in the case of so this was about 730 this is 1140 °C approximately. Now in this case this is your eutectic composition so you always prefer to have the composition of this.

So that you can get this eutectic composition eutectic mixture of austenite and ledeburite on this side and if you have the composition towards this side or towards this side so it will be giving you different kind of structure because if it is hypoeutectic so if it is less than this so you know that you will have pro-eutectic austenite will be coming out so because in this side it will be touching that this austenite line and in this side we will have this as the ledeburite.

So you will have austenite+ ledeburite. And if you go to the hypoeutectic side so you will have on this side you will have this cementite or in fact when we talk about cast iron so because of this slow cooling or because of the presence of the certain alloying elements you get graphite so you will graphite flekes coming up and then you have this ledeburite composition.

So what happens that it was seen that when carbon percentage is 4.3% you get the eutectic composition, but then because of the presence of certain other alloying elements like if you use the silicon in that case this will be shifted towards the left use of the silicon as the alloying element we will shift this eutectic composition point towards the left. So it was seen that if you take 3% carbon and 4% silicon in that case also you are getting that eutectic composition you have solidification in the eutectic manner.

So in normal case you could have got this solidification I mean solidified structure in like eutectic mixture at composition of carbon as 4.3% whereas if you get 3% carbon and 4% silicon in that case also you are getting. So basically you know this silicon is basically is changing the carbon equivalent value. So carbon equivalent value basically in that case so it is defined as percentage carbon+ percentage silicon by 3.

So if you look at this it will be 3 + 4/3. So that becomes 4.3 or so. So it becomes the same value of carbon you know for which without any use of alloying elements you are getting the eutectic composition. So similar is the case with other alloying elements also and mostly the two most important element which are affecting the carbon equivalent value in the case of cast iron is silicon and phosphorous.

And so phosphorus also has this similar contribution as that of the silicon. So normally carbon equivalent value we define it as in the term of percentage carbon + 1/3 of percentage silicon + percentage phosphorous. So basically it is because the phosphorous forms the low temperature eutectic low melting point eutectic in fact. So carbon equivalent value comes out in this fashion.

So this is basically used this type of, you know carbon equivalent value concept is used in casting of cast iron in such fashion. Now if you talk about the use of carbon equivalent value in the case of welding.

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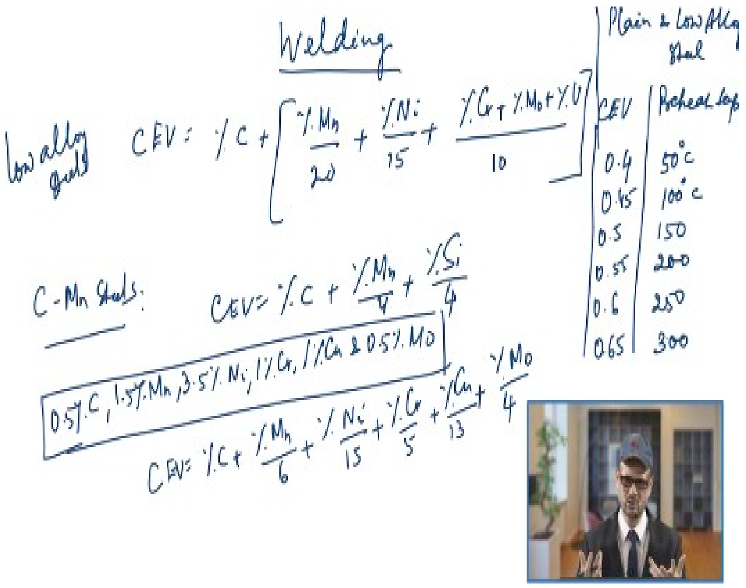

Now in case of welding many a time you may have to go for the pre or post weld heat treatment. So you may have to go for preheating or post weld heat treatment and that depends upon the carbon equivalent value. So if the carbon equivalent value will be more because you know for this stress relieving or so, because there will be chance of cracking. So apart from carbon if you have some other alloying element in that case that will also add too.

So some of the elements may increase the carbon equivalent value that is their presence will be showing the similar effect as the carbon shows because higher will be the carbon percentage more will be the chances to form martensite that is what normally because the carbon increases the hardenability. So with the presence of other alloying elements with certain alloying elements the carbon equivalent value will be increased.

Because that will tend to increase the hardenabiliy and with certain alloying elements that will be reducing the carbon equivalent value. So typically many researchers have given the different values of the carbon equivalent value and that will be depending upon the percentage of alloying element in such cases. So if you talk about you know the low alloy steels so certain relationships have been given.

And suppose some of the relationships are given like carbon equivalent value will be like %carbon + you know you will have $\frac{\%\,manganese}{20}$ + $\frac{\%\,Nickel}{15}$ + then you will have % chromium + % molybdenum + $\frac{\%\,vanadium}{10}$. So that is you know one of the relationship which is given for the low alloy steels.

Similarly, you may have another type of relationship even for the carbon manganese steels and for carbon manganese steels it is normally given as % carbon + $\frac{\% \, manganese}{4}$ + $\frac{\% \, Silicon}{4}$. So this way you will have the value of the carbon you know manganese steels or low alloy steels. Sometimes you will have when you have suppose for certain steel when the composition is like it is not more than 0.5% carbon or 1.5% say manganese, 3.5% nickel and 1% chromium, 1% copper and 0.5% molybdenum.

So for such typical steels also you have been given certain kind of carbon equivalent value. So suppose for them carbon equivalent value is given as $\% \, carbon$ + $\frac{\% \, manganese}{6}$ + $\frac{\% \, Nickle}{15}$+ $\frac{\% \, chromium}{5}$ + $\frac{\% \, Copper}{13}$ and + $\frac{\% \, molybdenum}{4}$. So it is all for different materials you will have the value of carbon equivalent value calculated based on the different relationships.

Main idea is that once you calculate carbon equivalent value that will assist you in deciding that when you do the welding whether after welding you need to do certain post weld heat treatment or you may think of going for the preheating. So as to confirm yourself that there will not be any chances of cracks after the welding. So once you find the carbon equivalent value then depending upon the carbon equivalent value basically you can judge whether preheat or post heat weld heat treatment is required or not.

So if you go for the carbon equivalent value then accordingly so suppose you have carbon equivalent value. So if you talk about certain you know plain and low alloy steels for plain and low alloy steels if you have carbon equivalent value for certain range then you will have some preheat temperature. So it has been reported that if the carbon equivalent value is 0.4 if the lower is the value of the carbon equivalent in that case lower will be the preheat requirement.

So you are preheat temperature requirement is only 50 °C, but as you increase the carbon equivalent value then this preheat requirement will be more. So suppose if you would go to 0.45 it will be 100 °C then if you go to 0.5 it will be 150 °C then if you go to 0.55 it will be 200 °C, 0.6 it will be 250 °C and 0.65 it will be 300 °C . So basically the preheat temperature requirement goes on increasing as the carbon equivalent.

So you can see that not only carbon is important in deciding what is the weldability, how it will affect the weldability in terms of basically when you do the welding in that case you will have to have some preheating. So this is for as far as the preheating you know is concerned for some of the steels. Now many a times we have other formulas also. So suppose you have to have to find HAZ hardness from the carbon equivalent value also.

So HAZ hardness also heat affected zone hardness can be predicted from the carbon equivalent values and for that basically again you will have the formulas like depending upon the manganese, nickel, chromium or copper you know percentages you will have the calculation of the carbon equivalent value and then if the HAZ hardness basically if it is less than certain value then you know it will be not susceptible to cracking.

And if it will be more than certain value then it will be susceptible to cracking. So based on that we calculate so that is the significance of this carbon equivalent value in the case of welding. So even for sometimes we are calculating the carbon equivalent value for even the higher quality of steels like HSLA steels, high strength low alloy steels. So for them also you have because in those cases you have very small amount of alloying elements are used that is high strength low alloy steels.

So in that also you have % carbon + % manganese/6 then you have vanadium, chromium and you know molybdenum so their percentage added divided by 5 and then you have silicon nickel copper there percentage is divided by 15 so that way you calculate the carbon equivalent value and then you can based on that you can decide whether you go for the preheating there is preheat requirement for this material or you have the inter-pass annealing is required or you have a post weld heat treatment is required.

So based on the carbon equivalent value you can calculate. So that is the significance of carbon equivalent value in the case of welding or casting. Similar will be in the case of heat treating because that is also you know what we do this heat treatment because the preheat or post weld heat treatment they are also type of heat treatment which you are giving.

So in the case of heat treatment also based on the carbon equivalent value you have to decide what kind of heat treatment you have to give. So this is about carbon equivalent value.

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Schaeffler Diagram

- The Schaeffler diagrams relate the nickel and chrome equivalents to lines which show the percentage of ferrite.
- The diagram is useful for estimating microstructure of weld deposit and filler metal composition required to produce prescribed amount of ferrite in the deposit.
- Cr equivalent and Ni equivalent values are calculated based on the percentage of different alloying elements.

Now we will be discussing something about the Schaeffler diagram which is very much used in case of welding processes. So the Schaeffler diagrams basically relate the nickel and chrome equivalent to lines which show the percentage of ferrite. Now this diagram is useful for estimating the microstructure of weld deposit and filler metal composition required to produce prescribed amount of ferrite in the deposit.

And the chromium equivalent and nickel equivalent values are calculated based on the percentage of different alloying elements. So as the name indicates this is the type of diagram and what happens that when we are welding in those cases many a times we required to have when we are using the filler metal. So we must be sure that what should be the filler metal composition or if with some type of filler metal which is used what will be the composition of the weld deposit.

So depending upon that because you will have austenitic steel welds. So you will have either austenite or you will have the ferrite so what will be that composition for prescribed amount of ferrite in the deposit. So for that you have a diagram this diagram we will talk about the chrome equivalent and nickel equivalent values and what happens that once you have the two values.

Based on this so you will have parent metal with certain composition of material and similarly you will have the filler metal with certain composition. So basically in welding what happens that where there is fusion taking place you will have both the parent metal also getting fused with the filler metal. So ultimately what will be the composition of the weld deposit that we will be depending upon, average of the two.

So depending upon the alloying elements because alloying elements are normally categorized when we talk in broad sense so either there will be something which is ferrite stabilizer or there will be some alloying elements which are the austenite stabilizers. So the ferrite stabilizers are normally so most prominent among them is chromium and the austenite stabilizers is the among them is the nickel.

So based on that we calculate the chromium and nickel equivalent and then we get a point. So depending upon the chrome and nickel equivalent of the material you will have a coordinate on that point. So this is the diagram how it looks this is the Schaeffler diagram what we see is that in the x axis you will have the chromium equivalent and in the y axis you will have the nickel equivalent.

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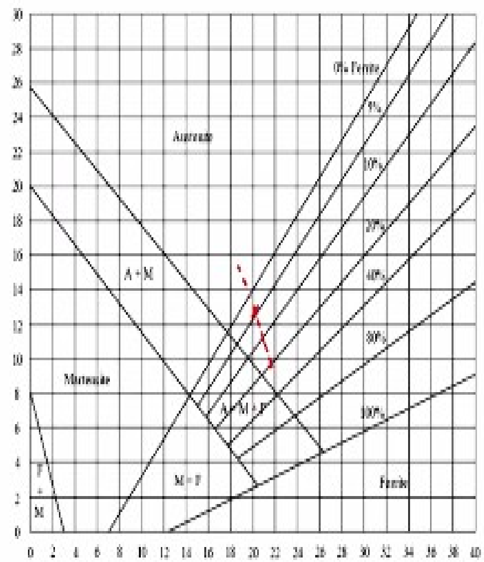

Schaeffler Diagram

So the process is that when you have any material of certain composition which will have some carbon, manganese, silicon, nickel and all that or chromium. So you will calculate the chrome equivalent value as well as the nickel equivalent value and you will have a coordinate on this point which we will be talking about the type of microstructure you are going to get it. Now suppose if you have the filler metal used and filler metal has some other composition.

If the filler metal is also the same composition you are going to get the same point so you have the microstructure like this the same one. However, if you have the filler metal of slightly different composition in that case for the filler metal you will have another point which will be coming on this diagram and then you will be joining these two points and the middle point we will be talking about the composition of the weld deposit.

Because in the weld deposit we will have the so it is a fusion of parent metal as well as of the filler metal. So we calculate this chrome equivalent as well as the nickel equivalent value and we calculate these.

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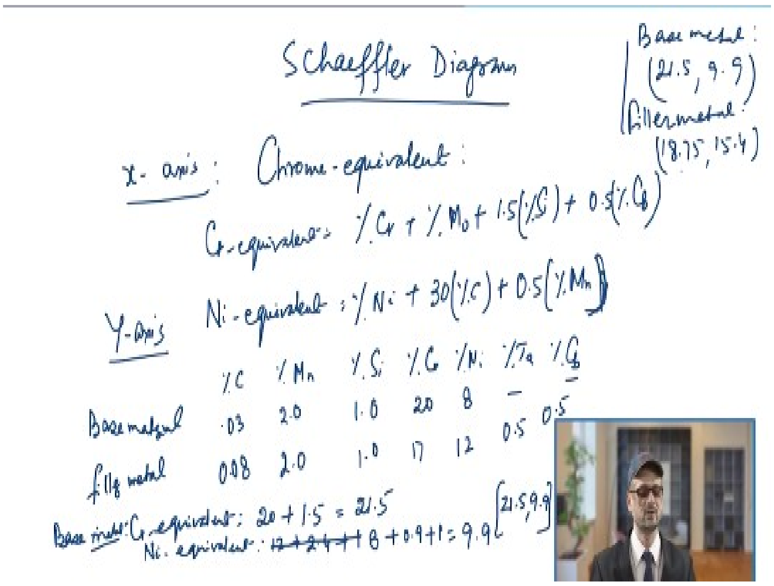

So in the case of Schaeffler diagram so you have x axis as the chrome equivalent and this is also known as chrome equivalent. So that will be basically % chromium + % molybdenum +1.5% silicon + 0.5% columbium. So this is normally the formula for the chrome equivalent. Similarly, you will have the nickel equivalent. Now nickel equivalent is % Nickel + 30% carbon + 0.5% manganese.

So this is the formula for finding the nickel equivalent and then once you find this chrome equivalent point and nickel equivalent point on this and this is your y axis on the y axis that will be your nickel equivalent. So as you see that if you have the parent metal as well as the filler metal of different composition so you can have the two points and you can predict the composition.

For example, if suppose you have you know a base material so you are doing the welding of stainless steel and you have base material composition as well as the filler metal composition. So if suppose the base alloy composition is like so you will have % carbon, % manganese, you will have % silicon, 5 chromium, % nickel, % tantalum and % columbium.

So suppose for the base metal it is like carbon is 0.3, manganese is 0.2 so that is 2% silicon is 1% and chromium is 20% and 8% nickel and there is no tantalum and columbium. And for the filler metal if you have 0.08 % of carbon, 2 % of manganese, 1% of silicon, chromium is 17% and you have nickel as 12%, 0.5 and 0.5 is the tantalum and the columbium.

Suppose this is you are doing welding of some stainless steel with some filler metal and filler alloy has this composition as well as the base material has this composition and you want to predict what will be the composition of the what will be austenite and what will be martensite in that case or ferrite. So that will be predicted with the help of the Schaeffler diagram. So what you will do?

You will use the chrome equivalent value and the nickel equivalent value using this formula. So if you find the chrome equivalent for this case so what you will do is % chromium so % chromium as you see so this is for base metal. For base metal if you try to find chrome equivalent will be % chromium so you will be having 20 + % molybdenum, so molybdenum is anyway not there. Then 1.5 % silicon it will be 1.5 into 1 so that is 1.5 and + 0.5% columbium it is anyway not there so it will be 21.5 and if you find the nickel equivalent for the base metal. So nickel equivalent will be % nickel so nickel is you know 12 and then you have the 30% carbon, carbon is 0.08 and it is 30 times so it will be 2.4 and then you have 0.5% manganese.

So you will have so 30 and then you will have 0.5% manganese so it will be 1. So…NO…. it is we are taking a different values basically we have for the base metal if you take the nickel is 8 then you have carbon as 0.03 so 03X, 30 so it will be 0.9 and then you will have 0.5 manganese, manganese 2% it will be 1 so it will be 9.9. So for the base metal you have the two points that is 21.5, 9.9.

Now you will go to this diagram and you will have 21.5 here and then on this you will also go to 9.9. So somewhere it will be close to this point. This point will be you know the point of chrome equivalent and nickel equivalent for the base metal. Similarly, you will be going to compute for the filler metal and for filler metal if you calculate that point that you can calculate and that point comes out to be 18.75 and 15.4.

So for base metal you will have 21.5 and 9.9 and for filler metal you will have 18.75 and 15.4. Now you will locate these two points you know on the diagram and you will get the you know average of the two values and if you are going to calculate the middle point and for that point you are going to see that what is the microstructure. So if you go to this point this line you will have two points so this is 1 and another point is 18.75 and somewhere close to 15.4.

So on this line we will be moving and we will go to about 15.4 so we will go somewhere here. Now on this line so we are going to make this point and we are going to take some middle point here. Now this middle point normally will be so what we see that this is falling on this line and this line is telling you that this is 5% ferrite so you will have you know the 95% of austenite

So this is austenite zone so you will austenite so once you have 5% ferrite you will have 95% of austenite. So this way you can calculate the weld metal composition what will be the composition of the weld metal that is either ferrite+ austenite or it may have fallen in the range of austenite and martensite and ferrite or it is ferrite or so, so that way it can be found out. So this is about the Schaeffler diagram.

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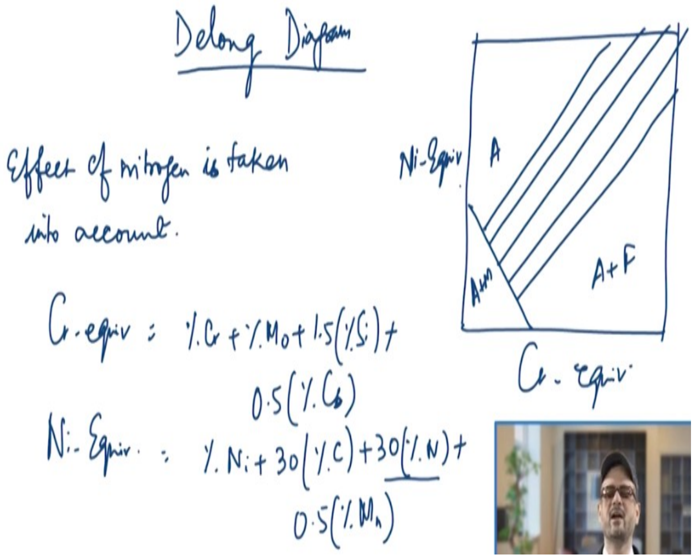

There is another diagram also which is along with Schaeffler diagram used in the case of welding and that diagram is commonly known as Delong diagram. So you will have also so that is not shown here, but that is also similar to the Schaeffler diagram. However, in this case it is normally used you know to take into the account the effect of nitrogen. So here also you will have the nickel equivalent and the chromium equivalent you know on the y axis and the x axis.

So in this side you will have nickel equivalent and this side it will have chrome equivalent and you will the reasons like you will have austenite + martensite and then you will have austenite and further you will have the different lines like this moving. So this will be you will have the ferrite lines and on this side you will have austenite + ferrite. So all this lines 0 to 4, 6, 8 up to 18% like that it will be going.

Now in this case as discussed that you are taking into account the effect of nitrogen. So effect of nitrogen is taken into account and you know because I mean basically it is effect on the balance of austenitic stainless steel phase balance of austenitic stainless steel that is the purpose and again in this case also if you try to find the chrome equivalent. So chrome equivalent will be something like % chromium + % molybdenum + 1.5% silicon+ 0.5% columbium.

And if you find the nickel equivalent so in the case of nickel equivalent value you will have the nitrogen term coming into picture so it will be % nickel + 30% carbon + 30% nitrogen +0.5% manganese. So that is a different between the Delong and the Schaeffler diagram in the case of Delong diagram when you will have the nitrogen because many a times we use the nitrogen.

So nitrogen we use for nitrogen killing. So nitrogen killed the steel. So in those cases when you d the welding now in that case when nitrogen content is there so this nitrogen effect is taken from here and then rest of the things are similar you will have to have the chrome equivalent and nickel equivalent for the base metal as well as for the filler metal and then you can, you know, predict what will be the weld metal composition or you can also use these diagrams in the reverse way if you have the weld metal.

And you want the weld deposit concentration to be somewhat having some particular value in that case what type of filler composition metal composition should you take so that it will give you that composition what you want. So that also can be adjusted by looking at this Schaeffler and Delong diagram. So that is about the relevance of these Schaeffler diagrams or the Delong diagrams or even the carbon equivalent values we discussed in this class which will be used by us in our subsequent lectures. Thank you very much.