Joining Technologies of Commercial Importance
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Lecture - 34
Weldability of Stainless Steels

Hello, I welcome you all in this presentation, this presentation is based on the topic Weldability of the Stainless Steel and it is - it is related with the subject Joining Technologies for the Metals.

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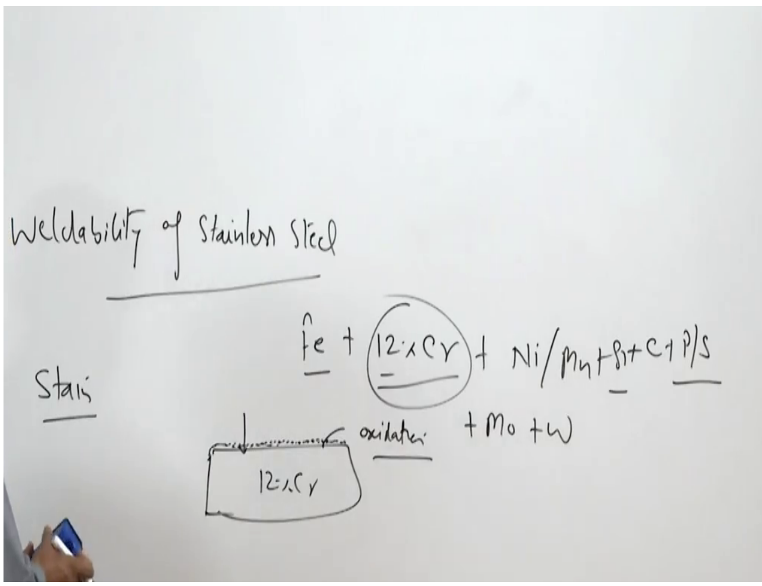

So if you have to talk about the weldability or is of welding of stainless steel then we need to first know a little bit about the stainless steel themselves, the stainless steel are basically these are iron based system where in chromium is normally added more than 12% and this presence of the chromium in steel apart from chromium there is other alloying elements like nickel or manganese + silicon + carbon, phosphorus and sulphur.

So phosphorus, sulphur or the residual elements while the nickel manganese or chromium apart from this like we may have molybdenum and tungsten also to achieve the specific set of properties, but it is the presence of chromium in the stainless steels which makes it stainless, because in this steals whenever the chromium is present more than 12% then this steel forms very thin layer of the chromium oxide which is non-porous and non-porous coherent and very protective to the base metal.

So it does not allow the direct contact of the atmospheric gases with the base metal itself, so it prevents the further oxidation or corrosion of the base metal and that is why whatever the shining is there related with the stainless steel whatever its original cover that - color that is maintained and that it retains, so we know that stain is about the kind of a spot or the stain which is formed on the steel due to the rusting or due to the oxidation.

But such kind of stains are prevented when the chromium content in the steel is more than 12% and that is why chromium makes it stainless and these steels having chromium more than 12% are normally found or commonly found in three forms and depending upon the matrix material structure.

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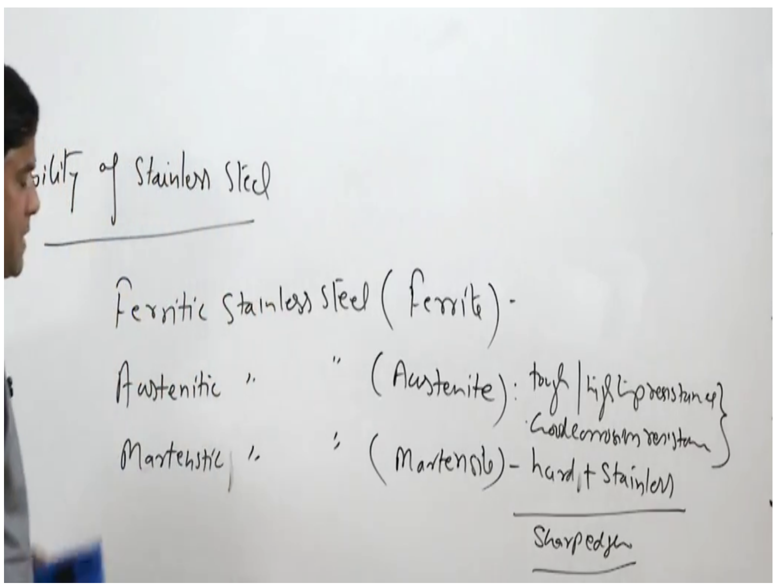

These steels are categorized as Ferritic stainless steels, Austenitic stainless steels and Martensitic stainless steels so ferritic stainless steels these have the ferrite as a main matrix material and which is retained from the room temperature up to the melting point, similarly here the austenite is retained from the room temperature up to the melting point and here the martensitic stainless steel primary has the martensite as a main phase or main constituent.

Since the martensite being hard this of the high hardness and apart from the stainless effect because of these two regions the martensitic stainless steel is used for making the components where like sharp edges need to be maintained - sharp edges need to be maintained, so cutlery and the surgical equipment's knifes etc. are commonly made of the martensitic stainless steel and where the very good ductility toughness and the stainless effect is desired especially.

So the good toughness, high temperature resistance and good corrosion resistance, low temperature toughness etc. are required the austenitic stainless steel is used and as a cheaper option ferritic stainless steel is used as compared to the stainless austenitic stainless steel, but the ferritic stainless steel does not show very good formability and that is why it is use is somewhat limited as compared to the austenitic and martensitic stainless steel.

So it is very commonly the martensitic stainless steel are very commonly used and thereafter martensitic stainless steel are also extensively used for fabrication of the various items of the general importance.

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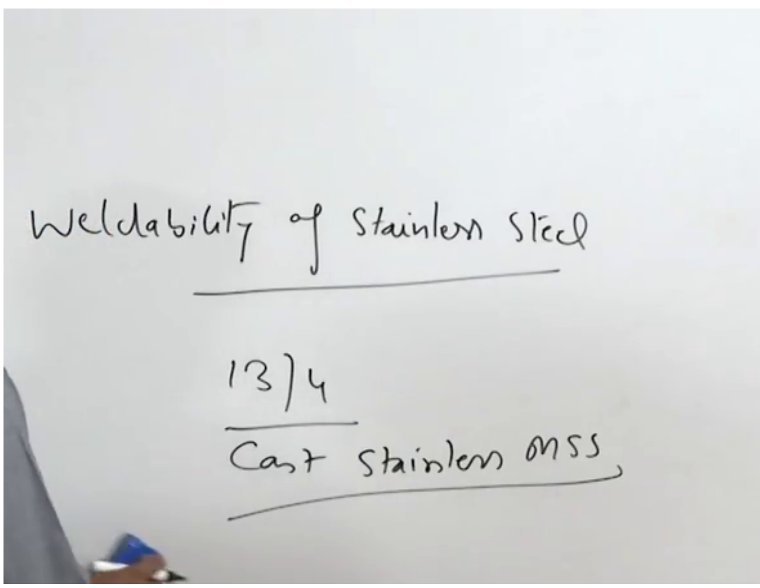

One typical use of the cast stainless steel is like making the - the turbine components in hydro turbine components typical 13 4 cast stainless steel is used this - this primarily becomes the martensitic stainless steel, because of its very good combination of the hardness strength and toughness its is used for making the hydro turbine components primarily these are used for making the blades.

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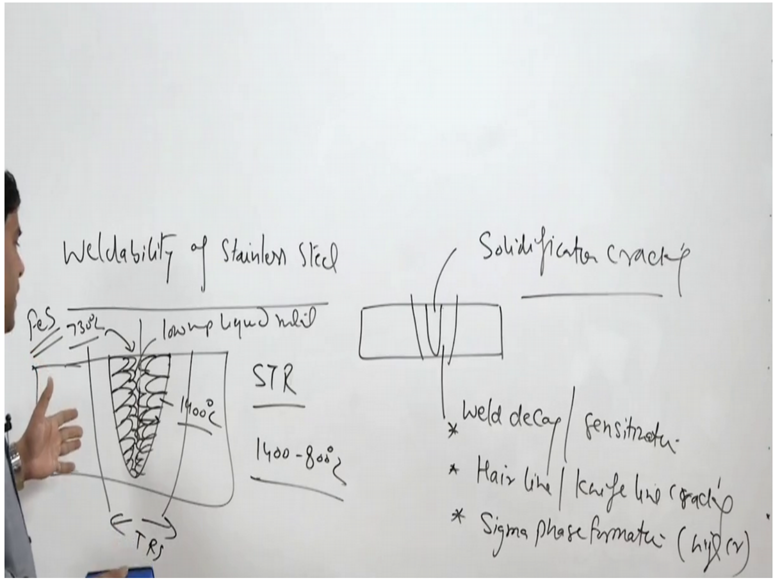

As far as since these steels are used for fabrication of the various engineering components which require welding that is why the weldability of these steels become of the great importance, so as far as the austenitic stainless steel is concerned - austenitic stainless steel is concerned the common problems which are encountered during the welding of the austenitic stainless steel are of the two categories.

One is those which are related with the welding - weld metal and those which are related with the heat affected zone, so the problems associated with the weld metal primarily inputs - includes the Solidification cracking of the weld metal and those which are related with the heat affected zone these include the Weld decay, this is also called the problem of the Sensitization of the austenitic stainless steel.

And the heat affected zone also experiences the problem of like Hair line or Knife line cracking and hair line or knife line cracking and in addition to this the sigma phase formation Sigma phase formation is also encountered in the austenitic stainless steel, but this is normally observed with the high chromium austenitic stainless steels and so we will talk about this three commonly encountered problems related to the welding of the austenitic stainless steels.

So here solidification cracking tendency let us talk about first this - this kind of problem is encountered when the solidification temperature range for the alloy - or for the steel is very long in that case what we see that the solidification proceeds or starts from the fusion boundary and then - then it then the liquid metal is pushed towards the center and finally at the end what we have the low melting point thing segregate at the center.

So the most of the low melting point liquid metal is segregated along the center line of the weld and if the solidification temperature range is really very wide say here solidification is starting at 1400 and at the low melting point liquid metal is of the say 730 degree centigrade then in that case it takes - it will take really very long time for completing the solidification reaching temperature from 1400 to the 730 degree centigrade.

so this is the common like say iron sulphide is the kind of low melting point the thing which is formed in the system's apart from this like the some of the silicates also which are of the low melting point, so these things lead to the presence of the low melting point liquid metal at the center line of the weld and it reminds for long because very low melting point, so what happens in this case whatever weld metal which has solidified that starts to shrink due to the cooling.

So during the cooling from say 1400 to the 800 degree centigrade the shrinkage takes place in both heat affected zone as well as in the weld metal and this kind of shrinkage sets in the tensile residual stresses in the weld and the presence of the low meeting point liquid metal at the center line. And the combination of the tensile residual stresses at the center line of the weld tensile residual presence of the tensile residual stresses due to the shrinkage develops the crack along the center line of the weld.

And that is that in turn leads to the presence of the solidification or that leads to the development of the solidification crack and the solidification crack is invariably observed along the center line of the weld along the same weld center. And so especially in case of the stainless steel this happens due to the presence of the low melting point constituents like phosphorus, sulphur and the lead and when these are present in the large amount.

They develop the solidification cracks, so to overcome the solidification tracking tendency if the stainless steel austenitic stainless steel is designed to have the 5 to 10% of the ferrite then this ferrite acts a sink. So the ferrite is formed first in that case ferrite formation results - results to the absorption of this impurities because of the solubility of this impurities the ferrite as compared to the austenite.

The problems associated with the solidification cracking is reduced and that is why efforts are made in such a way that the weld metal of the austenitic stainless steel has 5 to 10% of the ferrite.

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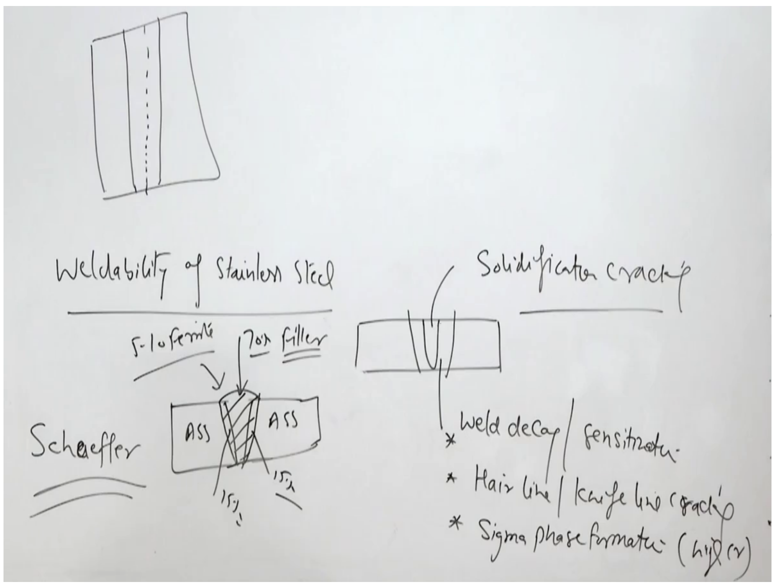

And for this purpose the filler metal is - is selected in such a way that the composition of the weld metal is adjusted accordingly, so that in the after the welding we have the 5 to 10% of the ferrite, so in this case let us say like this both the sides we have austenitic stainless steel and so here during the welding of course part of the base metal will be melting from both the sides say 15% from this side.

And similarly 15% from other side so 30% contribution is coming from the austenitic stainless steel and then remaining 70% contribution we can take from the so from the filler, so filler is designed in such a way or selected in such a way that whatever weld is obtained that has - that has 5 to 10% of the ferrite, if it does not happen then the weld metal will have tendency for cracking this is what.

So how to achieve this kind of composition so that our purpose is solved to understand this we need to know the Schaeffler - Schaeffler diagram and what it shows and how it can be used to achieve the 5 to 10% of the ferrite so that our purpose of avoiding the cracks in the weld can be avoided.

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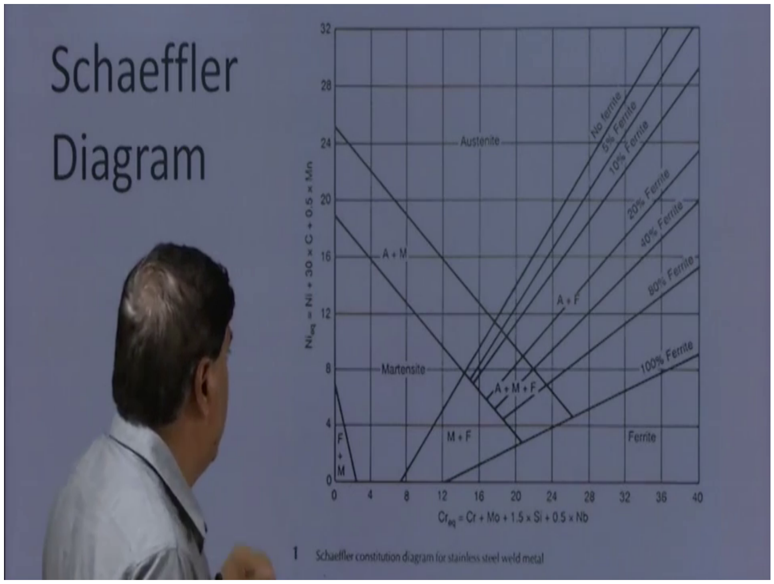

Schaeffler diagram is basically shows its diagram which shows the effect of the composition on the kind of phases which will be formed, so this diagram has the two axes, one is the x axis shows the chromium equivalent and y axis shows the nickel equivalent, so chromium equivalent means it is the sum of the all those variety stabilizing elements like and how it is obtained the chromium nickel comprises chromium + molybdenum + 1.5 multiplied by silicon + 0.5 of the niobium.

So all these are the chrome all these have the effect of similar to that of the chromium and that is why these are used to calculate the chromium equivalent and these tend to stabilized and chromium equivalent shows the effect of the chromium and its and elements associated with it on the stabilization of the ferrite. On the other hand, we have the nickel equivalent - nickel equivalent comprises nickel + 30 multiplied by carbon + 0.5 multiplied by manganese.

So this nickel equivalent all these elements in the nickel equivalent formulation they have the effect similar to that of the nickel which tends to stabilize the austenite, so chromium equivalent will be showing the effect of all those elements which tends to stabilize the ferrite, while the nickel equivalent all will be showing the effect of all those elements which are trying to stabilize the austenite.

So in this case here x-axis showing the presence of the like for the 4% for the various chromium equivalent and nickel equivalent combinations what kind of the phases we can have, so here if we see high chromium equivalent and the low nickel equivalent results in the ferritic only the ferritic stainless steel and very low chromium equivalent and the high nickel equivalent results in the austenitic stainless steel.

And combination of the nickel equivalent and the chromium equivalent results in the martensitic stainless steel and if the combinations are such that our the points are falling in the zone of the two phases like the 4, 4 chromium equivalent and the 2 nickel - 2 chromium equivalent and the 4 nickel equivalent will be resulting in the ferrite + martensite and here like the 16 nickel equivalent and 8 chromium equivalent will be resulting in the austenite and martensite.

And the 20 nickel equivalent - chromium equivalent of the 20 value and the 8 nickel equivalent will be resulting in the austenite, martensite and the ferrite and similarly the chromium equivalent of the 24 and nickel equivalent of the 12 will be resulting in the austenite and the ferrite and for the different percentages so this is the two-phase zone where we have austenite and ferrite both.

So here for the points falling along this line will be showing the combinations of the nickel and chromium equivalent correspond with 100% ferrite and in between we have the different combinations of the chromium and nickel equivalent corresponding to the different percentages of the ferrite + austenite, so this is corresponding to the 100% ferrite and no 100% austenite and no ferrite and this is corresponding to the 100% ferrite and no austenite.

So as far as the use is concerned if - if composition of the stainless steel is say 16 chromium equivalent and 16 nickel equivalent then it will be completely austenitic stainless steel and such kind of austenitic stainless steel will have the tendency for the cracking, so to avoid the cracking tendency of such kind of steel it is necessary that weld metal composition is shifted towards the it shifted suitably, so that it has 5 to 10% of the ferrite.

And for that purpose this composition point must be shifted either this way or this way so that the composition point - composition of the weld metal is adjusted either by increasing - either by increasing the nickel equivalent and either by increasing the chromium equivalent or by adjusting the combination of the chromium and nickel equivalent in such a way that we fall in the lines between the 5% and 10% of the ferrite.

So this is how this diagram can be used to show that the filler metal is to be adjusted in such a way so that the weld metal whatever is obtained that results in the ferrite of the 5 to 10% in the weld metal, so this is what is called the Schaeffler diagram which is used to show the effect of the alloying elements or the composition effect of the composition on the kind of phases that will have in the - in the stainless steel.

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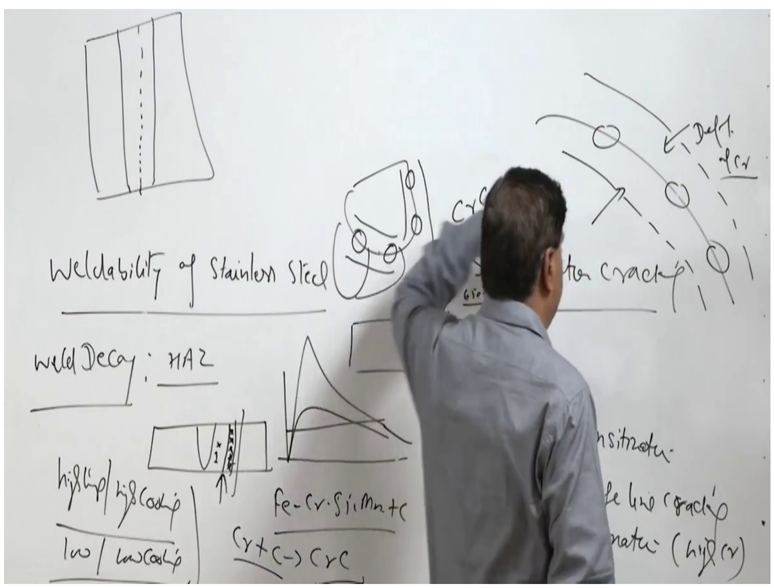

Now if we talk of the other problems then we can have the weld decay or the sensitization weld decay is the problem associated with the heat affected zone, so we know that whenever weld joint is made we - we get the heat affected zone having the different locations which are subjected to the different weld thermal cycles.

So if we take point 1 and point 2 and they are weld thermal cycles are plotted and what will have the point 1 will be experiencing the higher temperature higher cooling rate as compared to the point 2, so if we see here - if we see then the point 1 is very close to the fusion boundary while point 2 is away from, so under such conditions point 1 will be experiencing the high temperature and high cooling rate while the point 2 will be experiencing low temperature and the low cooling rate.

So if it is so then under the high cooling rate conditions when the stainless steel is heated to high temperature then all its alloying elements will be going into the solutions like iron, chromium, silicon, manganese etc. all these will be and the carbon all these will be going into the solution and when it is cooling fast there is no - when it is cooling fast all these tend to remain in the solution.

But when the cooling happened slowly in that case due to the high affinity of the carbon with the chromium, chromium carbide formation starts and this chromium carbide formation occurs slightly away from the fusion boundary not very close to the fusion boundary. Because region very close to the fusion boundary experiences very high cooling rate and then the high cooling rates time is less under the sufficient time for the diffusion due to the lack of time for diffusion to take place.

Chromium and carbon are not able to combine together to form chromium carbide and therefore chromium carbide formation very close to the fusion boundary is avoided but the chromium carbide is generally formed away from the fusion boundary. So in this case what we get that the heat affected zone having a certain locations where the temperature range 650 to 850 degree centigrade, the cooling rate is very low.

So low cooling rate conditions over a range of temperature 650 to 850 results in the formation of the chromium carbide and this particular chromium carbide is formed along the grain boundaries. So how it is formed whenever it is formed like say these are the locations where chromium carbide is formed, so the areas next to the location where chromium carbide particles are formed there will be seeing that the chromium has become deficient.

The concentration of the chromium has got reduced say this is a grain boundary and where the particles chromium carbide precipitation has taking place. So then all the regions nearby the grain boundary area will be depleted with the chromium because lot of chromium is consumed in the formation of the chromium carbide, so these regions become the deficient - deficient of the chromium, so these areas will be having the lesser chromium as compared to the other areas.

And that is why what we will be seeing here that the locations where chromium carbide precipitation due to the slow cooling over a particular range of the temperature that is 650 to 850 degree centigrade takes place, this temperature range is called sensitization temperature and slow cooling in this temperature range results in the formation of the chromium carbide.

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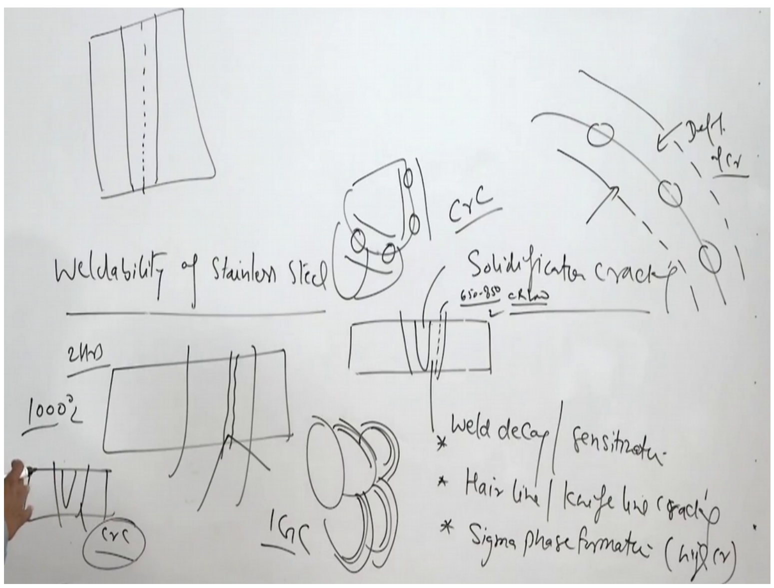

And whenever it is formed we see that the deficiency of the chromium in certain zone like this is the band where chromium carbide formation is taking place, then we will see that in this area certain areas become the depleted or deficient with the chromium and that is why this become very prompt for the corrosion attack and this attack primarily takes place in the grain boundary area.

If these are the grains and where the chromium carbide has precipitated then all the deficient areas where chromium carbide - chromium has been depleted they will be sensitive or prompt for the corrosion attack and that is why grain boundaries are eaten out by the corrosive media, so it results in the inter granular corrosion and it happens primarily in the locations away from the fusion boundary.

So this is the kind of problem which is called weld decay or the sensitization which happens over a range of 650 to 850 degree centigrade, so to avoid this problem basically what we do we reheat the entire weld after the - after development of weld and entire system, entire weld joint is reheated so whatever chromium carbide has been formed in the heat affected zone that will get dissolved.

So after heating to the 1000 degree centigrade and holding it at for 2 hours, so everything gets dissolved means this chromium carbide particles get dissolved and there after we cool it rapidly, so that re precipitation of the chromium carbide is avoided, knife line so this is one way that post weld heat treatment of the weld metal austenitic stainless steel weld metal is one way to avoid the welded decay or the loss of corrosion resistance due to the sensitization.

Another method is that since the chromium carbide is formed by reacting with the carbon, so if they steel is developed or the steel is developed using the low carbon content or the stainless steel to be welded is in very low carbon content then of course the chromium carbide precipitation can be avoided.

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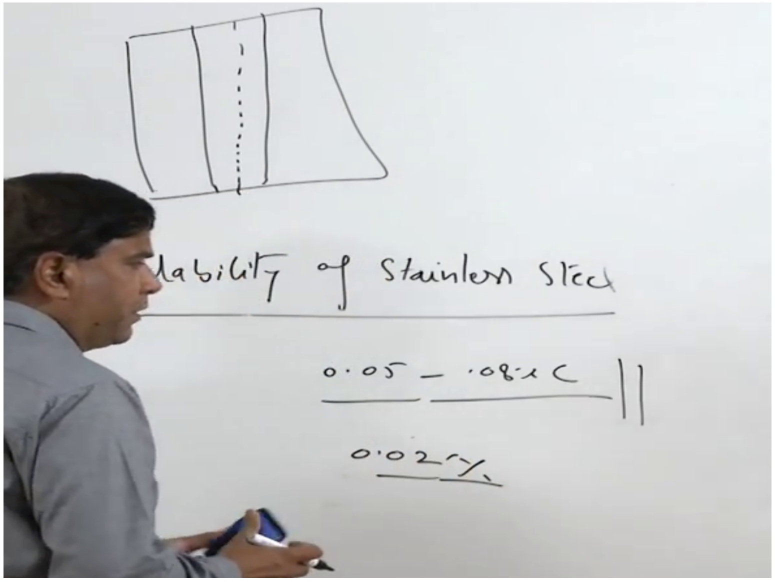

So especially normally the steels have austenitic stainless steel have 0.05 to 0.08% of the carbon, so these tend to precipitate quite rapidly after interactions with the chromium, but if the steel is having like 0.02% very low carbon content, then this tendency for chromium carbide precipitation is reduced and which in turn helps to use the - which in turn helps to improve the resistance for the weld decay.

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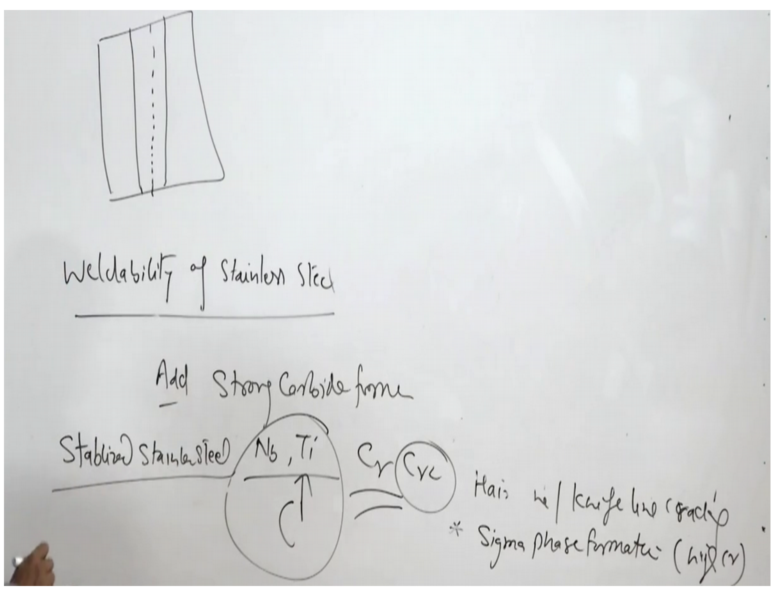

Another is - another method is use to add strong carbide formers in the austenitic stainless steel, so strong carbide former like niobium and titanium are commonly added, so whenever these are present so carbon reacts with this rather than the chromium and so the chromium carbide precipitation is avoided, so whenever these elements are added the - the - the chromium carbide precipitation tendency is reduced.

So then in that case we call it like stabilized stainless steel - stabilized stainless steels are not prompt for sensitive for the weld decay due to the carbide precipitation, but certainly these are so sensitive for another kind of problem and that problem is called knife line cracking, knife line cracking problem occurs near the fusion boundary and this also takes place due to the precipitation of the chromium carbide.

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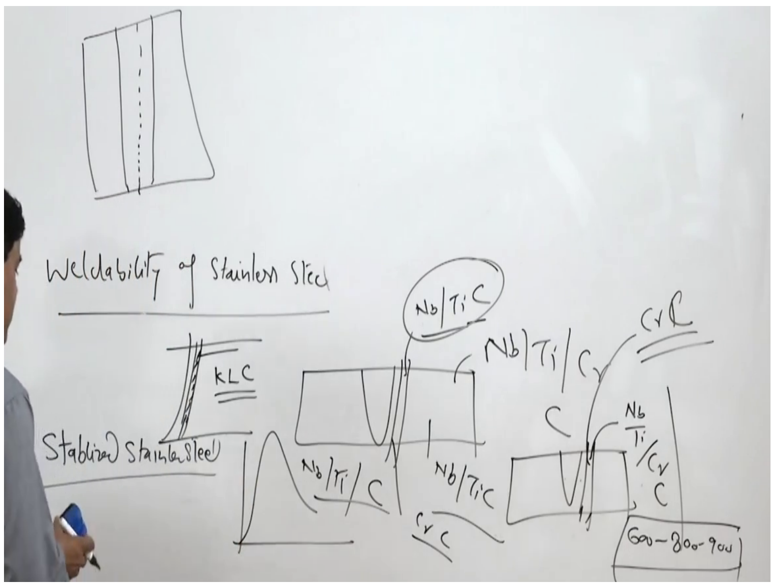

But under the different kind of the circumstances to understand that we will quickly see this diagram this one will be having say niobium and titanium of course it will have carbon and chromium, so whenever the weld is made so the regions very close to the fusion boundary where in the niobium, titanium all these carbides will be decomposing, while that location away from they will not decompose and they will have the niobium or titanium carbide stable.

So if the carbon is not going into the solution then it will not have the tendency to form chromium carbide, but very in the locations very close to the fusion boundary which experience very high temperature for longer time they will be - there the decomposition of the niobium and titanium carbide will be taking place, so the carbon will be going into the solution.

So initially during the heating due to the high temperature exposure for long - for longer period the niobium, titanium etc. they decomposed and carbon is released, so this portion due to the rapid cooling - due to the rapid cooling in the cooling regime chromium carbide or titanium or this niobium carbide are not precipitated again, because time is very less due to the fast cooling. So the chromium, carbon etc.

They remain in the solid solutions as it is without interacting with the titanium or with the niobium, so during the either subsequent passes or during the post weld heat treatment if or during the service if they were such kind of weld joint is reheated in that case. So the weld having the in this region which is close to the fusion boundary having the niobium, titanium, chromium etc.

And carbon in elemental form such kind of system when reheated during the reheating during the - either during the service or during the post weld heat treatment will be heating commonly like say 7 600 to the 800 or 900 degree centigrade. So this is very favorable temperature we really go for the temperature for to for the higher temperature where titanium and niobium can form and that is why during the service or during the post weld heat treatment whenever such kind of temperatures or experience to by this steel it again forms the chromium carbide.

In such a kind of formation again leads to the same kind of problem like deficiency or depletion of the chromium in certain areas as compared to the other areas and that leads to the precipitation of the chromium carbide, but in the regions very close to the fusion boundary and this occurs over extremely narrow region like this and this wherever it occurs only that area is affected by the loss of the corrosion resistance.

And that is why this one, so the crack will be developing only along this thin line or thin area that is why it is called knife line cracking or hair line cracking, the solution for this problem is also the same that system is reheated followed by the rapid cooling, so that everything gets resolved and re precipitation is avoided. Another thing is that having the low carbon content in the stainless steel can further be used as another method to avoid the problem associated with the - associated with the knife line cracking.

Sigma phase formation is another problem which is encountered in high chromium austenitic stainless steel.

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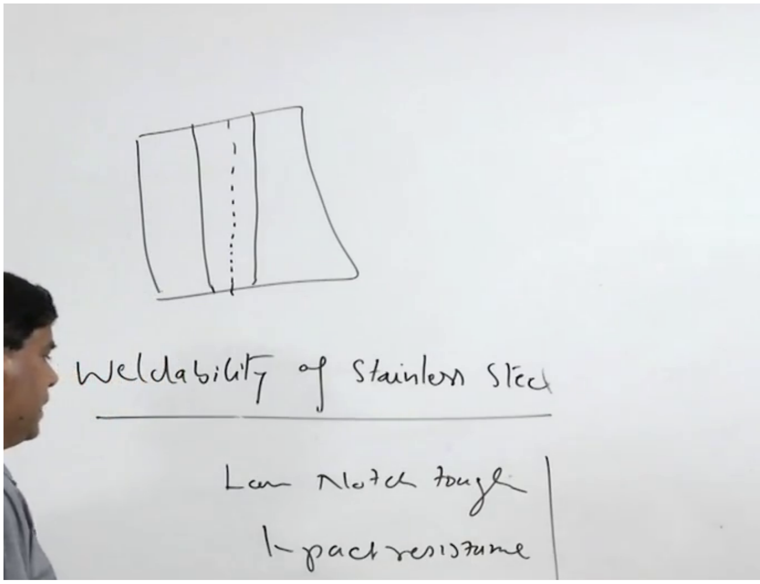

And such kind of intermetallic phases whenever they form or loss of no toughness and impact resistance, these two are very badly compromised and that is why their formation is avoided during the welding of the austenitic stainless steel, apart from the similarly the problems are also associated with the ferritic stainless steel and martensitic stainless steel. Ferritic stainless steel primarily experiences the problem of loss of toughness in the heat affected zone due to the grain coarsening.

Apart from the sensitization, sensitization in the austenitic stainless - ferritic stainless steel takes place very close to the - close to the fusion boundary not away from the fusion boundary like in case of the austenitic stainless steel and the kinetics of the precipitation in the ferritic stainless steel is different than that is observed in case of the austenitic stainless steel. So here I will summarize this presentation.

In this presentation I have talked about the use of the Schaeffler diagram as primarily to see the kind of phases which will be present in the stainless steel and how the filler metal can be selected suitably so that the composition of the weld metal such that it has 5 to 10% of the ferrite. At the same time, we are also talked about the weldability of austenitic stainless steel and the commonly encountered problems related to the welding of austenitic stainless steel especially in the heat affected zone and the weld metal.

In the weld metal, it primarily possesses the problem solidification cracking. And in the heat affected zone, the weld decay, knife line cracking and the sigma phase formation are the common problems, so we have talked about the mechanisms that led to the development and the methods which can be used to overcome the problem associated with the heat affected zone and the weld metal, thank you for your attention.