Weldability of Metals

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Lecture - 37
Weldability of Ferritic Stainless Steels - I

Hello, I welcome you all in this presentation related with the subject weldability of metals and your know we are talking about the weldability of the martensitic stainless steel. We have talked about the various aspects related with the weldability of the martensitic stainless steel. In this presentation basically we will be focusing on the two processes related with the welding of the martensitic stainless steel and thereafter we will take up the weldability of the ferritic stainless steel.

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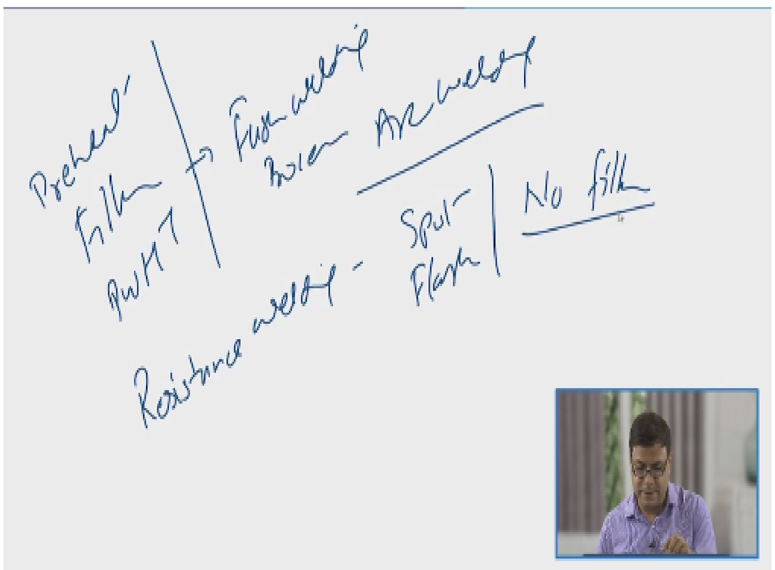

So whatever we have talked about the kind of the preheat or the filler which we have to use or the post weld heat treatment to be carried out all that was applicable for the fusion welding processes like arc welding. Now if we compare these welding processes with respect to the resistance welding processes like the spot welding and the flash butt welding. In these welding processes there is no use of the filler. No filler is used.

So in that case, the way by which the weldability of the martensitic stainless steel that is affected that we will try to see.

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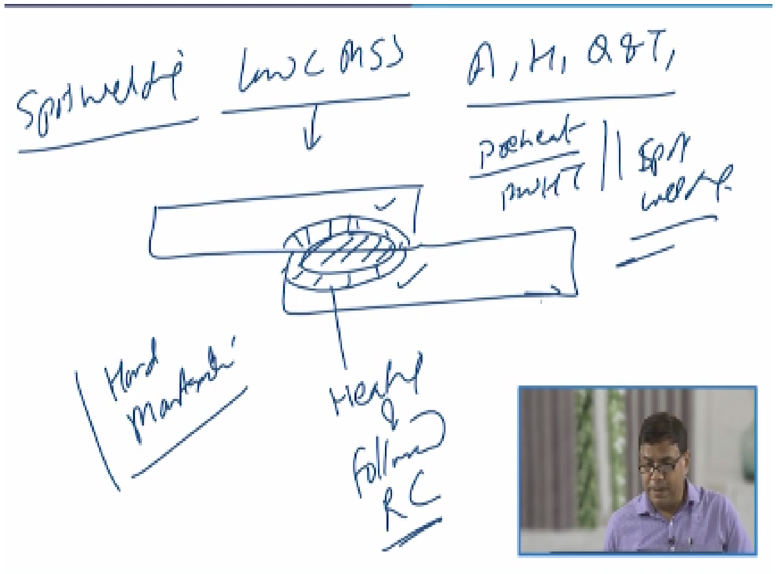

Like say as far as the spot welding is concerned, the low carbon martensitic stainless steel can be welded in all the conditions like annealed or hardened or Q & T conditions. In all those conditions whenever the plates are welded by the spot welding process like this, so we will notice that there will be partial melting and a nugget zone formation.

At the same time as soon as the heating is switched off by stopping the flow of the current the next zone near to the weld nugget zone is subjected to the higher cooling rate. So the heating followed by rapid cooling leads to the formation of the hard martensite in the heat affected zone. So this martensite is not that hard especially when the carbon content in the martensitic stainless steel is low.

But still if it is required then by controlling the proper preheat and post weld heat treatment cycles we can control or we can regulate the supply of the current accordingly so that there is a preheat as well as the post weld heat treatment in course of the spot welding process so that any kind of the embrittlement and the cracking tendency can be reduced.

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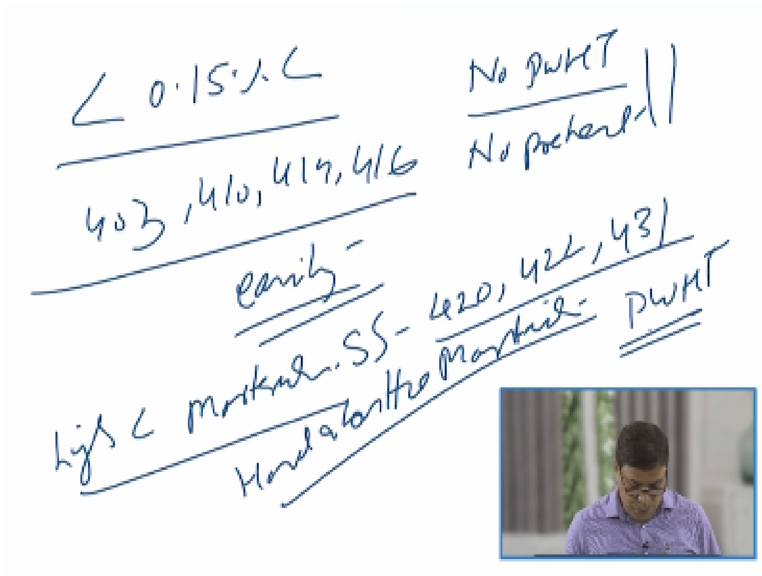

But as I have said no PWHT is needed and no major preheat requirements are there if the carbon content in the martensitic stainless steel is less than 0.15. So in the steels like 403, 410, 414 or 416 these steels can be easily spot welded without any major requirement of the preheat and the post weld heat treatment.

But in case when we need to weld the high carbon martensitic stainless steels SS like the AISI 420, 422 and 431 in that case in view of formation of the hard and the brittle martensite formation tendency in the weld as well as heat affected zone PWHT becomes critical so suitable post weld heat treatment must be designed so that the unnecessary embrittlement and the cracking tendency of the weld as well as heat affected zone of the spot weld joints can be reduced.

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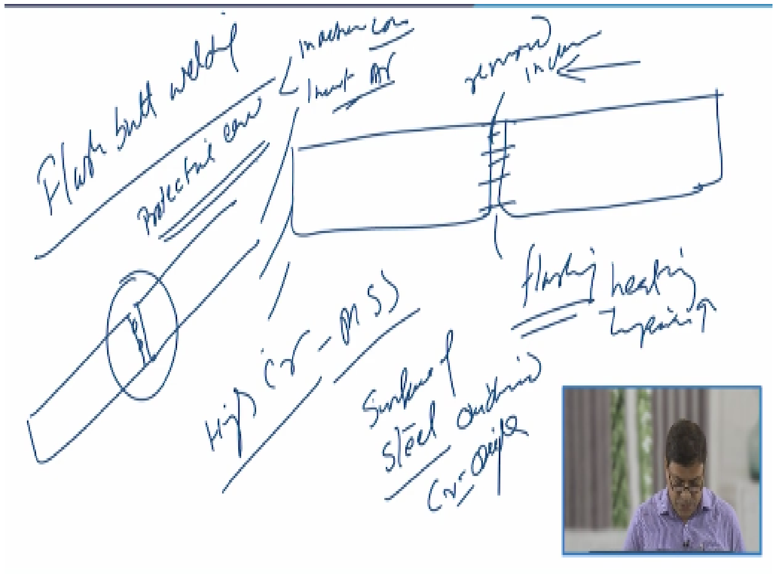

Another resistance welding process is the flash butt welding. Flash butt welding process like it is used mainly for producing the butt joints of the rods and the tubes. So here the one end is kept fixed another end is made moveable. So when the another component is brought close to the member which is to be joined with the flushing takes place. In this process of flushing heat is generated, temperature rise takes place.

And because of this temperature rise surface of the steel, martensitic stainless steel gets oxidized. So whatever the chromium, since in martensitic stainless steel especially those having the high chromium content, high chromium martensitic stainless steel the chromium forms the chromium oxide at the faying surfaces. So this chromium oxide must be removed.

So the process must be designed in such a way that all this chromium oxide is removed from the interphase. Otherwise this chromium oxide will be left as inclusion at the interphase and will deteriorate the mechanical properties of the joint significantly. So in order to avoid such kind of the possibility like the formation of the chromium carbide, chromium oxide and its entrapment at the interphase it is good to protect the weld zone using the suitable protective environment.

And for that purpose we may use inactive gases like carbon dioxide or we may use the inert gases like argon. So wherever the heat is being generated that will be shielded using these protective gases so that the formation of the chromium oxide at the joint interphase can be reduced or eliminated.

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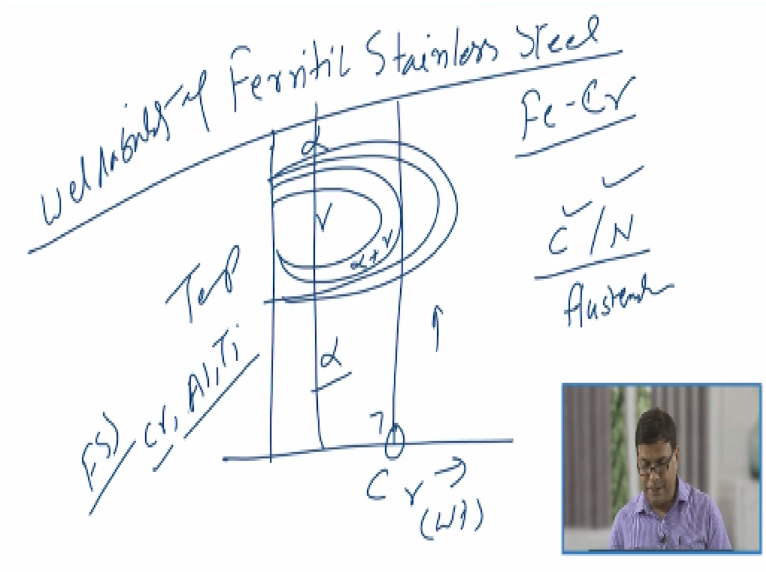

Now we will talk about the weldability of the ferritic stainless steel. Ferritic stainless steel means these are made by adding the chromium content in the iron in sufficient quantity so that the gamma loop which is found in this form like say this is the temperature scale, this is the weight percentage of the chromium. When the carbon is absent or it is very negligible so the kind of the binary phase diagram for iron and chromium shows it like this.

Here we have mostly alpha ferrite then alpha plus gamma and then gamma and then again we have the alpha. So on heating like say if the chromium content is less than certain amount, it is like 7% for those cases when the carbon is absent and this can be on the higher side if this limit of the chromium beyond which there is no austenite formation that will depend upon the kind of carbon and nitrogen which is present because both carbon and nitrogen are the austenite stabilizer.

So greater the percentage of the carbon and nitrogen present in the steel, greater will be the chromium content requirement. The size of this gamma loop is increased in presence of the carbon and nitrogen. When there is no carbon and nitrogen the chromium percentage to avoid the formation of the austenite on heating from room temperature to the melting point, the chromium content required in the iron is 7%.

So if we see this diagram, in ferritic stainless steel we have the chromium and other alloying elements like aluminium, titanium etc. in such a way which are also ferrite stabilizers that on heating from room temperature to the melting point, the austenite is not formed especially when the chromium and aluminium and titanium content is sufficiently high in the given stainless steel.

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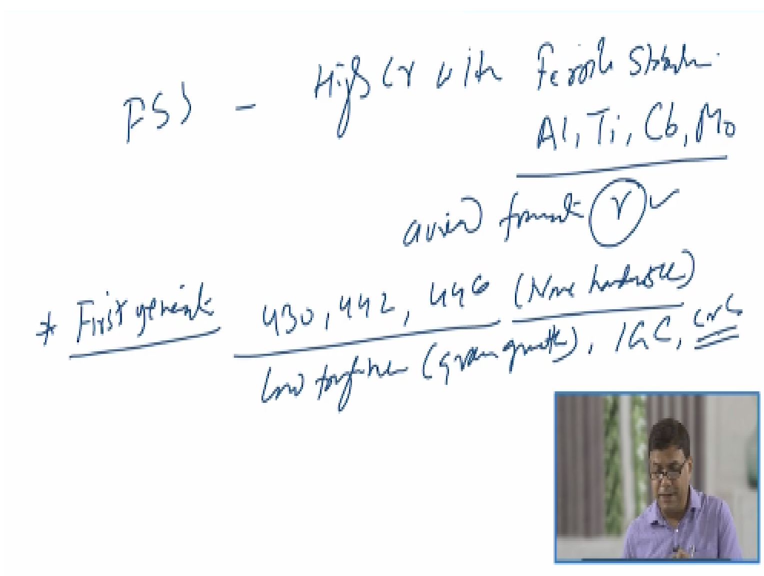

So the FSS are mostly designed with the high chromium with other ferrite stabilizers like aluminium, titanium, columbium and there is molybdenum. These elements are added in the different category of the stainless steel. Because these are austenite stabilizers, ferrite stabilizers so they will be avoiding the formation of the austenite on heating of the ferritic stainless steel from room temperature to the melting point if these have been added in the sufficient quantity.

So there have been various developments as far as the ferritic stainless steels are concerned like the first generation ferritic stainless steels are like AISI 430, 442, and 446. These steels are non-hardenable because they do not form the austenite on heating from the room temperature to the melting point. So there is no formation of the other phases even if the different kind of the cooling rates are given.

But since these steels suffer with the low toughness due to the grain growth during the welding of the heat affected zone and these also suffer from the intergranular corrosion especially due to the formation of the chromium carbide along the grain boundary.

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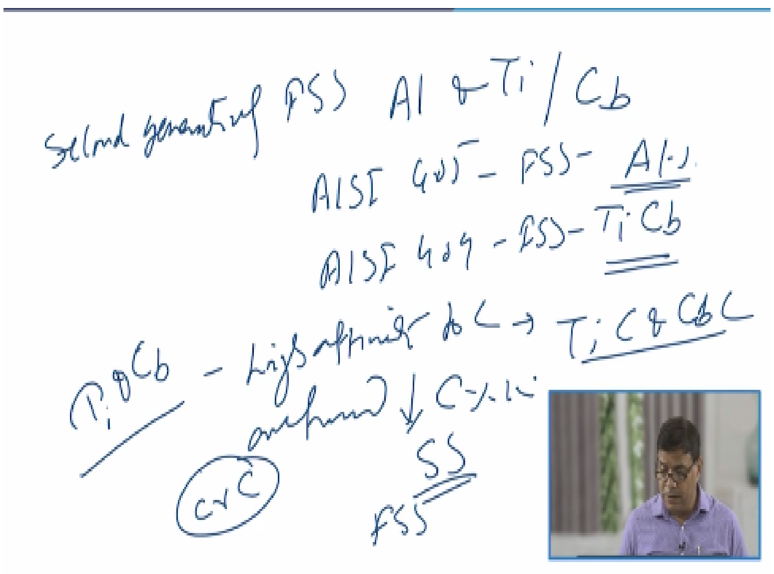

And therefore the further developments have led to the second generation of ferritic stainless steel which were developed with the addition of the columbium and the titanium and aluminium. So like the second generation ferritic stainless steels involve the addition of the aluminium and titanium and the columbium. So typical AISI 405 grade ferritic stainless steel was developed with the addition of the aluminium.

On the other hand AISI 409 ferritic stainless steel was developed with the addition of titanium and the columbium. So when these were added this led to the because the columbium and the titanium had very high affinity to the carbon. So the titanium and the columbium carbides are formed and these decrease the percentage carbon in solid solution which is present in the ferritic stainless steel and that is why these reduce the possibility for precipitation of the chromium carbides.

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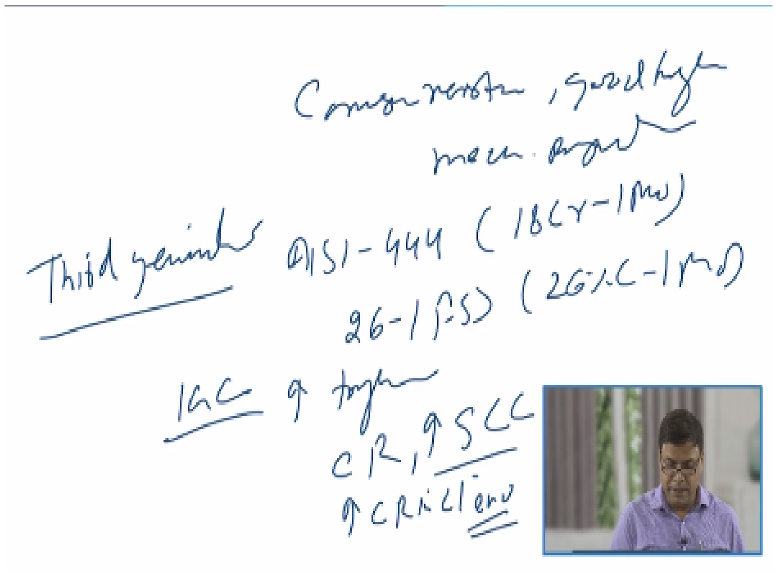

And these factors in turn led to the improvement in good corrosion resistance, good toughness and good mechanical properties of these steels. Then there were third generation ferritic stainless steels were developed, third generation ferritic stainless steels like AISI 444. This was developed with the addition of 18% chromium and 1 molybdenum.

And another one was like 26-1 ferritic stainless steel which had 26% chromium and 1% molybdenum. And this steel showed excellent resistance to the intergranular corrosion and improved toughness, improved corrosion resistance, increased resistance to the stress corrosion cracking as well as increased resistance to the corrosion in the chloride environment.

You see the all stainless steels are very sensitive for corrosion in the chloride environment. So with the addition of the titanium, columbium in these steels led to the significant improvement in the corrosion resistance of these steels.

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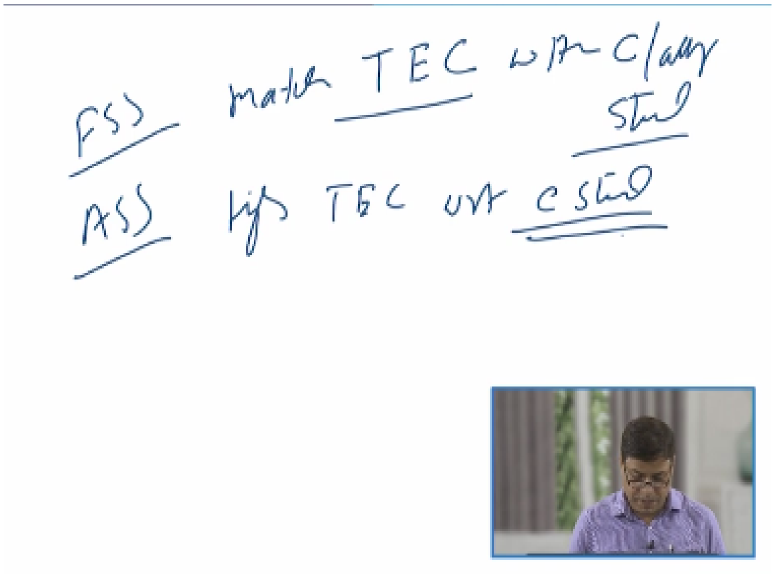

Another important point as far as the ferritic stainless steel is concerned FSS has matching thermal expansion coefficient with the simple carbon or alloy steel. So this is another good aspect because ASS has a very high thermal expansion coefficient with respect to or as compared to the simple carbon or alloy steels which creates lot of residual stresses and distortion related issues in the weld joints especially when the dissimilar welds are made.

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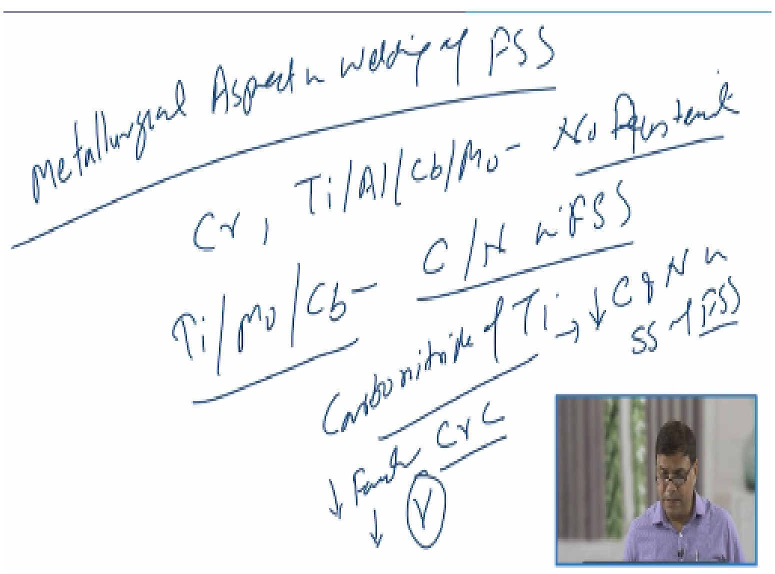

Now we will see some of the metallurgical properties related with the metallurgical aspects in welding of the ferritic stainless steel. We know that when the chromium content in these steels is high with the presence of other elements like titanium, aluminium, columbium and molybdenum, there is no austenite formation. Only ferrite is stable up to the room temperature.

And when these elements are present, titanium or molybdenum or columbium, these elements react with the impurities or like say the carbon and nitrogen present in the ferritic stainless steel and so the formation of the carbonitrides of titanium or molybdenum or columbium leads to the reduction in the carbon and nitrogen content in the solid solution of the FSS.

And this in turn reduces the formation of the chromium carbide as well as it reduces the tendency for the austenite formation. So austenitic formation tendency is reduced especially when these elements are present in the steel.

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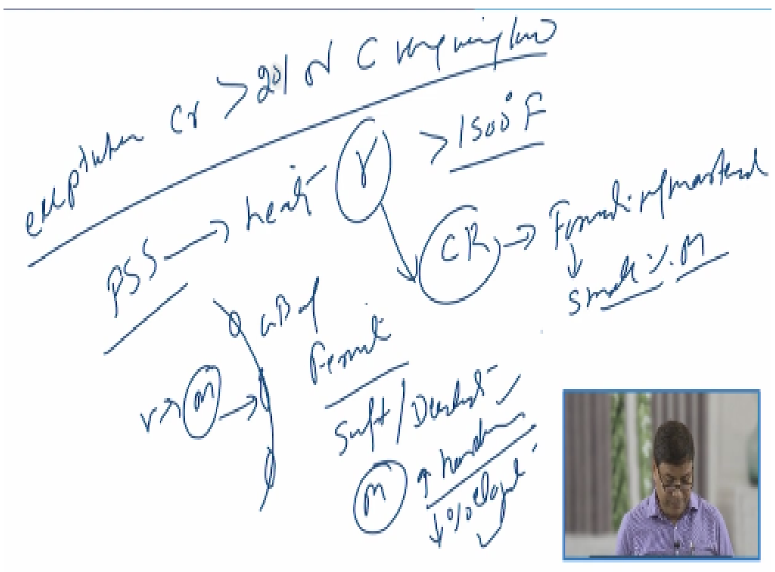

But except when the chromium content is greater than 20% or carbon content is very low usually in FSS on heating with the different grades of the ferritic stainless steels austenite is formed on heating at one or other range of the temperature. So this kind of the austenite is especially formed when the heating happens about like say greater than 1500 degree Fahrenheit.

And thereafter suitable cooling means the cooling rates or high cooling rates or whatever the cooling rates is available that leads to the formation of martensite. But this martensite is very little in quantity, in small fraction the martensite is formed and this martensite is especially formed along the grain boundary, grain boundary of the ferrites.

Since the ferrite is soft, it is ductile so the formation of the martensite at the grain boundaries in the little quantity does not create much problem except that it marginally increases the hardness of the heat affected zone or the weld metal or marginally it decreases the percentage elongation or the ductility of the weld joint. But it effectively accommodates the strain being created due to the transformation of the austenite into the martensite in the ferritic matrix.

So the austenite to martensitic transformation is effectively accommodated from the transformation strain point of view but since it is present along the grain boundary so it decreases the percentage elongation and marginally increases the hardness of the ferritic stainless steel weld joint in the weld metal as well as the heat affected zone.

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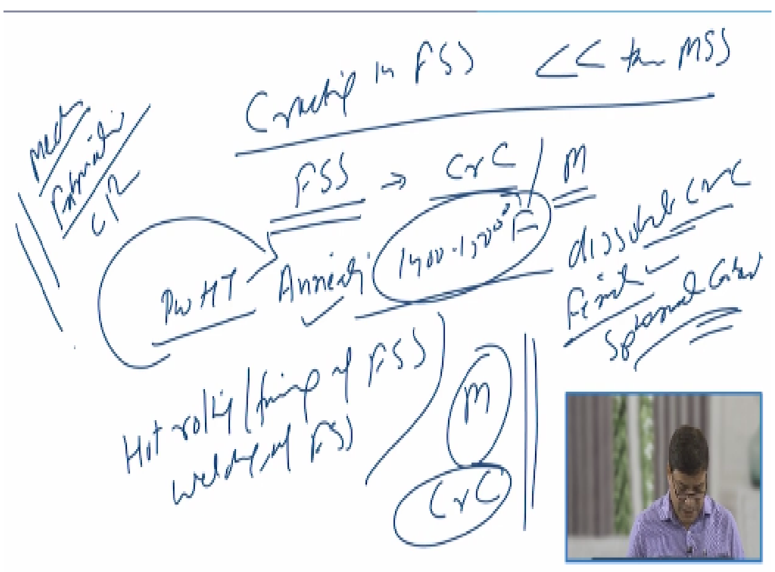

Since the fraction of the martensitic which is being formed and the hardness which is there with this kind of the stainless steels is very low so the chances for cracking in ferritic stainless steel is far less than the what we have seen in case of the martensitic stainless steel.

So if at all any kind of the in martensitic stainless steel if any chromium carbide has been formed or some undesirable phases in form of like martensite has been formed then post weld heat treatment of the weld joint in form of like annealing around 1400–1500 degree Fahrenheit helps in dissolution of the chromium carbides as well as the formation of the ferrite and spheroidization of the carbides.

So these are the kind of the transformations which are realized through the annealing in order to avoid the undesirable effects of the formation of the martensite and the chromium carbide along the grain boundaries which may be formed during the hot rolling or hot forming of the FSS or welding of the FSS. These have resulted in the formation of the martensite at the grain boundary or formation of the chromium carbide.

Then to eliminate the undesirable effects related to these two post weld heat treatment in form of annealing at this temperature range will help to dissolve the chromium carbide as well as it will help in formation of the spheroidized carbides and the ferrite in order to restore the mechanical properties, improve the fabrication or formability properties and improve the corrosion resistance in case of the weld joints of the ferritic stainless steel.

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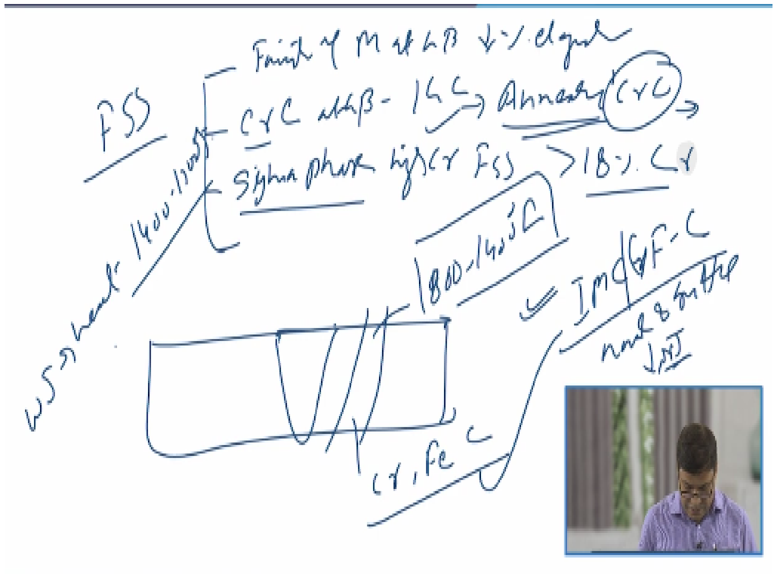

Now we will see there are certain kind of the issues which are commonly encountered during the welding of the ferritic stainless steel and these issues are basically are of the 3 or 4 types. One we have seen already like formation of the martensite at the grain boundaries decreasing the percentage elongation. The second one is the formation of the chromium carbide at the grain boundaries leading to the intergranular corrosion.

And for this purpose certainly we need the annealing about this aspect also we have talked so that here chromium carbide gets dissolved and homogenous chromium distribution can be realized in the austenitic stainless steel. Another problem which is observed is basically annealing treatment helps in restoring the corrosion resistance. Another problem which is commonly observed is the sigma phase formation.

And this problem is observed especially in the high chromium ferritic stainless steel like those having the greater than 18% chromium. So in this case when the martensitic stainless steel either in the weld zone, the zone which is heated in the range of like say 800–1400 degree Fahrenheit, this zone in presence of the chromium, iron, and carbon and this temperature range, despite of the rapid cooling can lead to the formation of the intermetallic compound in form of chromium- iron-carbon intermetallic compound which is hard, brittle and reduces the notch toughness significantly.

So brittleness is increased, notch toughness is reduced, hardness is increased. So and the ferritic resistance is also reduced whenever the sigma formation takes place. This is the kind of undesirable metallurgical transformation which occurs in the regions which are heated in this temperature range especially the ferritic stainless steels of the high chromium content. So this is one of the problem.

In order to avoid this problem the weld joint is heated in the range of 1400–1500 degree Fahrenheit so that these undesirable intermetallic compounds can be dissolved followed by the rapid cooling so that undesirable effects can be eliminated. The another one is the grain growth.

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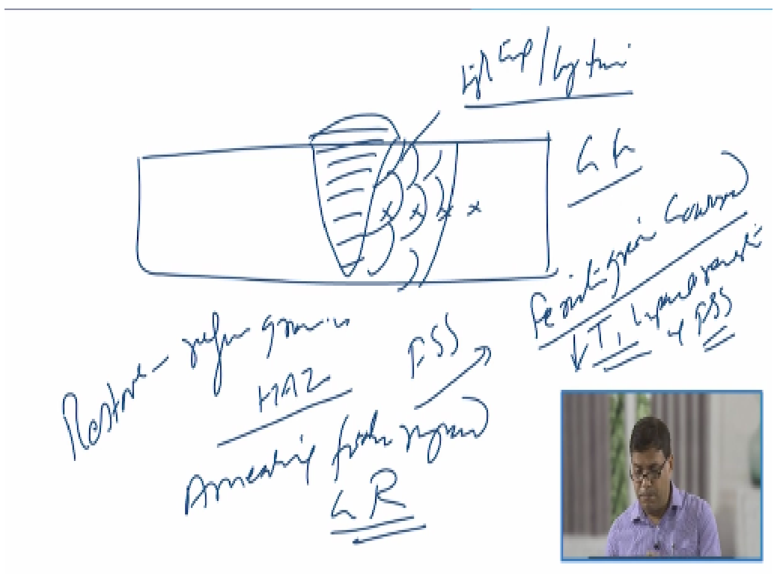

We know that the weld joints whenever it is made either by the fusion welding or by any other process different zones will be experiencing different weld thermal cycles. So zones which are very close to the fusion boundary they experience the high temperature exposure for long time. And this leads to the grain growth especially near the fusion boundary.

Since in ferritic stainless steel it is expected that there would not be any other fresh transformation so the ferrite grains basically get coarsened in the heat affected zone and this kind of coarsening decreases the toughness significantly. So impact resistance of the

FSS weld joint especially in the heat affected zone is very adversely affected. And therefore to restore like this zone is very coarse.

It is ferritic and which is very coarse in the weld joint so the grain growth in the heat affected zone deteriorates the toughness and therefore to restore the toughness we need to refine the grain structure in the HAZ. And for that we will be doing the annealing followed by rapid cooling. So basically the heat treatment is carried out in such a way that the grains in the heat affected zone are refined so that its properties in terms of the toughness can be restored.

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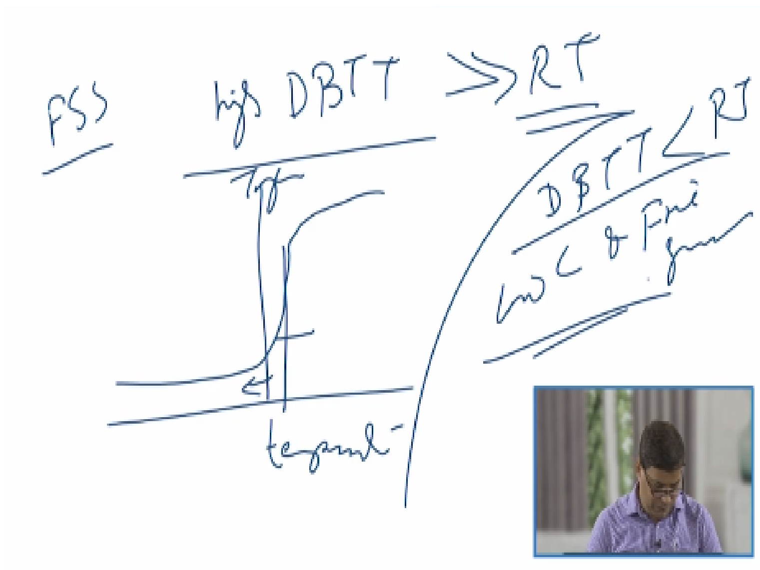

Another important aspect related with the weld joints of the ferritic stainless steel is that most of the steels have the high ductile to brittle transition temperature and we already know what this ductile brittle transition temperature is like this side we have temperature and this side we have toughness. So we know that with the drop of the temperature there is a reduction in toughness.

So this temperature range below which the toughness is dropped significantly, this temperature range for the ferritic stainless steel sometimes is found to be even above the room temperature. So if the ductile to brittle transition temperature is greater than the room temperature then there will be every possibility that the ferritic stainless steel weld joints can fail in very brittle manner under the ambient condition or the room temperature conditions.

And therefore these ferritic stainless steels in order to have that ductile to brittle transition temperature less than the room temperature these should have the low carbon content as well as fine grain structure. So that the resistance to the impact under the low temperature conditions of such kind of the weld joints can be improved. Now I will summarize this presentation.

In this presentation basically I have talked about the different compositions, different the elements which are present in the steels and the kind of role that they perform during the welding of the ferritic stainless steel and what are the various metallurgical changes which affect the weldability aspects of the ferritic stainless steel. Thank you for your attention.