Welding Metallurgy
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Lecture No. 49
Chevron Cracks and Reheat Cracks

Welcome to the lecture on Chevron cracks and reheat cracks. So, we are going to have the discussion about these two special type of cracks which occur in either developmental zone sometimes or in the HAZ zone. So, depending upon the type of cracks, we will talk about these cracks.

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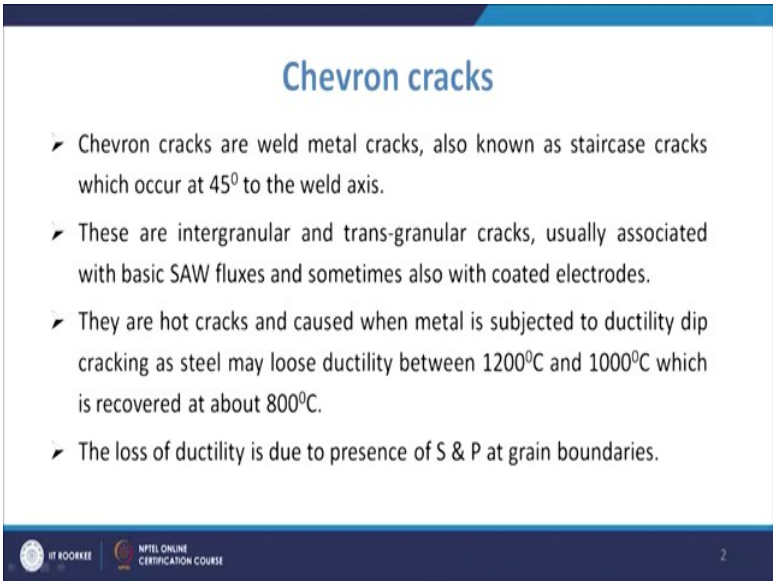

So, coming to first the chevron cracks, basically these cracks are the intergranular and trans-granular cracks and usually associated with basic SAW fluxes. So, we use these fluxes in the submerged-arc welding processes and also sometimes with the coated electrodes. So, there you have the chances of having the formation of such kind of cracks.

So, these cracks are also known as the staircase cracks or even the 45° cracks because they are basically among the category of weld metal cracks and they are known as 45° cracks also because their orientation is at 45° to the weld axis. Now, what happens is that they are hot cracks and caused when metal is subjected to ductility, you know, deep cracking as steel may lose ductility between certain temperatures like 1200 to 1000 °C.

In that range the steel will lose the ductility and it will be recovered when it is coming again to 800 °C. So, what is happening when the specimen or the region is undergoing that temperature range. So, basically, what is happening is that there will be segregation of the sulfur and phosphorus on the grain boundaries. This segregation will be causing that intergranular type of cracks. Now, these cracks show the thermal facets by the oxide colors so that they are exposed to the high temperature.

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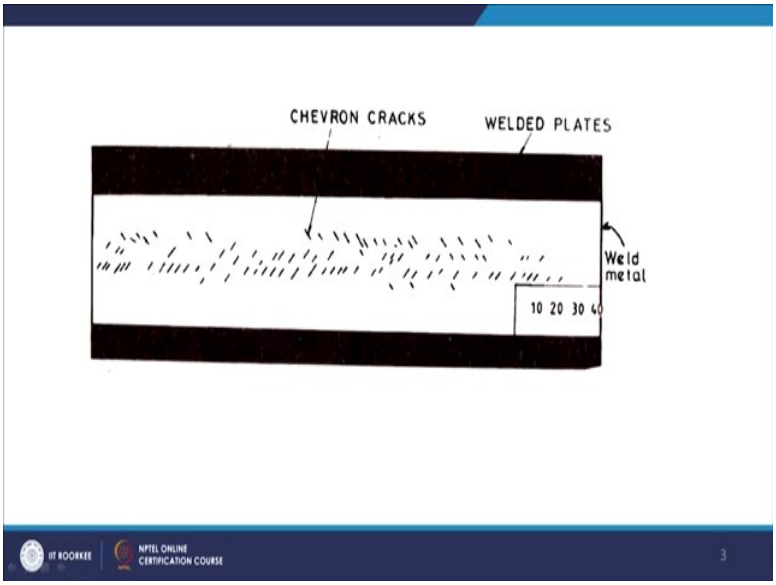

Now, if you try to look at these cracks, what you see is that this is how their orientation is looking like. So, on the top it is coming like this. So, they are basically at 45° to the weld axis. So, basically, this type of cracks which is seen in the weld metal that is the indication of having these chevron cracks. Now, these intergranular cracks they are also joined by the trans-granular tracks at low temperature by hydrogen cracking.

So, basically, that way you get these chevron cracks and that is what is shown in this figure. Now, another theory which is talking about the chevron cracks is that the cracking will be all due to the hydrogen embrittlement and that will be taking place at different temperature ranges. So, because of that these chevron cracks are coming. Normally, chevron crack is most commonly observed in relatively thick sections of carbon magnesium steel plate and that too when you are welding that with high heat input welding processes.

In those cases, you are likely to have, so that is why we talked about these SAW processes, in that you are likely to have the formation of these chevron cracks. Then, another crack which is observed which is to be discussed today is the reheat crack. Now, this reheat crack or it is

also known as the PWHT crack, that is post weld heat treatment crack, as the name indicates these cracks are because of the post weld heat treatment to which the weldment is subjected to. During that post weld heat treatment these cracks are basically likely to come.

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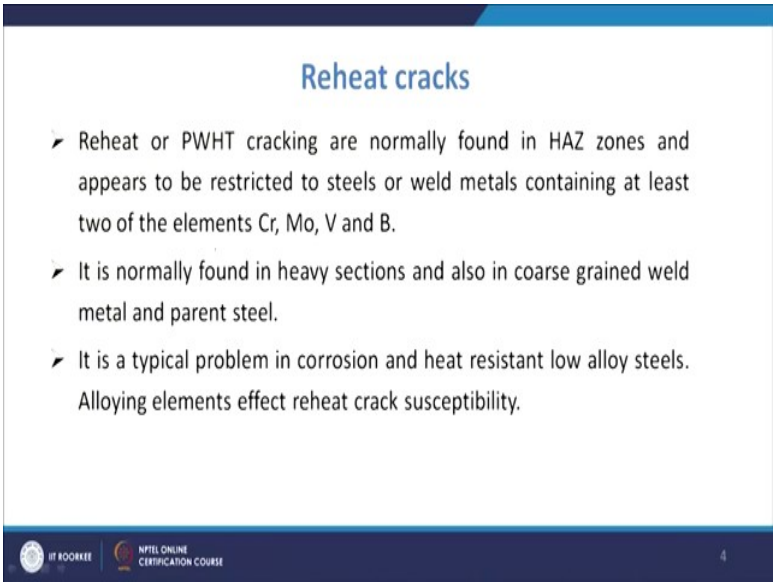

So, reheat or the post weld head treatment cracking are normally found in HAZ zones and appear to be restricted to steels or weld matters containing at least two of the elements, chromium, molybdenum, vanadium, and boron. Normally, if any of these two elements are there in the steel, so they are more likely to have the chances of having the reheat cracks. So, if you look at these elements, they are basically the strong carbide formers.

So, basically we will have the discussion on that line about the occurrence of these kind of cracks. Now, they are normally found in the heavy sections and also in the coarse grained weld metal and parent steel. So, normally that is where they are found, like in heavy sections also and in the case of those weld metal where you have the coarse grain or in the parent steel where you have the coarse grain formation.

So, there it is more likely to have the occurrence of these type of cracks. Now, it is a typical problem in the corrosion and heat resisting low alloy steels basically, that is your ferritic steels which contain chromium, molybdenum, and even sometimes vanadium also. So, these are the ferritic steels. Now, normally, what we do? Normally, we are providing these annoying elements for the increased corrosion resistance to the steel and also mostly they are used for the nuclear applications. Their typical use is at those places.

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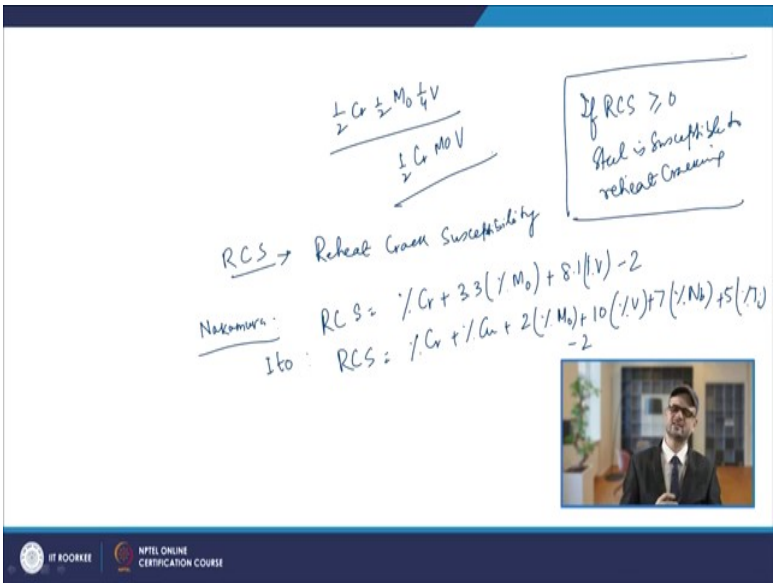

Now, if you talk about these ferritic steel, they are basically ½ chromium, ½ moly, and ¼ vanadium, that kind of steel, or ½ chromium moly vanadium steels. So, these steels they are the one that is used for corrosion resistance. Now, what happens is that because of their presence the susceptibility to the of reheat cracking is there so because of the presence of certain alloying elements they are susceptible to the reheat cracking.

So, for that there has been a parrameter, that is your reheat crack susceptibility, so that is RCS. This shows the relationship. RCS. So, you will have the effect of alloying element on the reheat crack susceptibility, RCS, and that has been given by authors. One author, that is Nakamura, he has given certain expression that his RCS will be % Cr + 3.3% Mo plus 8.1% V – 2. So, that is by Nakamura.

And similarly, by Ito, so Ito and Nakamura both have given; using Ito's relation this RCS is % Cr + % Cu + 2% Mo + 10% V + 7% Nb + 5% Ti – 2. So, if you look at most of the elements which are used, they are the strong carbide formers.

So, basically, these elements they will be giving you these reheat crack susceptibility. And if RCS is found to be ≥ 0, in that case, the steel is susceptible to reheat cracking. So, that is what the condition is there for the existence of reheat cracking. So, what is happening basically?

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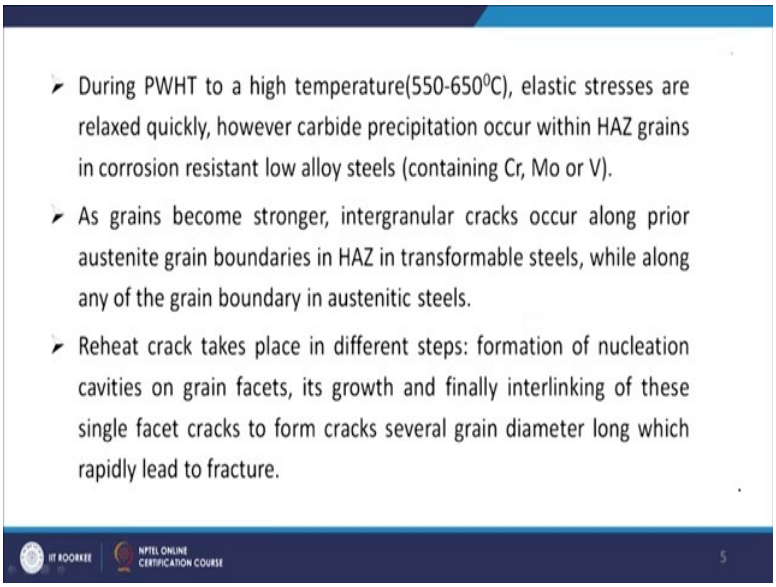

So, if you will come further, what happens is that when we are doing these post weld heat treatment to a higher temperature, we normally do in the range of 550 to 650 °C, so that basically will be quickly releasing the elastic stresses, so they are relaxed quickly.

But then, there will be carbide precipitation that will be occurring within the HAZ grains in the corrosion resistant low alloy steels which is containing the chromium, molybdenum, or vanadium as the alloying elements and as we know that these alloying elements are strong carbide forming elements. So, there will be carbide precipitation also that can occur in these corrosion and heat resistant low alloy steels when you are doing the stress relieving treatment.

So, these carbide precipitation which occurs, that will be making the grains stronger, so the interior of the grains will be relatively becoming stronger, but then the grain boundary will be weaker. So, your interior will be stronger than the grain boundaries. So, when the residual stresses are relaxing, then what is happening is that the rupture or the failure may occur along the grain boundaries and that is how you have the formation of the inter-granular cracking in those conditions.

So, basically, the cracks will be occurring along the austenite grain boundaries or in the HAZ of the transformable steels and also it will be around the grains along the other grain boundaries in the case of austenitic steels. So, that kind of cracking can be observed when you do these post weld heat treatment. So, if you look at the reheat crack which is taking place, you have the different steps which is going on, how these reheat cracks are coming up.

So, initially you will have the nucleation cavities on the grain facets that will be appearing and normally it will be appearing on the grain facets as well as on the triple junction. So, that is the first stage. The next stage will be that all these individual cavities which you are getting formed their growth will be there. So, that will be the next step, that there will be growth of these formed nucleation cavities and that will lead to the formation of one grain facet in length, of that length basically it will become once it will grow.

And then, you will have the interlinking of these grain facets, so grain facet cracks which has occurred. So, once they are interlinked then you will have the crack that will be propagating. So, that length will be having several grain diameter long and that will lead to the rapid fracture of the weld in the specimen. So, this way, in that different steps you have these failure taking place. We talked about the reheat crack tendencies, so the tendency basically will be affected or accentuated by many factors.

These factors are like, if you have the structure having poor ductility, so in those cases you will have the chances of having reheat cracking. So, if you suppose have the upper bainitic type of structure, so it will have more susceptibility towards the reheat cracking because at elevated temperature you will have embrittlement that will be taking place. So, that is why the structure with poor ductility is important. Then, coarse grain is more susceptible to the reheat cracking as compared to the finer grains.

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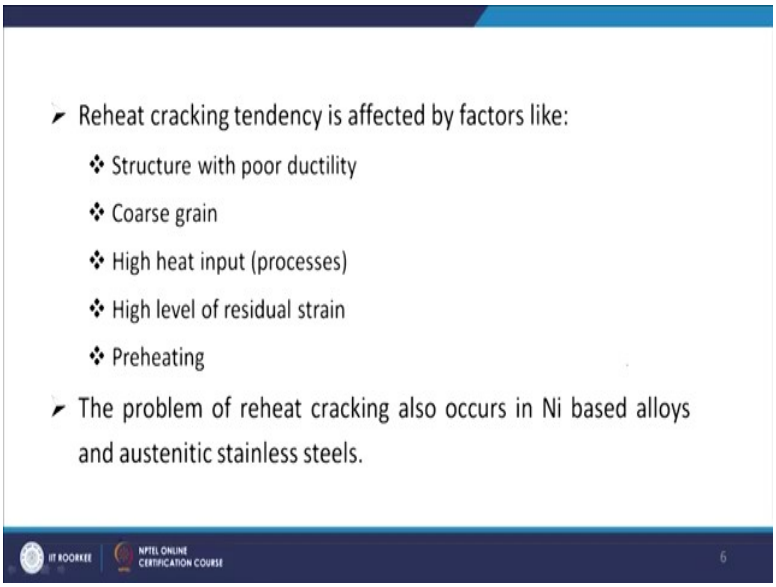

Then, you have high heat input processes, whichever has the specific high heat input processes are there like electroslag welding or submerged arc welding processes, the joints which are made by these processes they are more susceptible to reheat cracking of the specimen. Also, many a times it is affected by the section size also. So, many a times it is more for the higher thick sections, more than, say, 50 mm section thicknesses.

In that case, it will be more. Then, the next is the preheating. So, if you do the preheating, then it will increase the grain size and once the grain size is increased in that case it will again be more susceptible towards reheat cracking. Apart from that, you will have high level of residual strains if they are there and also some degree of triaxiality. So, in those cases you have more chances of having reheat cracking and all.

Then, further, what we see is that these factors they are important ones to see that your cracking tendency becomes more or less. Accordingly, you can have the proper way to control these tendency to have the reheat cracking. Now, the next point is the problem of reheat cracking. So, this problem basically is also occurring in the nickel based steels, in nickel based alloys, and also in the case of certain steels.

So, that is the low alloy steels. So, what is happening is that, in the case of nickel based alloys and also the austenitic stainless steels we see the occurrence of these reheat cracking and among the low alloy steels, if you look at, so you will have some grains which are very much susceptible to this reheat cracking.

So, in a general rule, if you talk about the post-weld heat treatment of carbon-manganese steels, then that basically will be improving the fracture toughness although it will have the low impact toughness, basically, whenever you deal with the high specific heat input processes.

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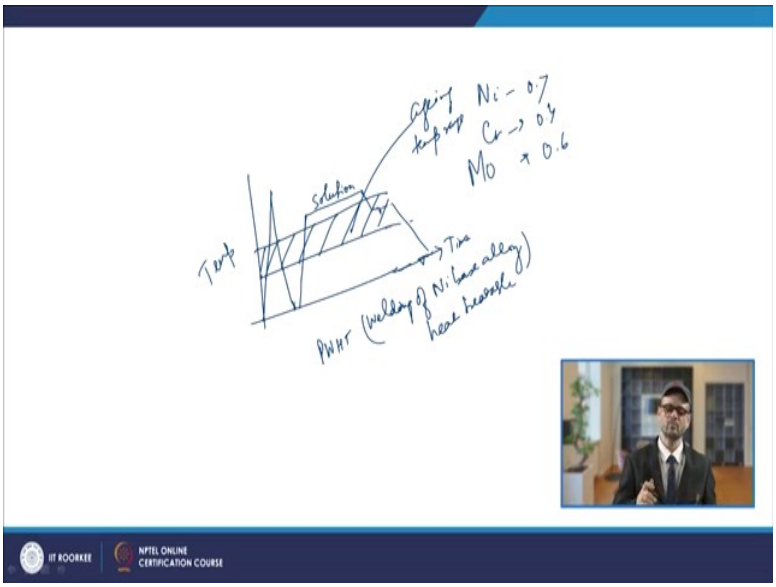

So, these low alloy steels which we use normally, a typical low alloy steel, which has the nickel % is suppose 0.7, Cr is 0.4, and Mo is 0.6, so they are normally used in the nuclear pressure vessels and they are very much known to this reheat cracking. So, crack will be occurring in the grain growth zone, either as the longitudinal macro-cracks or micro crack network. So, that way these reheat cracks are observed in such case of steels which is the low alloy steel which is used in the nuclear pressure vessels.

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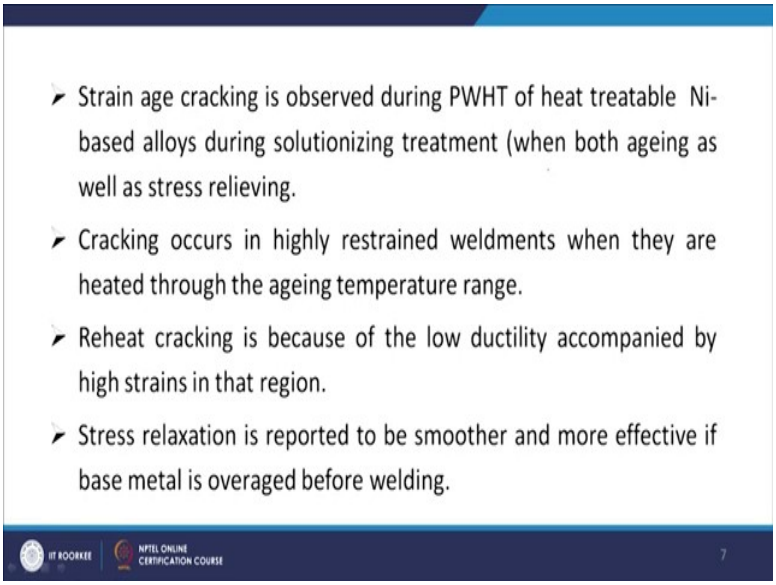

Now, what is happening is that many a times you have the observation of these reheat cracks in a different manner. So, we term is as the strain-age cracking also. When we do the post weld heat treatment of heat treatable nickel based alloys, what we do normally is that we are solutionizing first in those cases and then, in that case, there are two things which are happening; one is aging and another is the stress relieving.

So, what will be happening in that case? In this case, what we do is that when we use these heat treatable these nickel based alloys during the solutionizing treatment, so to have more strength what we do is we normally solutionize and then we age harden. So, in that case it gets aged also, that is aged. So, what is happening is that when we do the solutionizing in that case the stresses are relieved.

However, the aging also occurs in the weldment. The aging temperature range is normally lower than the solutionization temperature. So, the aging is occurring before the residual stresses are relieved. So, what is happening is that before that residual stresses are relieved and since the aging occurs, so that results into the cracks during that post weld heat treatment. And this crack which is occurring during that post weld heat treatment that is known as the strain age cracking, because this is occurring in the highly restrain weldments. and they are heated in the range through which the aging is occurring that's why we call it as strain age cracking.

And if you look at the cycle where the reheat cracking may occur for these nickel based alloys, so that cycle basically, if you look at these nickel based alloys, so this is your post weld heat treatment, so this is welding of nickel based alloy, this is heat treatable, so this is your temperature and this is the time. So, you do the welding here and then it is getting cooled and so you will have a range and then you are heating.

And this is your solutionizing during this time and then you are coming into this time and this is your aging which is occurring, and then it is following like this. So, this is your basically aging temperature range. While heating, basically, this is your temperature at which you have to go. This is your solutionizing temperature. And before that, basically, this aging is done. So, you will have the residual stresses will be there.

So, you have residual stresses which are relieved once you go into that region. So, before that the residual stresses and because of that aging you will have the crack formation. So, in this case, here you have the residual stresses, therefore for relieving that you are going. So, this way, because of this range through which it is passing you have the chance of crack that is formed.

Now, if you talk about the reheat cracking, reheat cracking in the nickel based alloys is because of the low ductility in HAZ accompanied by high strains in that region. And, in those cases, many a times the practice is that over-age before the welding. So, that gives even, sometimes, better results in those cases, although the over-aging if you do that may not be good in the HAZ zone.

But then, it has been seen that before the welding you can go for the over-age. So, that may be advantageous. So, HAZ of a weldment in a heat treatable nickel based alloy after the post weld head treatment, that responds in a different way. Now, if you look at avoidance of these reheating cracking in the steel, there are certainly some steps which can be followed, that way you can have the avoiding of the reheat cracking.

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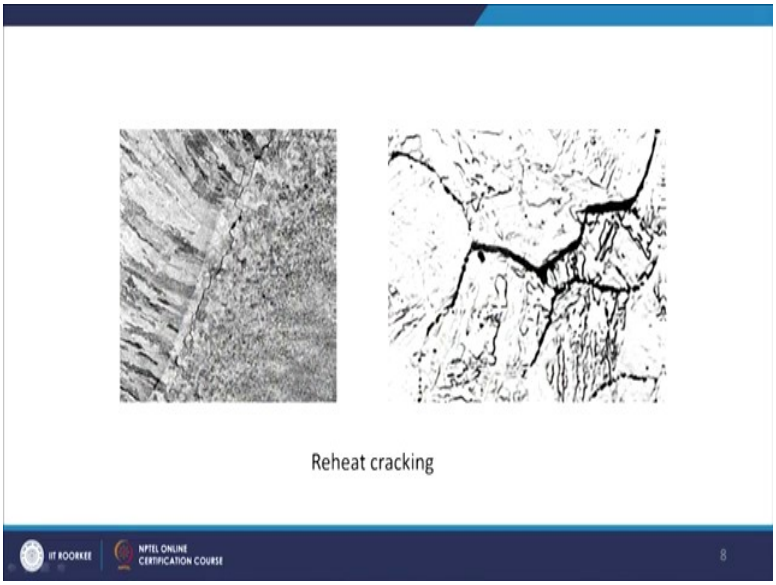

So, this is basically the example of these reheat cracks which you can see here. This is how the reheat crack looks like. So, if you try to avoid these formation of reheat cracks, there are certain steps by which you can avoid these reheat cracks and these are that you should have the eliminate vanadium content in the thick sections and then you can have the design to have the minimum restraint, and further, you can have higher preheat temperature.

So, these are the ways to avoid these reheat cracking in the steel welds. Now, there is one more thing which is important to know while we discuss about the reheat cracking, it is the C curves for the crack susceptibility. So, if you talk about the crack susceptibility, so there is a crack susceptibility C curve.

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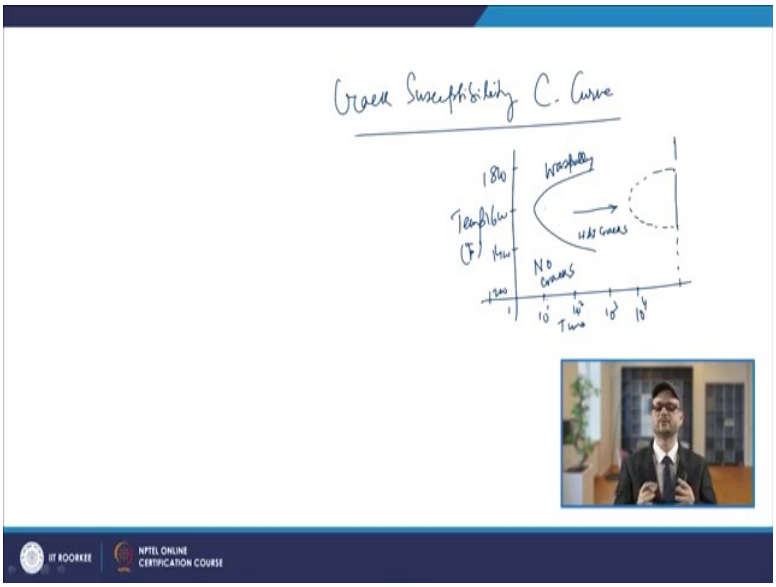

So, if you see, for materials like Waspalloy or Inconel, so what has been seen is that, so this will be temperature and this will be time, so this is on the log scale, so it will be 10 1, 10 2, 10 3, so what is seen is that this curve is found and in that case you have no cracks on this side. So, this is your crack susceptibility C curve, how much it will be susceptible to the crack and this is for Waspalloy. And if you go for alloy 718, for alloy 718 it goes like this.

So, you have improved weldability in these cases and you have the HAZ cracks which is likely to form here. So, this curve indicates that at the lower temperature range, so this is about 1200 °F, so this is in °F, so 1200, 1400, 1600, and then 1800. So, what this curve indicates is that at lower temperature range what you see is that this is going to stay asymptotically. So, for infinite time it may go.

So, that way there is no chance of this crack formation, whereas if you increase the temperature, in that case you have certainly the chances of these HAZ cracks which is at lesser time. So, this way, this reheat cracks susceptibility is basically represented in terms of this crack susceptibility C curves. So, you know, that is approaching higher temperature limit also, one limit is there.

So, that way you must understand that there are conditions because of which these materials are more susceptible to the reheat cracks. There are many factors that is what we have studied and mostly because of the presence of these elements which are there, which are the strong carbide formers, of carbide forming elements.

And since they are present that leads to the formation of these reheat cracks in the case of the steels, whereas, as we see in these cases, in the case of nickel based alloys or so, you have other factors apart from those factors, you have factors like restraint factor and you have factor like limiting amount of certain material or so. This is something we have discussed about, the reheat cracks, and we also talked about the chevron cracks. We will talk about a few other types of cracks also in our coming lectures. Thank you very much.