Welding Metallurgy

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Lecture No. 52
Weldability of Carbon Steels

Welcome to the lecture on weldability of carbon steels. We had the introduction about the weldability and that it is very important to have a good weldability because ultimately the welded specimen which you are going to use they are supposed to perform satisfactorily under the specific set of conditions. We talked about the definition of weldability, how the weldability may be affected because of the constituent elements.

Then, what are the tests which are done for checking the weldability. So, we will be talking about the weldability and issues related to that in different materials. Typically, we will talk about steels. Then we will talk about the cast iron and also a few of the non-ferrous materials also because they are the ones which are normally used for engineering applications and we must be having proper information about the weldability aspects of these materials.

As you know, we have nowadays use of carbon steel is there. Carbon steel certainly when we are limiting the carbon to may be close to 1% or so. But then, apart from steel like carbon steel you have others like low alloy steels, then you have alloy steels, then you have another alloy of iron that is cast iron is there, and then we will talk about the different materials.

But in this lecture we are going to have the discussion about the material that is carbon steels. As we know, when we talk about steel or carbon steel, then your classification is normally in that low carbon steel, mild steel, medium carbon steel, or high carbon steel. As you see that carbon content is given a range for all these kinds of steels.

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Weldability of Carbon Steels

Type	C content	Use	Welding rating
Low carbon steel	0.15% Max.	Sheet, strip, welding electrodes	Good
Mild steel	0.15-0.30	Structural shapes, plates and bars	Good
Medium C Steel	0.30-0.50	Machine parts and tools	Fair
High C Steel	0.50-1.00	Springs, Dies, Rails	Poor

In the case of low carbon steel, the carbon content is limited to a maximum of 0.15% and its use is normally sheet, strip, welding electrodes. All these are made by 0.15%, less than that even, the carbon. So, that is classified as low carbon steel. Now, these have good weldable behavior. And, as you know, once you are making the sheets or strip or welding electrodes, so for that it must have very good ductility.

So, lower value of carbon ensures that you have a very good ductility. So, they can be converted into sheets or strips or so, or even fine rods for making the welding electrodes. So, they have a very good reasonable, you know, they are weldable. So, they can be welded. And normally, if you talk about the hardness, then hardness is certainly smaller. As we go on increasing the carbon percentage, so the hardness will increase.

Then, you have mild steel. Mild steel has carbon content of 0.15 to 0.3% and it is normally used for structural shapes, plates, and bars. In this case, the welding rating that is considered is from good to excellent. In fact, the weldability may be considered even better than the low carbon steel. We will discuss that, for which conditions or for what reasons the weldability is even better than it is said to be. Then, we have the medium carbon steel.

In this case, carbon is in the range of 0.3 to 0.5% and they are normally used for the machine parts and tools. And here the welding rating is said to be fair. Normally you have the preheating requirement or you have the requirement of post weld heat treatment. So, that is why it is known as fair. We will talk about it that we normally try to have the adoption of low hydrogen processes to avoid the cracking or any problem in the weldment or HAZ zones.

Then, if you come to the high carbon steels, high carbon steels are basically classified as those steels where the carbon percentage is from 0.5 to 1%. You see that their use is normally in springs, jigs, dies, rails as they require more hardness. So, you have these high carbon steel. Now, in these cases the weldability is poor because of the very high carbon that we see, as you know that with increase in carbon the hardenability will be increasing.

And if the hardenability is increasing, it means even at slower cooling rates also you are likely to have the undesirable phases like hard and brittle phases like martensite. So, basically, that way its weldability is said to be poor and you have to have the precautions like you have to have the preheating as well as the post heating techniques that is required for avoiding any kind of defects or cracks especially in the weld metal and HAZ zones.

Coming to the welding of low carbon steel, as you know, you have the low carbon steel where the carbon steel is smaller, so you have carbon steel is up 0.13%.

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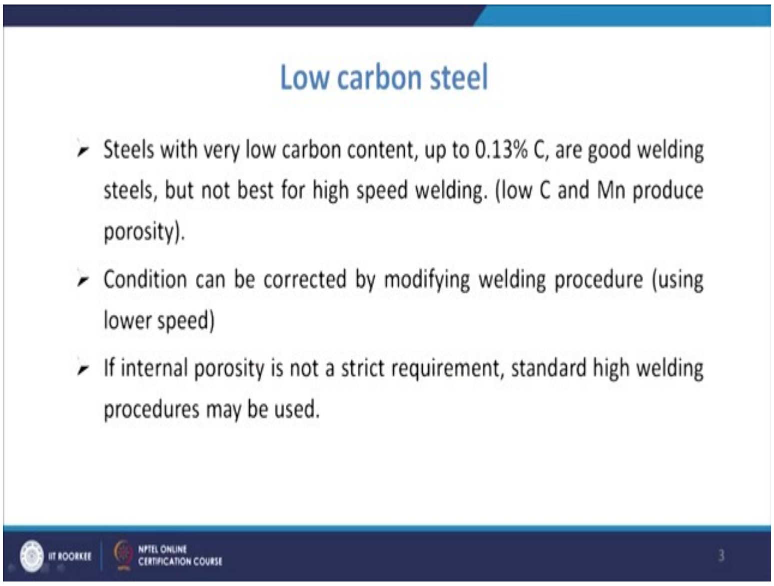

Now, in this case, they are good welding steels, but not best for high speed welding. This is because of the presence of very low amount of carbon and also manganese. So, if it is very low, in that case it is reported that they produce porosity in the weld. So, that way you have to see that you go for slow speed, that way you can avoid these formation of porosity especially when you have low carbon and also you have low manganese.

That condition can be corrected by modifying the welding procedure. The procedure means you must go low, I mean speed should be low so that your welding is okay, I mean you are avoiding the formation of porosities in those cases. And, basically, if you have the product in such a manner that you are not very much concerned with the presence of the internal porosities too much, in those cases certainly you can go with standard high welding processes, and that way you can have the economical process.

So, that is the advantage. The advantage of these steels is that, as we know, they have very good ductility and they are easier to form as compared to the high carbon steels. Otherwise, there is not much of a problem because as the carbon is less the ductility will be higher.

Apart from the problem related to internal porosity there is not much of a challenge in these cases.

Coming to mild steel, mild steel basically is where you have the carbon which is a little bit more, maybe 0.15 to 0.2% or 0.25% of so. They have very good weldability. In this case, what we have seen earlier, this is your mild steel, it is used for structural shapes, plates, and bars and they have good welding rating.

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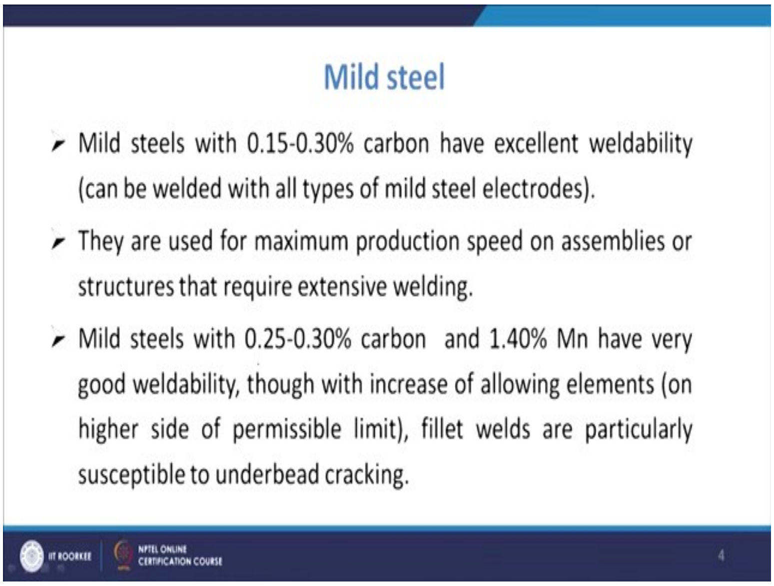

Basically, they have very excellent weldability and they can be welded with all types of mild steel electrodes. So, that is the advantage of these electrodes. Since the carbon percentage is somewhat higher, may be you are going from 0.15 to 0.20 or 0.25%. Since in this range or 0.25 to 0.3% carbon and when we have 1.4% manganese, in that case, particularly, they have excellent weldability.

But the thing is that you will have to see control on the limit of these alloying elements, one or more alloying elements. If they are more than the limit, in those cases, under-bead cracking may be possible typically in the case of fillet welds. So, in those cases, you will have to have control on the welding speed, somewhat lower the welding speed, and then you can have satisfactory results.

Otherwise, they are used for maximum production speed on assemblies or structures that require extensive welding. So, extensively this material is used for welding applications and in those cases for maximum production speed you are going to use these mild carbon steels because they have very good weldability.

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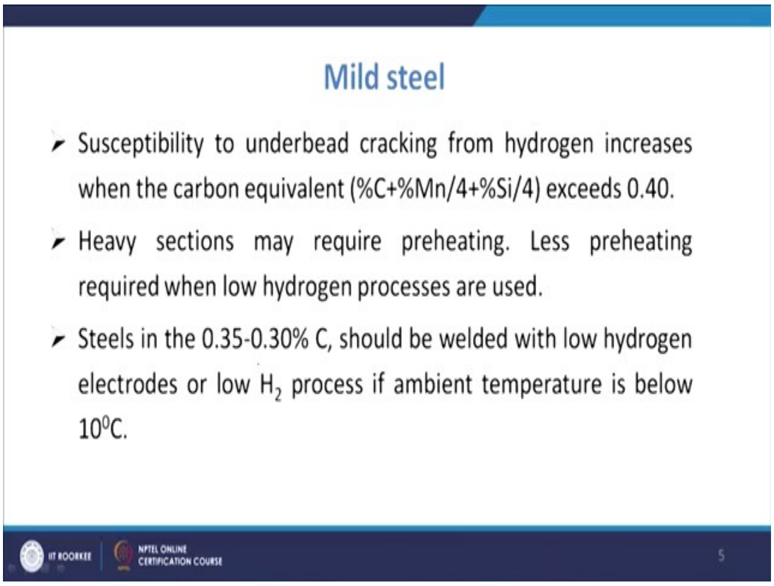

Now, one more thing which is defined in this case, you know, susceptibility to this under-bead cracking, that increases when the carbon equivalent is exceeding 0.4. So, basically, what happens is that depending upon the alloying elements, whether it is going to have the effect on the carbon equivalent or not, positively or negatively. As we know that carbon equivalent basically is defined and carbon equivalent will be defined by the %C + %Mn/4 + %Si/4.

That way you find the carbon equivalent when we are welding such carbon steels and what is seen is that when this carbon equivalent value will be exceeding 0.4, in those cases, the susceptibility to under-bead cracking from hydrogen basically increases. So, that is one thing which is basically seen, which is observed in the case of these mild steels.

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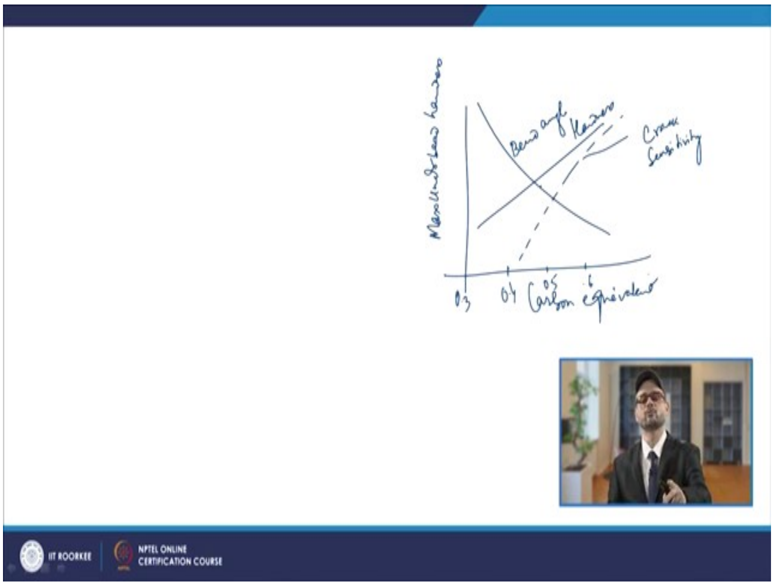

Basically, if you look at the composition and under-bead hardness, so a graph will be there. Suppose you have the carbon equivalent on the abscissa, and suppose this is your 0.3, then you have 0.4, you have 0.5 and 0.6 and so on. Now if this is your maximum under-bead hardness, accordingly you can have also the average under-bead cracking sensitivity percent also.

What is seen is that the hardness basically is increasing like this. So, if your carbon equivalent is increasing, your hardness is increasing, then band angle basically is decreasing. So, this is your hardness and the bending which is possible that will be the band angle which is possible without failure. So, band angle basically is decreasing. Similarly, the crack sensitivity also is increasing.

So, as you increase the carbon equivalent value, the crack sensitivity, that is your average under-bead crack sensitivity that also goes on increasing. So, that is the effect of the carbon equivalent and that is how it affects the weldability of the material. So, what we are discussing is that if your carbon equivalent is exceeding 0.4, in that case, your under-bead cracking from hydrogen basically increases.

Now, the thing is that many a times the preheating requirement is more mostly, basically, when you use the heavy sections. In that case, you require preheating and less preheating basically will be required when you use low hydrogen processes. In those cases you can have not so much of requirement about the preheating. So, that is depending upon the low hydrogen processes or low hydrogen electrodes which you use.

In that case, the extent to which you have to do the preheating that may be affected. That is the case normally with this kind of steels, and especially when the ambient temperature is smaller. Normally when your ambient temperature is below 10 °C, in those cases, you need to have this precaution that you should weld it with low hydrogen electrodes.

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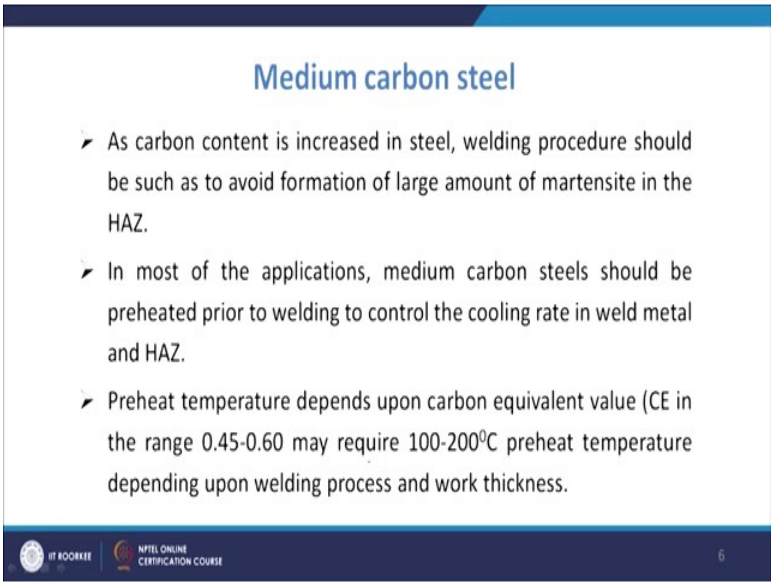

Next will be your medium carbon steel. As you see, when you further increase the carbon, in that case, that is defined as medium carbon steel. Since you increase the carbon, then normally since the hardenability is increasing, you are expecting to have the formation of martensite which is very hard and brittle phase and this you try to avoid. So, in most of the applications what you do is, normally medium carbon steels they should be preheated prior to welding.

So, for controlling that cooling rate in the weld metal and the HAZ zone what you do is normally we do the preheating. So, that preheating is somewhat essentially you can say in the case of these medium carbon steels. Now, this preheat temperature which appropriately you are going to have that will be depending upon many factors. That will be depending upon, say, the carbon equivalent value, then the joint thickness, and what type of welding procedures you are taking.

That way you can have the selection of appropriate preheating temperature. Now, if you have the carbon equivalent value which is coming in the range of 0.45 to 0.6, in those cases, we take the preheat temperature in the range of 100 to 200 °C depending on the welding process and also the thickness. And normally the interpass temperature also will be kept same as the preheat temperature.

So, that is normally the requirement in welding those medium carbon steels. In these cases, the low hydrogen welding procedures are mandatory. You must use the low hydrogen welding procedures to avoid any kind of crack formation or undesirable microstructural products.

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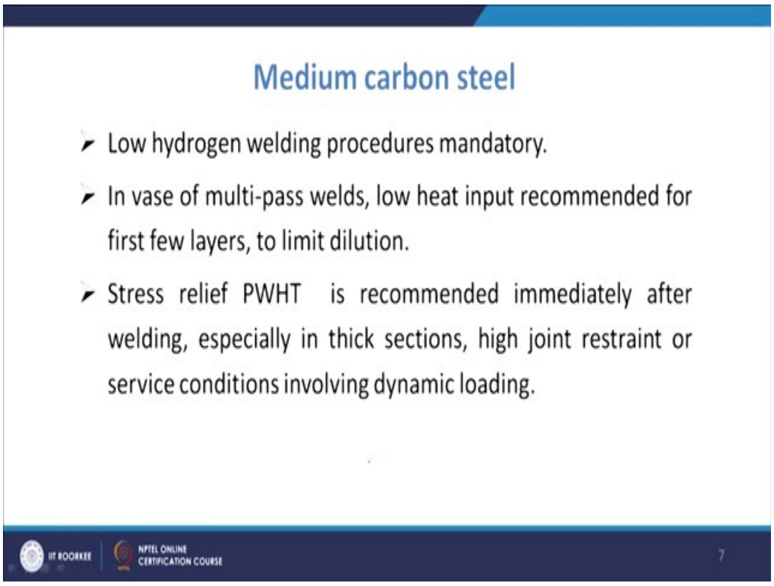

Normally what you do is you are going to have low hydrogen welding processes, use low hydrogen electrodes. Then selection of filler metal also is very important because as the carbon content is increasing there may be pickup of the carbon also from the weld, so pickup of carbon from steel containing point 0.5% carbon by dilution that will result into high weld metal hardness.

Because if that is picked up, then that will result into very much hardness and if the hardness increased, then that will result into the formation of cracks because, that will not accommodate any kind of deformation which is likely to be because of the thermal gradient. So, first of all when you go for the multi-pass welds, then the thing is that you must give low heat input in the first few layers just to limit the dilution.

We try to go for the low heat input so that the dilution that may lead to the formation of hard phases or cracks, so we try to have low heat input in case of these multi-pass welds. Then stress relief post weld heat treatment is recommended highly immediately after welding especially in the thick section.

Then, you also require, in the case of high joint restraint or wherever you have the service where you feel that it is expected due to dynamic loading, so in those cases you require to have the application of the stress relief post weld heat treatment that should be given in those cases. And if possible, the welding joint should be heated to that stress relief temperature without immediate cooling to that ambient temperature. That also is one of the way by which you can avoid the formation of cracks or so.

And also slow cooling to room temperature from that stress relief temperature that is also recommended to avoid formation of the thermal stresses. Now, when immediate stress relief treatment is not possible, in those cases, when it is not possible to have immediate stress relief treatment, you can maintain above the specified preheat temperature for 5 to 7 minute per mm of section thickness or joint thickness. What it does is normally that also promotes the diffusion of hydrogen from the weld zone.

And consequently once you have that process, then it will reduce the crack formation tendency or any undesirable process, any undesirable microstructure which may result into because of the other parameters. So, that is what should be followed in case of medium carbon steel.

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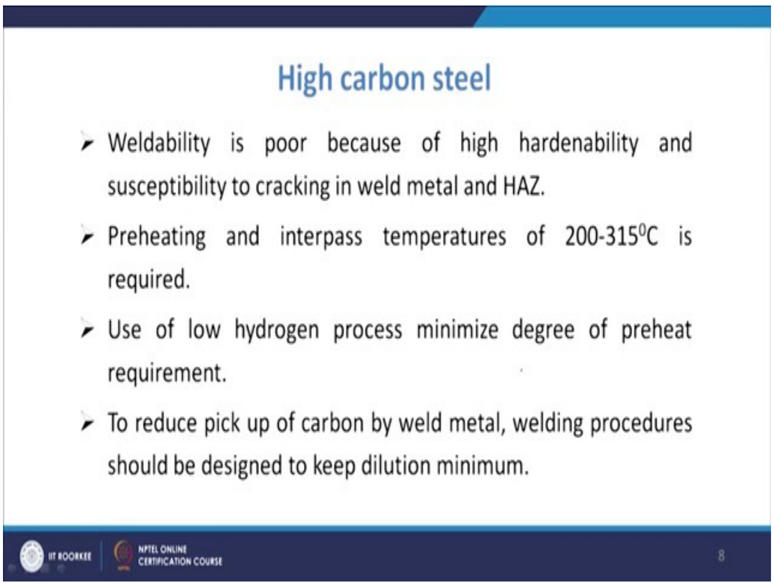

Coming to the high carbon steel, as we discussed, high carbon steel welding is a great challenge. Since the hardenability is increasing in the case of high carbon steel, the weldability is considered to be poor and there is great chance of cracking in the weld metal or HAZ zone if proper precautions are not taken.

So, precautions are that you will have to have the control on the thermal gradient which is established during the welding process, heating or cooling process and that has to be accommodated. Normally, you are maintaining the preheating and the interpass temperature of the order of maybe 200 to 315 °C. So, that is a requirement when we talk about the weldability in the case of high carbon steel.

Now, in these cases, what we do is, we normally go for low hydrogen processes. If you go for low hydrogen processes, in those cases, your degree of preheat requirement is decreased. And what you can also see is that, if you have the material thickness of less than 2 mm or less, if the use of low hydrogen processes are there, in that case, you can even eliminate the use of preheating.

As a thumb rule, if you use these low hydrogen electrodes, in that case, your preheat temperature requirement will be reduced by 45 °C to 90 °C lower than what you require in the normal process. That is normally the situation that is there in the case of high carbon steel welding. Now, further, if you look at high carbon steels, the earlier point which was there that if you are willing, many a times you have to also consider the use of the filler material.

So, appropriate filler metal has to be selected and normally the filler metal dictates that there may be pickup of carbon in the weld pool. So, to reduce that pickup of carbon by the weld metal you must have proper welding procedure designed so that the dilution is minimum. That is also to be taken care of.

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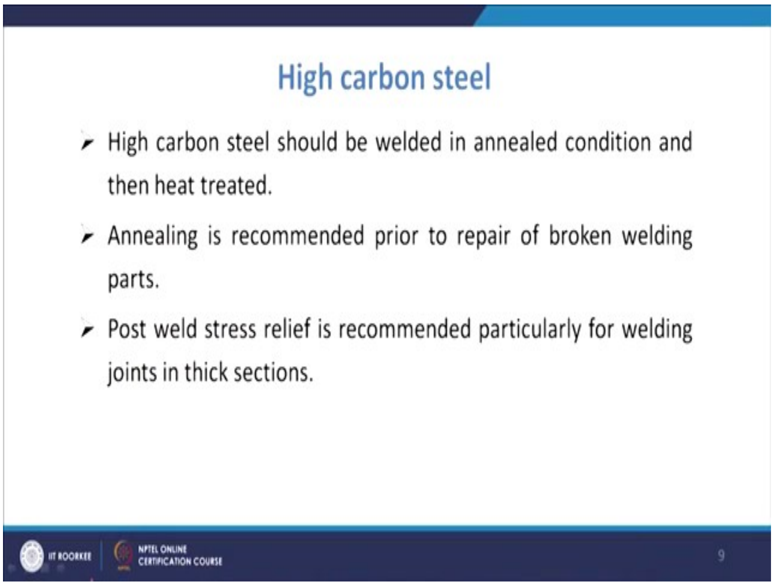

Now, when we are talking about high carbon steel welding, normally that should be welded in the annealed condition and then heat treated. So, that is better, that is suggested that if you do that, then the likelihood of these crackings or undesirable effects are less. Annealing is also recommended prior to the repair of broken welding parts. So, many a times welding is used for the repair of these welding parts.

So, it is one of the very potential use of welding processes. So, there also if you have high carbon steel part, in those cases, you are suggested that you should go annealing prior to doing the repair work. Then, post weld stress relief is recommended particularly for, if you talk about the thicker sections, so in the thicker sections you need the post weld stress relief. For that proper welding procedure is there.

So, post weld stress relief process is in fact very much recommended for the thick joints. There it is more prone to have those places and those regions are more prone to have the cracks. There you will have the requirement of the post weld stress relief treatment too. So, these are the issues related to the weldability in the case of carbon steels and there we have seen different carbon steels, low medium and high carbon steals.

Especially once you move towards the higher carbon content, then you require these special precautions to avoid the formation of these hard phases or embrittlement and HAZ zones and to avoid the cracking. So, we will about the weldability issues in other materials also in our subsequent lectures. Thank you very much.