Welding Metallurgy
Prof. Pradeep K. Jha
Department of Mechanical and Industrial Engineering
Indian Institute of Technology Roorkee

Lecture No. 53
Weldability of Alloy Steels

Welcome to the lecture on weldability of alloy steels. In this lecture, we are going to have the discussion about the welding characteristics and weldability aspects of alloy steels and in that also we will talk about the low alloy steels also. First, we will talk about one of the very important variety of low alloy steel, that is, high strength low alloy steel.

Although alloy steel are categorised as low alloy, and then once you have the alloy content more than a certain specified percentage, then only it is alloy steel. This is a typical material which is very much used in specific areas. That is high strength low alloy steels.

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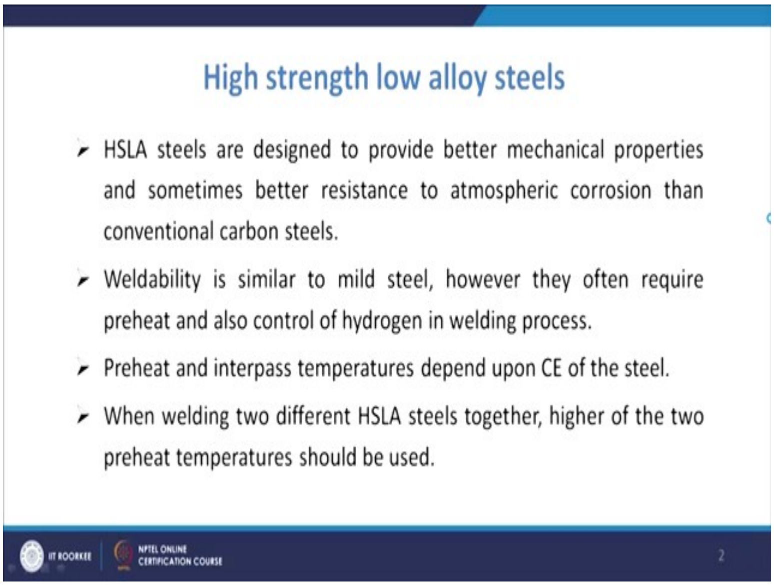

So, these steels are basically designed to provide better mechanical properties and sometimes better resistance to atmospheric corrosion than the conventional carbon steels. So, high strength low alloy steels are very much used in the automobile applications and even in other transportation industries or so. The weldability is similar to the mild steel, however, they often require preheat and also control of hydrogen in the welding process.

So, basically, in this case you require preheat and also the hydrogen control is very important. The preheat and interpass temperature that will be depending upon the carbon equivalent value of the steel. And the carbon equivalent value will be depending upon the different alloying elements which are used in the steel. And when we are using the two different HSLA steels together, in that case, the higher of the two preheat temperatures for the two steels which are to be joined, that has to be selected.

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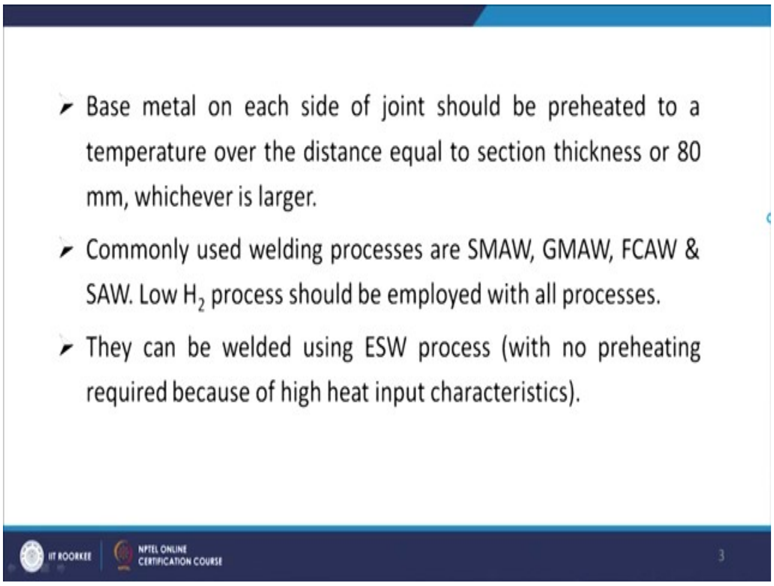

Then, in these cases, the base metal on each side of the joint they should be preheated to a temperature over the distance equal to section thickness or 80 mm whichever is larger. So, in these cases, what we do normally is we take care that on each side of the joint a minimum of 80 millimeters or equal to the section thickness that much must be preheated. Commonly used welding processes are shielded metal arc welding, gas metal arc welding, flux-cored arc welding, and also the submerged arc welding.

So, these are the commonly used methods which are preferred for these kind of materials. And also low hydrogen process should be implied in all the cases to have better results. Now, they can be welded using the ESW process, that is electroslag welding. In that case, we do not require preheating because of the high heat input characteristic of the ESW process. That way you will have certainly some differences as compared to the mild steel of these processes.

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Stainless steels

- At least 11.5% Cr is added to get corrosion resistant/Stainless steels. The film of chromium oxide acts as a barrier to oxidation, rust or corrosion.
- Stainless steel can broadly be divided into following types:
  - Austenitic stainless steel
  - Ferritic stainless steel
  - Martensitic stainless steel

Now, more importantly, when we talk about alloy steels, then we talk about stainless steel. And as we know that these type of steels, as they are corrosion resistant, you are typically adding certain alloying element which tend to increase the corrosion resistance of the material and among the elements which are to be added is chromium as the most important alloying element and at least 11.5% of chromium is added to get the corrosion resistant or stainless steel.

They are also known as corrosion resistant steel. So, basically, this layer or chromium oxide that basically acts as a barrier to further oxidation, rust, or corrosion. So, that is why they are known as corrosion resistant steels. Since they cannot be stained easily that is why they are also known as stainless steels because if you provide the stain it will not be possible on these, you cannot see them.

So, that way, that is why they are known as stainless steels. Now, if you talk about these stainless steels, they are broadly divided into different types and these types are you have austenitic stainless steel, you have ferritic stainless steel, and you have martensitic stainless steels. So, that way, accordingly, you have broadly these three categories of stainless steel which are there.

Now, coming to the austenitic stainless steel, if you try to see the properties of these steels, first of all these steels have the austenitic structure at room temperature. That is why they are known as austenitic stainless steel. Now, they exhibit the highest corrosion resistance among all the ferritic or you have the martensitic, or among these three types the stainless steels they have the highest corrosion resistance.

They get the best strength and also scale resistance at high temperature as compared to other two steels. They retain the ductility even at very low temperature, even at absolute zero temperature also they are ductile. This property has to be used in many applications when you are using the material in those kinds of environment. Then, they are also non-magnetic, it is their property. So, this is about the austenitic stainless steel.

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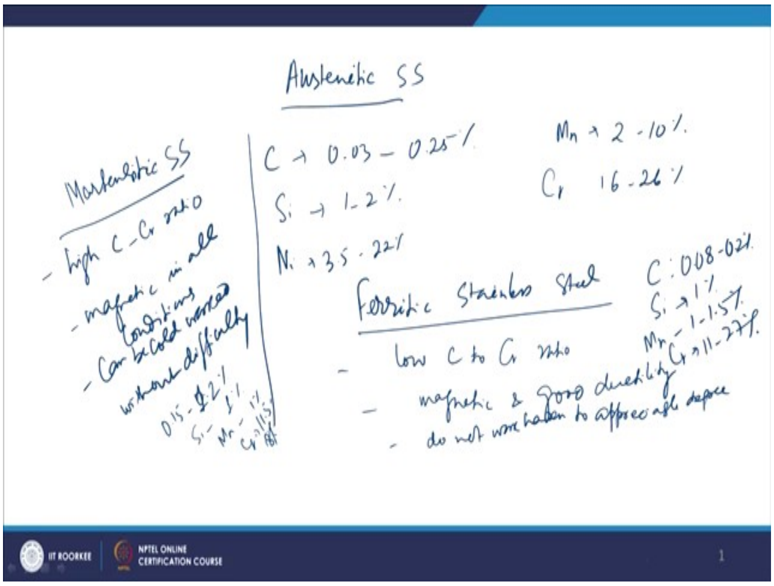

Then, if you come to talk about the other kinds of steel, so normally if you look at the austenitic stainless steel, so we discussed about these properties and normally you have carbon as 0.03 to 0.25%, you have manganese from 2 to 10%, you have silicon is 1 to 2%, chromium is here from 16 to 26%. So, that is quite a large value in this austenitic stainless steel here. Then, you have nickel as 3.5 to may be 22% or so.

That basically is making it really austenitic, so that is nickel alloying element, and then you have phosphorus in sulphur which is normally there, used in the aircraft industries and you have the heat exchangers, food processing, kettles and all that, you know, milk cans, all these are made by this austenitic stainless steel. Similarly, if you go to the ferritic stainless steel, as the name indicates, their microstructure is primarily ferritic.

That is why they are known as ferritic stainless steel and they have normally low carbon to chromium ratio. So, that is the property of these materials, these kinds of steel. So, basically they will be eliminating the effect of this thermal transformation and also it will prevent the transformation or the hardening by heat treatment. So, because of this low C to Cr ratio they will not be very much responding to the heat treatment processes.

These steels are basically magnetic and have good ductility. So, that is again property of these ferritic stainless steels. And they do not work harden to appreciable degree. Now, ferritic stainless steels they are more corrosion resistant than the martensitic stainless steel. So, that is the property. And they have good softness and ductility and corrosion resistance in the annealed condition.

Normally, if you come to the composition of the ferritic stainless steel, normally you have carbon is 0.08 to 0.2%, then you have silicon as 1%, manganese as 1 to 1.5%, and chromium is about 11 to 27%. Carbon, if you look at, it is smaller. Carbon to chromium ratio actually is the smaller one in this case and they are used in the lining for petroleum industries, you have its use in the heating elements for the furnaces.

So, that way, you have its use in different areas. Then, if you come to the martensitic stainless steel, the martensitic stainless steel again as the name indicates it will be having the martensitic structure, you know, microstructure. That is why they are known as martensitic stainless steel. They have high carbon to chromium ratio. So, they are hardenable type of material and they can be hardened by the heat treatment process, because of the high carbon to chromium ratio.

Then, they are magnetic in all conditions and they have the best thermal conductivity among all. Then they can be cold worked without much difficulty. Then they can have good finishing, they can have good toughness, all these properties are there with these martensitic stainless steels. If you talk about the competition, so carbon is 0.15 to 1.2%, then you have silicon as 1%, you have manganese again as 1%, and chromium is from 11.5 to maybe 18%.

So, this way, quite high value of carbon to chrome, 0.15 to 1.2, so that is there. They are used in pumps and valve parts and used for turbine buckets. So, these are the special usage of different types of stainless steels.

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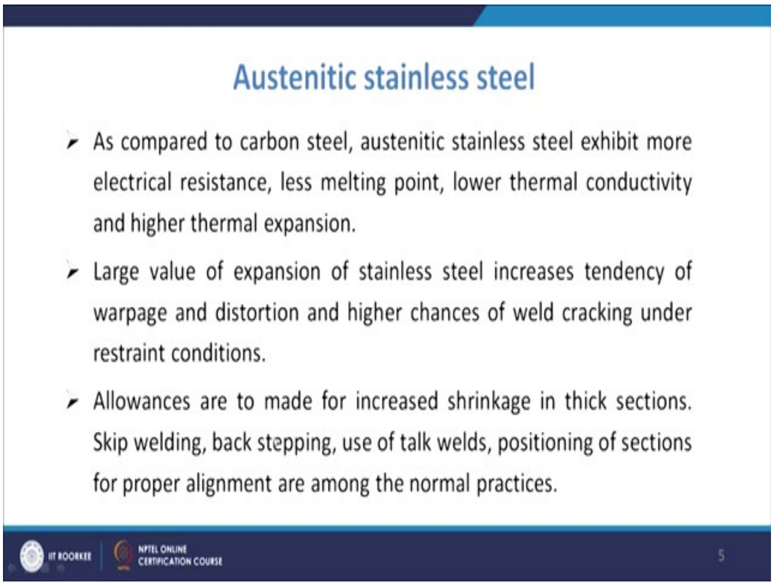

Now, we are coming to the austenitic stainless steel. As compared to carbon steel or austenitic stainless steel has more electrical resistance. So, basically, the electrical resistance is six times more than carbon steel. Similarly, it has less melting point than carbon steel. It is normally close to 90 to 100 °C lower than the conventional carbon steel. So, it has less melting point.

It has lower thermal conductivity, about 50% low value of the thermal conductivity is there. But it has very high thermal expansion about 50% higher thermal expansion is there in the case of austenitic stainless steel as compared to the conventional carbon steel. Now, because of these properties, what is happening is if you take these three properties like the electrical resistance which is quite high, so you will have more heating possible if you use electrical means to heat.

Similarly, less melting points certainly you again require less heat, and then low thermal conductivity, so heat dissipation will be less. So, all these three points they will give you a good condition for lower welding current requirement in the case of austenitic stainless steel. Then, higher thermal expansion if you look at this point, so that is certainly a disadvantage; because of the higher thermal expansion it will have the tendency of warpage and distortion.

And it will also have higher chances of weld cracking under restrained conditions. Because of the temperature variation you have more expansion or contraction going on. In those cases, the chances of weld cracking under that restraint is higher. So, allowances are to be made for the increased shrinkage in the thick sections because you have quite a large thermal expansion.

So, especially in the thick section you will have to have precautions by taking the allowances. So, that basically will diminish the probability of having defects related to these large expansion in the case of welding. The points which are to be taken into consideration at that point will be like you use the skip welding technique, that is what we have discussed earlier, you can use the back-step procedures, you can have the welding in the back-step directions.

Then, use of tack welds, you can have the use heavy tack welds or you can use the heavy and frequent tack welds, positioning of sections also so that the contraction which is there that puts them into alignment. So, all these are the ways basically to account for or to take care of the increased shrinkage probabilities in thicker sections.

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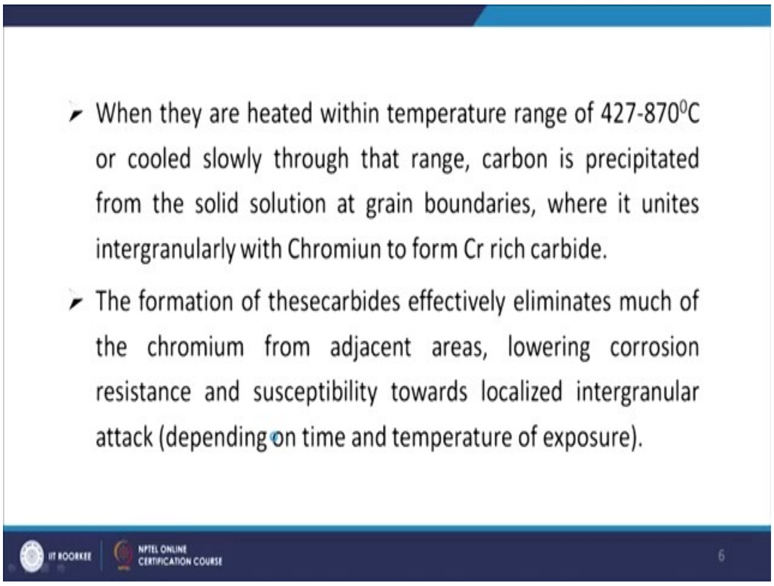

When they are heated in the temperature range of, say, 427 to 870 °C, or in fact cooled even through that range, in that case, the carbon is precipitated from the solid solution at the grain boundaries. That is one thing which is important because the carbon which is precipitated you will have the depletion also. You have the chromium carbide formation and then accordingly the chromium which is primarily used for the formation of chromium oxide will give you the stainless properties.

So, in those cases, carbon is precipitated from the solid solution at grain boundaries and there it will be uniting intergranularly with the chromium again to form the chromium rich carbide.

So, basically, you will have formation of chromium rich carbide instead of having chromium oxide. So, formation of these carbides effectively eliminates much of the chromium from the adjacent area. That is what it normally does; if you have the formation of chromium carbide, you will have depletion of chromium oxide.

Once you have the depletion of chromium oxide, then you will have lowering of the value of the corrosion resistance, and also you have susceptibility towards localized intergranular attack that will be depending upon the time and temperature of the exposure. So, that is what normally happens when you have susceptibility, when you are passing through that temperature range.

In those cases, this is likely to happen and it will also be depending upon the time and temperature of the exposure. So, what we do is normally for avoiding these carbide precipitation during the welding of austenitic stainless steel, we can have certain ways we can adopt to have control on the carbide precipitation.

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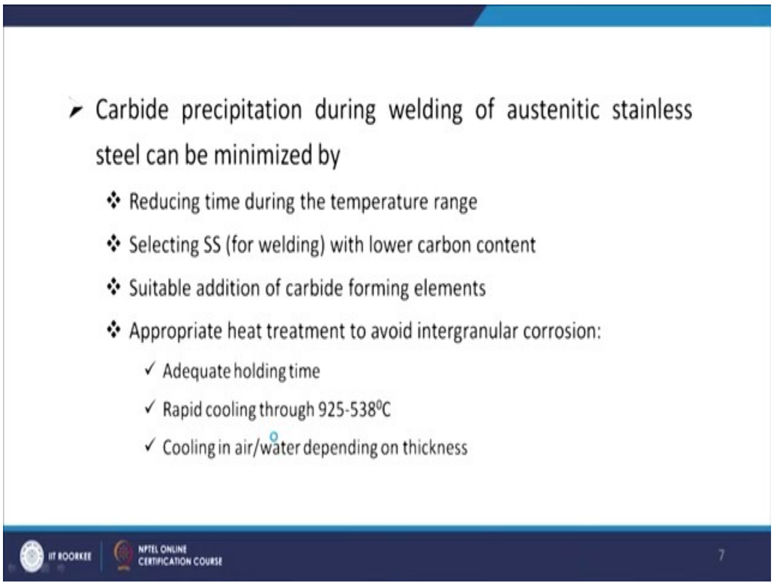

So, first is that you reduce this time during this temperature range, temperature range which is there like 427 to the 870 °C temperature range is there. So, in that temperature range you have to reduce that time. So, you can have lower heat input into that or may be you can go for rapid cooling through that temperature range. So, basically, that will avoid the formation of these chromium carbide.

Then, you have the selection of the stainless steel with lower carbon content because if the amount of carbon will be lower, the chances of chromium carbide formation will be smaller. So, that is another way that you will have control on the carbide precipitation. Then you can have the addition of different elements also which can control the carbide formation and certainly by adding those elements which have very strong carbide forming tendency.

That will help. For that, we take different types of elements which are very strong, you know, carbide forming elements like titanium is there, columbium is there, so all these elements, or we can use tantalum. So, these are strong carbide forming elements, so we use them so that instead of chromium carbide you have the formation of those carbides and you have still the availability of chromium to have the formation of chromium oxide.

So, that is another way to have the avoidance of the carbide precipitation. And then, you can have even the appropriate heat treatment process you can use which will reduce the susceptibility to have intergranular corrosion. So, because of that what will happen is that there will be complete solution of these carbides and then you can have the heat treatments, that will be kind of annealing heat treatment where you can have maximum corrosion resistance.

So, for that, what is done is normally you are heating the weldment between 1040 to 1120 °C normally. So, you go and heat between that temperature and you have to have adequate holding time, may be one hour for every 25 mm of section thickness, and you cannot have less than half an hour of holding. So, that is your adequate holding time that should be there.

Then, you go for rapid cooling through this temperature range of 925 to 538 °C, in that you are going for rapid cooling to hold its carbon in the solution. Then, you are also cooling in the air or water depending on the thickness. So, when your thickness is less, in that case you can cool in the air and if your thickness is more than that, in that case it can be plunged into water or spray cooled. So, this way you will have control on the carbide precipitation during the welding of the austenitic stainless steel.

Apart from that, you have many other processes by which you can do the welding of these austenitic stainless steels. You have techniques like austenitic welding, you can go for arc welding, all the type of arc welding can be used satisfactorily for this purpose, you can use the resistance welding and all other welding processes can be used satisfactorily for this material.

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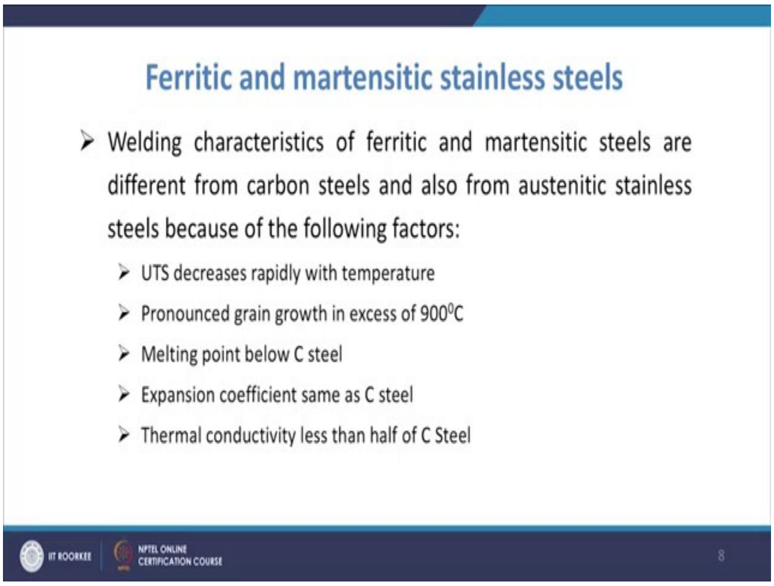

Now, we will come to the weldability aspects of the ferritic and martensitic stainless steels. We have talked about these three kinds of steel and welding characteristic of the ferritic and martensitic steels are different from the carbon steels and also from the austenitic stainless steel because of certain factors like you have, there seems to be decrease in the UTS, ultimate tensile strength more rapidly with the temperature.

Then you have pronounced grain growth when your temperature is going in excess of 900 °C. Then melting point is also below the carbon steel. And expansion coefficient of these steels they are same as the carbon steel. So, here what you see is that, in those cases, for austenitic stainless steel the expansion coefficient is quite high, whereas for the ferritic and martensitic stainless steel you have the expansion coefficient which is same as that of carbon steel.

And then, if you talk about the thermal conductivity of these steels, they are less than half of the carbon steel. That way, if you talk about this, electrical resistance is also more than that of carbon steel. So, basically, because of these effects what you see if you talk about the effect of these points, so in the case of ferritic and martensitic stainless steels what you see is that less heat input is there because of the same characteristic as that of austenitic stainless steel.

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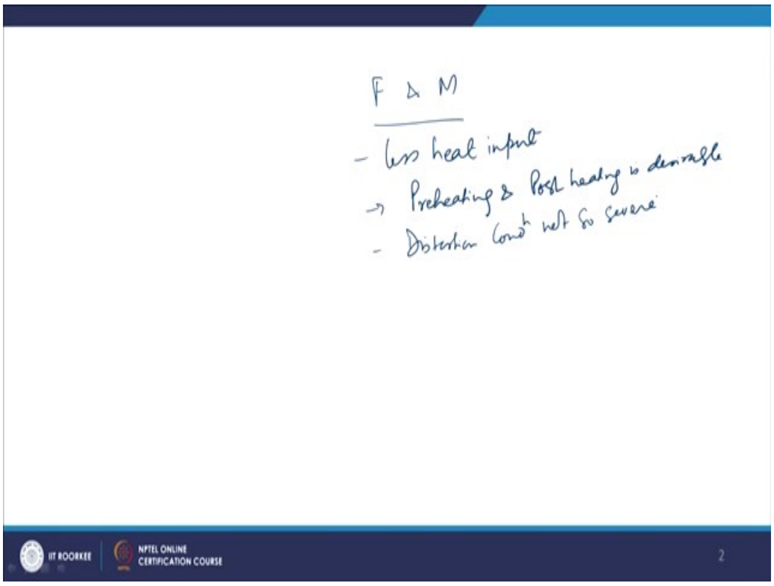

So, less heat input is required. Then, preheating and post weld heat treatment is very much desirable, because there is also grain growth going on, so those things are to be taken care of. And distortion condition is not so severe, it is not as high as that of the austenitic stainless steel. So, these are the traits of these steels.

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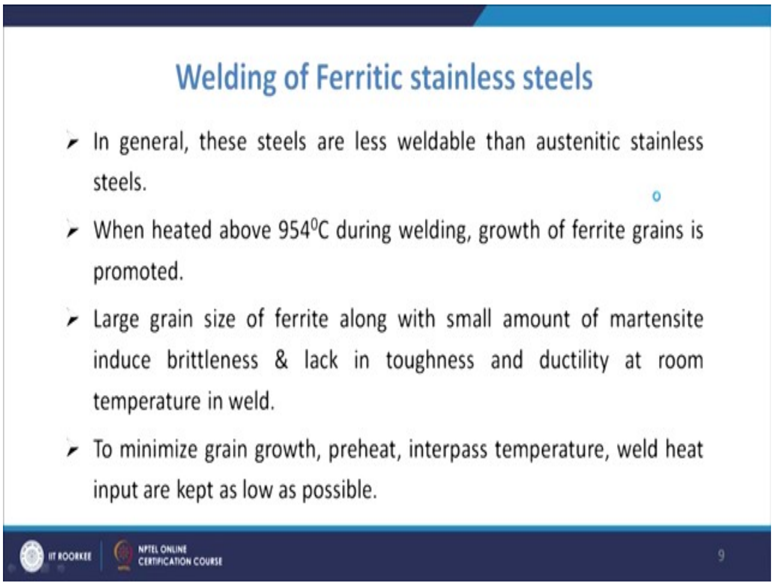

Now, coming to the welding of the ferritic stainless steel, in general, these steels are less weldable than the austenitic stainless steel. When they are heated above 954 °C during welding, then actually growth is very much a matter of concern in this kind of materials. So, here the growth of ferritic grain is promoted and what we see is that these larger grain size of the ferrite along with small amount of martensite also that is formed because of the cooling conditions.

So, that will induce brittleness. And then, there will be lack in toughness and ductility at room temperature in the weld is observed. That is one thing which is normally observed in the case of this kind of steel. So, what we do is, for minimizing this grain growth, we keep the preheat and interpass temperature which is normally used, we try to keep that as low as possible, so that is what we do.

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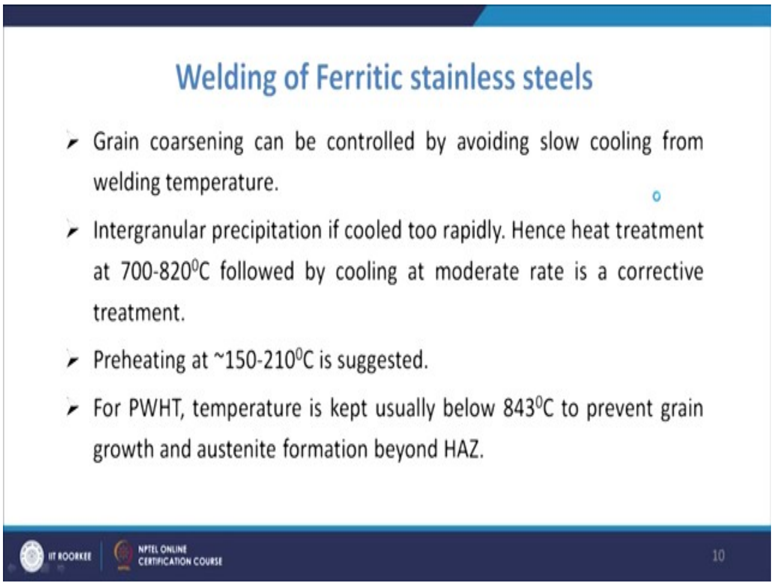

Grain coarsening can be controlled by avoiding slow cooling from the welding temperature, we have the intergranular precipitation if cooled too rapidly, that is if you do the cooling too rapidly, then there may be intergranular precipitation. So, heat treatment from 700 to 820 °C, so from here you must go for moderate cooling for avoiding that intergranular precipitation.

Then, preheating at about 150 to 210 °C is suggested and for the post weld heat treatment temperature is generally kept below the 843 °C to prevent this grand growth and austenite formation beyond the heat affected zones. This kind of precautions are taken in the case of ferritic stainless steels.

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Welding of Martensitic stainless steels

- During welding, when martensitic stainless steels are heated, austenite forms which subsequent to rapid cooling generated large amount of transformation stresses.
- Chances of cracking because of low value of thermal conductivity (especially in brittle microstructure formed by rapid cooling rate).
- For reducing transformational stresses and to increase toughness and ductility, preheating and PWHT is suggested.

If you come to the martensitic stainless steel which have martensitic type of structure at room temperature, here the problem is that when you are heating these steels, austenite will form and if you are going for further cooling, in that case, because of the austenite transforming to martensite you will have transformation-induced stresses formed. That is one aspect, and also it has very low value of thermal conductivity.

So, you will have the chance of cracking especially when you have brittle microstructure which is found because of the rapid cooling rate. So, this is possible normally in this kind of steels. So, what we do is, for reducing the transformational stresses and to increase the toughness and ductility we preheat also and also we go for post heat of these materials. Most commonly what we do is you are preheating about 150 to about 260 °C.

So, that is normally the preheating and for post weld heating you go from about 750 °C to that temperature and then holding there for about one hour per 25 mm section thickness and then further you are cooling slowly at the rate of 10 °C/h. So, that way you are cooling up to close to 600 °C and then you are cooling in the air. So, that kind of post weld heat treatment you are doing in these cases.

So, this is roughly the welding characteristic of these materials and you can have the use of different processes like TIG, MIG, you have the SMAW processes are used, you can use submerged arc, you can use the resistance welding processes for these steels. So, that is about the weldability aspect of the different types of stainless steels. Also, we talked about the SSLA steels. Thank you very much.