Weldability of Metals
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Lecture - 36
Weldability of Martensitic Stainless Steels - II

Hello, I welcome you all in this presentation related with the weldability of metals and you know we are talking about the weldability of the stainless steels and we had talked about the general properties of the stainless steels and the common different types of the stainless steels like martensitic stainless steel, ferritic stainless steel, then austenitic stainless steel and precipitation hardening stainless steel.

Now we have also talked about some of the important chemical compositions and the physical properties and metallurgical properties related with the martensitic stainless steel.

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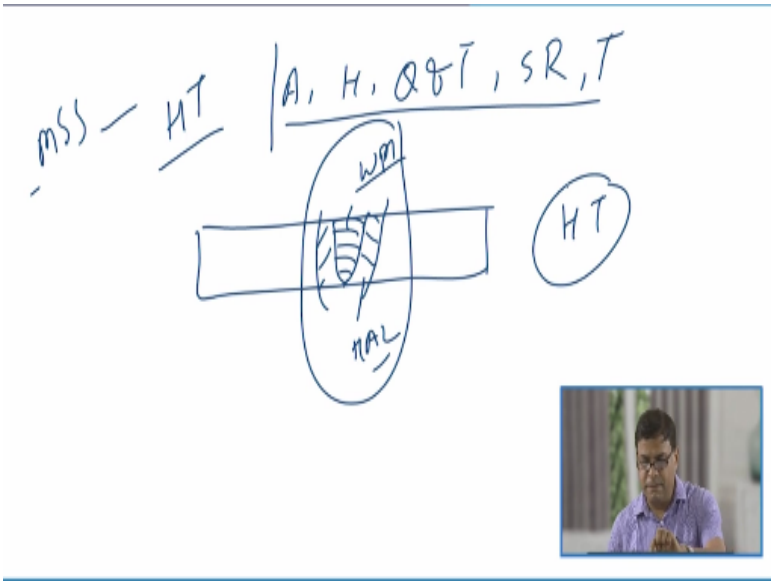

As far as the weldability of the martensitic stainless steel is concerned like the MSS can be welded in any condition. Like the martensitic stainless steels can be available in the any condition in the hardened condition, like quenched condition, or in the Q&T conditions, stress relieved conditions or simple tempered conditions. So these are various heat treatment conditions.

So whenever the MSS is welded in any of these conditions, we notice that the properties of the weld metal as well as the heat affected zone HAZ are not appreciably different. So the almost similar kind of the properties are realized irrespective of the heat treatment condition. So what we say that the heat treatment condition of the martensitic stainless steel does not affect the weldability aspects appreciably.

And therefore apart from the heat treatment condition we need to look for the different aspects affecting the weldability of the martensitic stainless steel.

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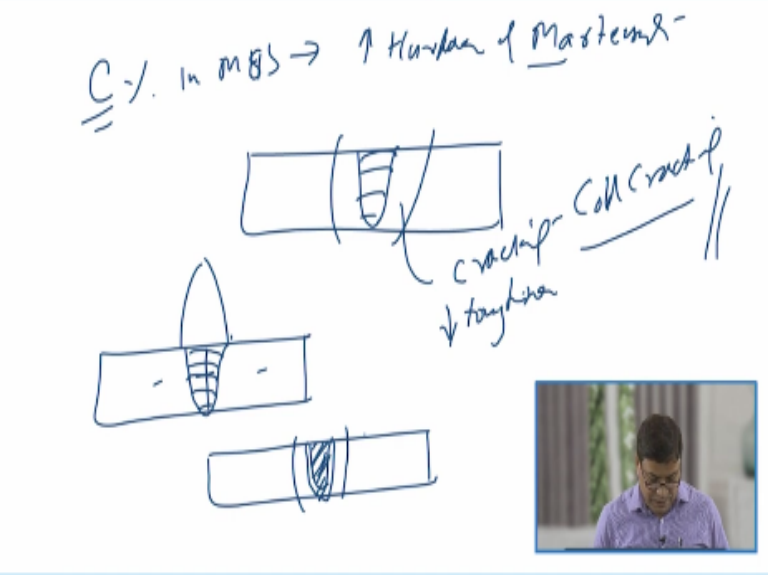

And among this what we notice especially when the carbon content, carbon percentage in MSS is high, then it leads to the increased hardness of the martensite which is being formed. And increased hardness of the martensite which is being formed in the weld as well as heat affected zone, this increases the tendency for cracking especially the cold cracking tendency is increased due to the martensite formation.

At the same time, formation of the hard martensite in the weld as well as heat affected zone decreases the toughness and this may lead to the reduced resistance to the impact load conditions of the martensitic stainless steel weld joints. So these are the kind of

situations which may arise especially when either we are using the matching kind of the filler or autogenous weld is being used.

So matching filler means the weld metal is similar to that of the base metal or when the autogenous weld is being made then just a fusion of the faying surface is realized and subsequently on the solidification we get the weld joints. So in both the cases, the chemical composition of the weld metal is similar to that of the base metal and that is why it promotes the cracking tendency as well as the properties of the weld metal and the heat affected zone will be responding almost in the similar way.

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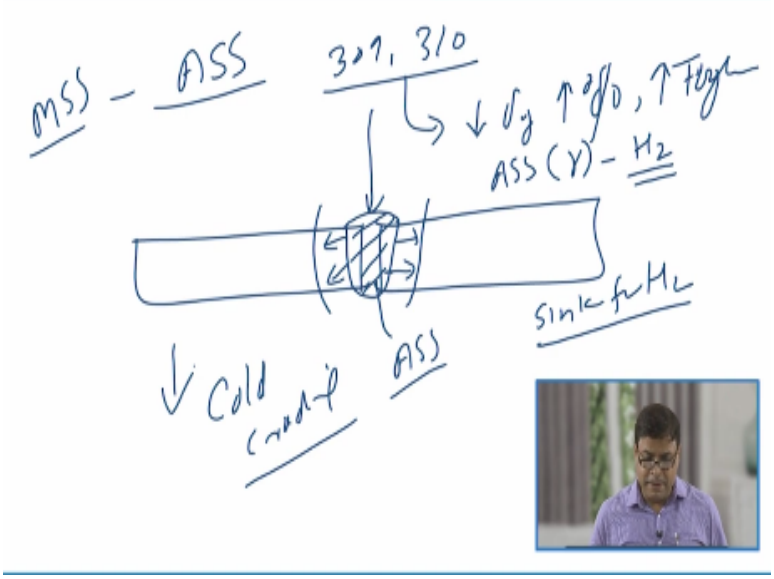

But in the situations when the martensitic stainless steel is welded using the austenitic stainless steel filler metal like we may use 309 or 310 kind of the filler metal. So since the austenitic stainless steel is of the lower yield strength, higher in percentage elongation and high in toughness. So these are the added benefits like the martensitic stainless steel plates are welded using the austenitic stainless steel filler.

So the weld metal predominantly is comprised of the austenitic stainless steel. Since it is of lower yield strength, greater elongation, greater toughness, so the chances for cracking of the heat affected zone are reduced due to the reduced residual stress formation because the weld metal is of the lower yield strength and the greater elongation. So it imposes

lesser strain in the heat affected zone as compared to the case when we had used the similar or the matching kind of the filler metal.

At the same time, since the austenitic stainless steel is having the austenite which shows the greater solubility to the hydrogen. So the ASS weld metal acts as a sink for hydrogen and it does not allow the hydrogen to get into the heat affected zone as well as in the base metal and that is why the cold cracking tendency is reduced when the austenitic stainless steel fillers are used.

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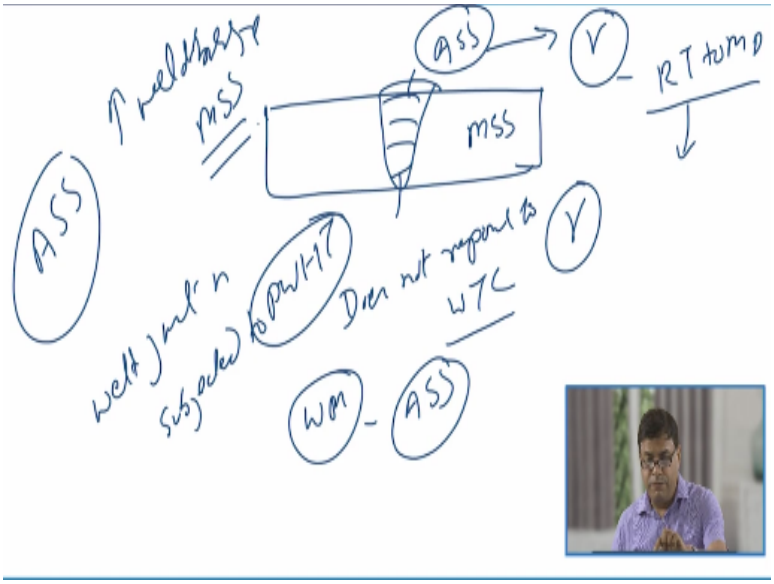

But we know that whenever the ASS is welded using the austenitic stainless steel filler like ASS and here we have MSS; so since the ASS remains in austenitic state right from the room temperature to the melting point, so despite of the higher cooling rates it does not respond to the heat treatment and it leads to the austenite even at the room temperature. There is no hardening.

So the weld metal does not respond to the weld thermal cycle and this must be assessed from the property variation point of view across the weld joint especially when the austenitic stainless steel fillers are used or subsequently the weld joint is subjected to PWHT, post weld heat treatment for improving the properties. Then the weld metal which is of the ASS will not be responding to the heat treatment.

And so these aspects must be assessed for when the filler metal is used in form of austenitic stainless steel. In general application of the ASS improves the weldability of the martensitic stainless steel.

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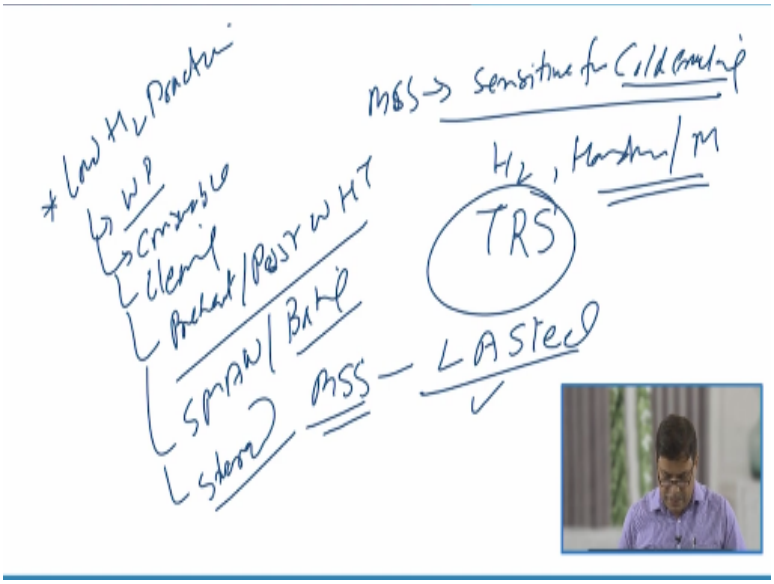

And if we do not use this kind of the filler metals then we will find that MSS is sensitive for cold cracking due to the high hardness and presence of the hydrogen; high hardness in form of the martensite structure, in form of martensite and the development of the tensile residual stresses. So such kind of the combination promotes the cold cracking and this kind of the cold cracking tendency in case of the MSS is similar to that of the low alloy steels.

And therefore to prevent the cold cracking in case of the MSS we will be using the similar kind of the procedures as in case of the low alloy steels to control the delayed or the cold cracking tendency and what we had in our procedural aspects like we have to use the low hydrogen practices which will include the use of the suitable welding processes which will be generating lesser hydrogen in the weld zone.

Which will be leading to the lesser content of the hydrogen in the weld zone, use of the suitable consumables in form of shielding SS or in form of the electrodes so that

hydrogen does not get into proper cleaning methods, proper preheating and post heat treatments, post weld heat treatments so that whatever hydrogen is there that gets enough opportunities and scope to escape out from the weld metal as well as heat affected zone so that the cracking tendency can be reduced.

Like say in case of the SMAW where the coated electrodes are being used so proper baking must be done and these must be stored properly before using them for the welding purpose and if these have been exposed to the humid environment before using them for the welding purpose then the baking must be applied so that the moisture from the electrode coating can be driven off.

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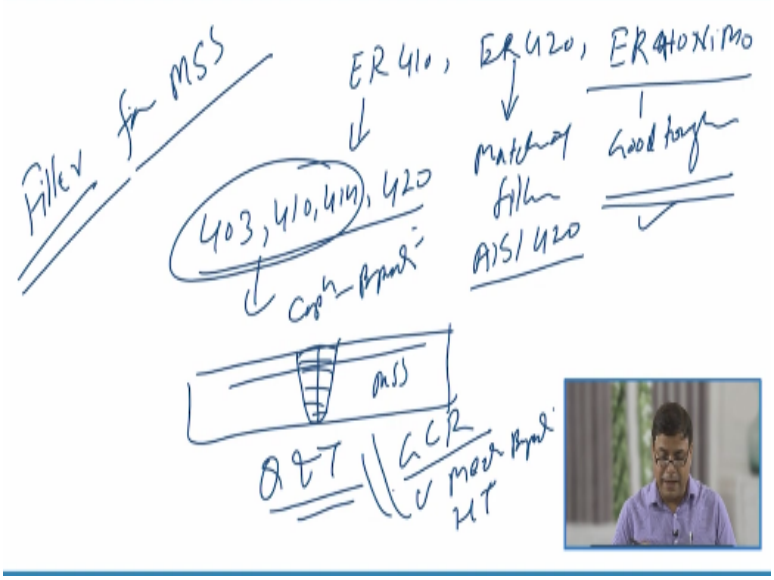

Now we will see the kind of the fillers which are used for the welding purpose in case of the filler for welding of the martensitic stainless steels. There are 3 most common types of the fillers which are used in form of like say ER 410, ER 420, and there is ER 410 Ni Mo. This particular electrode offers very good toughness of the weld metal while ER 420 is used especially when the matching filler is to be used for welding of the AISI 420 base metal martensitic stainless steel.

And the most commonly used the filler is this one ER like 410 and which is very commonly used for joining of the number of grids of the martensitic stainless steels like

403, 410, 414 then it can also be used for joining of the 420. Except this 420 the carbon content in these 3 grades is very low and therefore the issues related with the welding of these steels is not much.

When we want that the weld joint is used in as welded conditions then ER 410 Ni Mo kind of filler is used. It offers very good the toughness. While if in case of the AISI 420 martensitic stainless steel when it is welded with the matching filler, in that case the entire weld as well as base metal will be same and in that case we can apply the complete Q & T heat treatment for having the uniformity in properties across the weld joints.

So 410 in that case will be offering 420 filler for joining of the AISI 420 base metal will be leading to the uniformity with regard to the composition and the properties. And therefore whenever we need very good corrosion resistance and uniformity in mechanical properties and good response to the heat treatment then the matching filler actually helps in realizing this.

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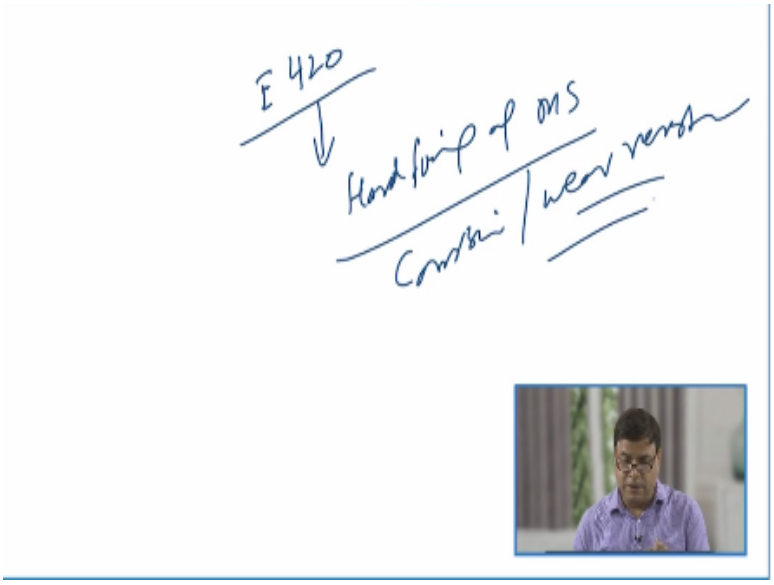

At the same time the electrode E 420 is also used for hardfacing of the simple mild steels where good corrosion as well as wear resistance is required. So these are the some of the fillers which are used for the purpose of joining of the mild steels.

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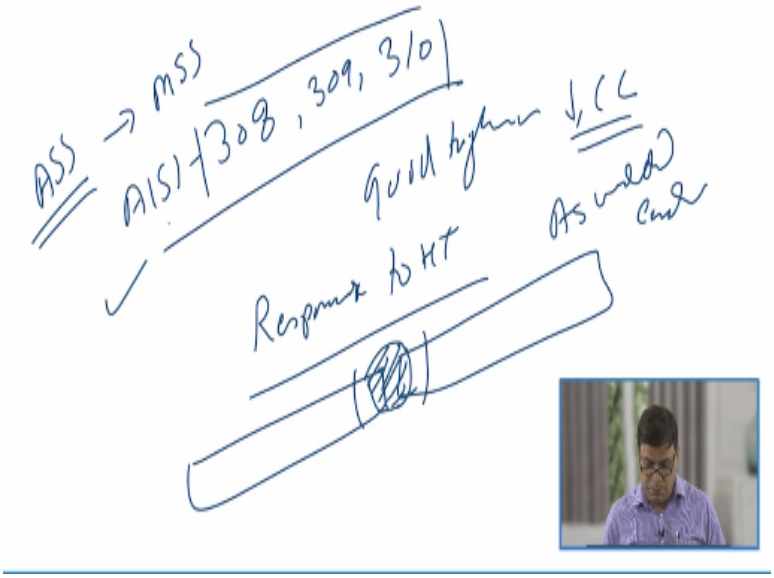

When we use the austenitic stainless steel fillers as I have said that use of the austenitic stainless steel fillers help in improving the weldability of the martensitic stainless steel because it offers the lower strength, greater ductility, greater toughness.

And it also acts as a sink for the hydrogen so it reduces the cold cracking tendency. So there are few grades of the austenitic stainless steels which are effectively used for the welding of the martensitic stainless steels and these grades are like 308, 309, 310 and all these offer very good toughness and reduce the cold cracking tendency of the weld joint.

But before choosing a particular grade we must assess the response to the heat treatment, response of the weld joint to the heat it must be assessed before it is using and these are mostly used since the austenitic stainless steel fillers do not respond to the heat treatment. So these are normally preferred when the MSS weld joint is to be used in the as welded condition.

So in that case the use of the austenitic stainless steel filler will be helping in to develop the weld joint with the minimum possible residual stresses and minimum possible tendency for the cracking due to the reduced value of the residual stresses and the reduced cold cracking tendency. So ASS fillers are used when the weld joint is to be used in as welded condition.

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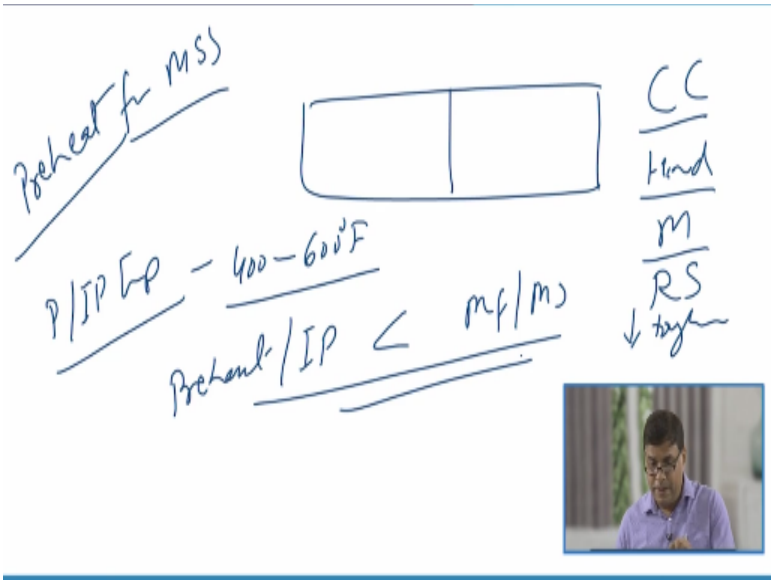

Apart from this there are other aspects like the kind of the preheat we need to use for welding of the martensitic stainless steel. We have seen that this kind of the steel is sensitive for cold cracking because of the high hardness martensite formation and development of the residual stress.

So in order to reduce the cold cracking tendency and especially the reduction in toughness of the heat affected zone it is important to use the appropriate preheat so that the cold cracking tendency can be reduced and enough opportunity for escaping of the hydrogen can be provided. So normally the preheat as well as the interpass temperature which is used for welding of the martensitic stainless steel ranges from 400–600 Fahrenheit.

We do not use the preheat or interpass temperature should be less than the MF or MS temperatures. So this is the another point which should be kept in mind while deciding the different preheat values of the temperature.

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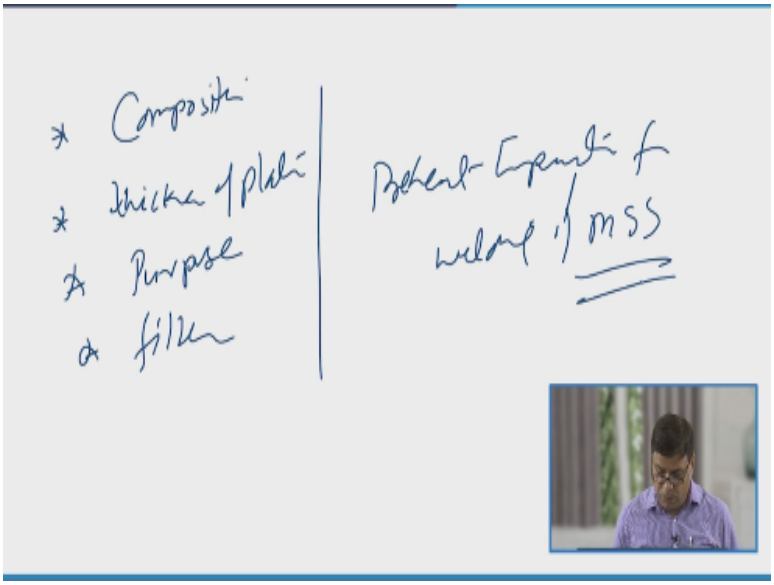

The kind of the value of the preheat to be used will depend upon the carbon content especially present in the steel so we will say that composition, the thickness of the plate or the section which is to be joined and then the purpose for which weld joint is to be used, filler which is being used, so these are the 4 important factors that will be affecting the kind of the preheat temperature to be used for welding of the martensitic stainless steel.

So now we will see that as per the thickness and as per the composition as per the purpose the different preheat temperature values are used. If we do not preheat and if we allow the weld joint to cool down directly to the room temperature then the chances for the cracking will be more.

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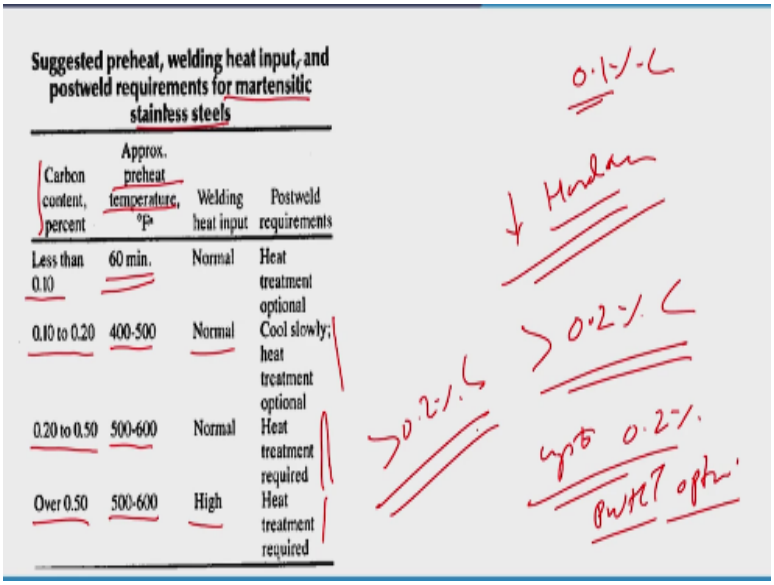

Suggested preheat, welding heat input, and postweld requirements for martensitic stainless steels

Carbon content, percent	Approx. preheat temperature, °F	Welding heat input	Postweld requirements
Less than 0.10	60 min.	Normal	Heat treatment optional
0.10 to 0.20	400-500	Normal	Cool slowly; heat treatment optional
0.20 to 0.50	500-600	Normal	Heat treatment required
Over 0.50	500-600	High	Heat treatment required

And this will happen especially when the carbon content is greater than 0.2%. So we know that if the carbon content is less like say 1% or even less than 1% then the hardness of the martensite and the hardness of the heat affected zone as well as the weld metal that will be low and less hardness will too avoid the cracking tendency. So mostly the preheat is very crucial especially when the carbon content is greater than 0.2%.

Apart from the composition, the thickness, the filler welding process and the restraint, these are the other factors that will be affecting the kind of filler to be used. So this table is showing the kind of the preheat temperatures to be used in Fahrenheit, preheat temperature to be used in Fahrenheit as a function of the carbon content present in the martensitic stainless steel, it is this.

So for low carbon content, when the carbon content is less normally the preheat is not used and we may get the successful weld joint without any tendency for the cracking. And when the so say minimum preheat is like 60 degree Fahrenheit is the minimum preheat, in any case if the ambient temperature is lower, very low then the minimum preheat of the 60 degree Fahrenheit is to be used.

And when the carbon content is in the range of 0.1–0.2% then the preheat in the range of 400–500 degree Fahrenheit is used. With a normal heat input and the kind of treatment as

far as the welding is concerned we need to use the slow cooling after the heat treatment, after the welding and heat treatment is optional. When the carbon content is in the range of 0.2–0.5 then the high preheat temperature is used like 500–600 Fahrenheit.

And in this case post weld heat treatment is important in order to relieve the residual stresses and induce the toughness and the required mechanical properties. Likewise, when the carbon content is greater than 0.5%, then 500-600 degree Fahrenheit preheat is used and especially high heat input is recommended for this case so that the cooling rate can be reduced and also the post weld heat treatment is recommended.

So they are basically, when the carbon content is up to 0.2 then heat treatment like post weld heat treatment is optional and for the carbon content greater than 0.2% in the martensitic stainless steel heat treatment is mandatory. So what are the purposes of the post weld heat treatment and the kind of post weld heat treatments which are carried out?

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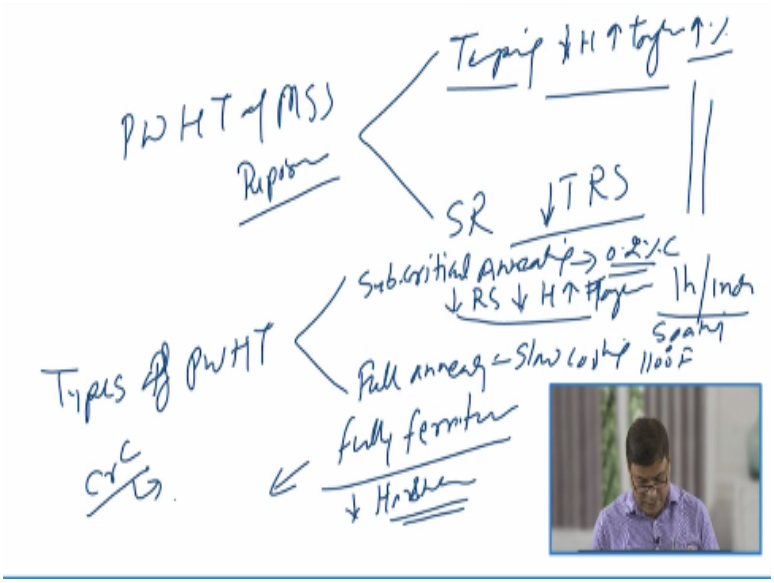

Post weld heat treatment of the martensitic stainless steels. There are two broad categories of the post weld heat treatment. One is used for the tempering purpose. So tempering will be reducing the hardness, increasing the toughness of the weld joint and improving the percentage elongation and the ability to take up the impact load.

On the other hand the residual stresses, stress relieving heat treatment is also carried out in order to lower down the tensile residual stresses if they have been developed. So these are the basically two purposes of the performing the heat treatment like improving the toughness, reducing the hardness and relieving the residual stresses. So these are basically the purposes of the post weld heat treatment.

As far as the types of the heat treatments which are, types of the PWHT which are given to the weld joints of the martensitic stainless steels, one is like subcritical annealing and the second is the full annealing. Subcritical annealing is normally carried out in the temperature range of like say 1400 – 1500 degree Fahrenheit and at higher temperature the full annealing is carried out.

Primary purpose of the subcritical annealing which is carried out for the martensitic stainless steels having the carbon content greater than 0.2% and it helps in reducing the residual stresses, lowering the hardness, improving the toughness. So these are the 3 main the responses which are realized when the subcritical annealing is performed and one hour per inch section thickness that is the kind of soaking time which is given for the subcritical annealing purpose.

On the other hand when full annealing is carried out exposure is given at higher temperature and thereafter we apply slow cooling especially up to 1100 degree Fahrenheit and thereafter air cooling can be given. And this gives us the fully ferritic structure which helps in lowering the hardness. So when increased softness is needed through the formation of the fully ferritic structure full annealing is performed.

But this process is quite long because the chromium carbide which is present in the steel it needs longer time to get dissolved to form the homogenous solid solution in the austenitic state followed by the slow cooling up to 1100 degree Fahrenheit. Thereafter air cooling can be performed.

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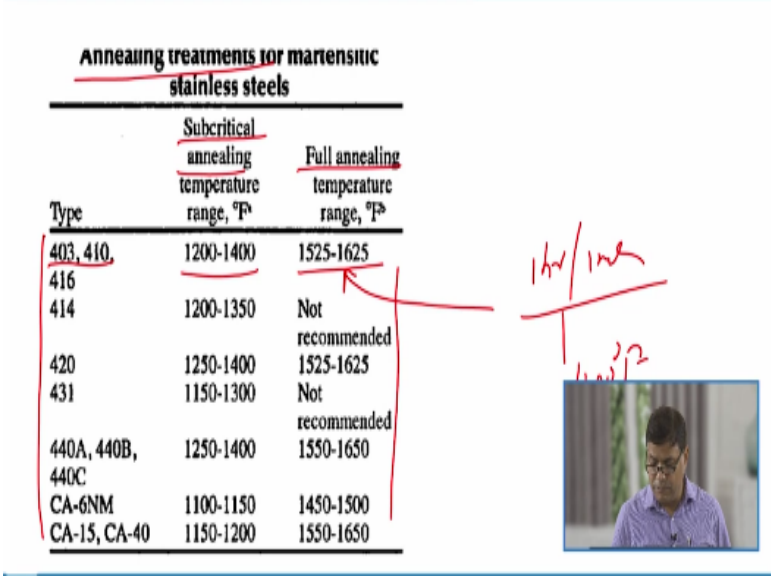

Annealing treatments for martensitic stainless steels

Type	Subcritical annealing temperature range, °F	Full annealing temperature range, °F
403, 410, 416	1200-1400	1525-1625
414	1200-1350	Not recommended
420	1250-1400	1525-1625
431	1150-1300	Not recommended
440A, 440B, 440C	1250-1400	1550-1650
CA-6NM	1100-1150	1450-1500
CA-15, CA-40	1150-1200	1550-1650

Now we will see the kind of the heat treatment conditions which are used like there are two broad types of the annealing treatments which are carried out. One is the subcritical annealing and another is full annealing. So for different grades of the martensitic stainless steel weld joints, the different temperature values for the subcritical annealing as well as the full annealing is carried out.

So the different values of the exposure, the maximum heating temperature is different for the different types of the annealing like 403, 410. Martensitic stainless steel needs the subcritical annealing 1200–1400 degree centigrade. While for full annealing it is 1525–1625. And likewise we can see there are different values of the maximum temperatures which are to be performed for the different grades of the stainless steels, martensitic stainless steels.

So for full annealing as I have said after heating to the required temperature the exposure is given at the rate of 1 hour per inch section thickness and thereafter the slow cooling up to 1100 degree Fahrenheit followed by air cooling. That is how it is performed. Now we will see there are few additional precautions which are needed when we are performing the welding of the martensitic stainless steels.

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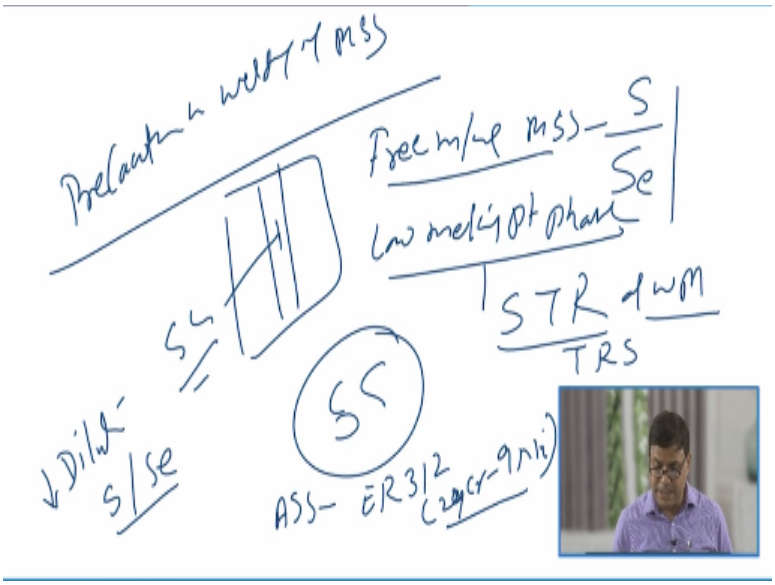

Precautions in welding of MSS: So basically these precautions fall in the two categories. One is when we are using the free machining MSS. The free machining MSS will have the sulphur or another is selenium Se and both these elements when they are present in the martensitic stainless steel forms the low melting point phases and compounds.

And presence of the low melting point phases increases the solidification temperature range of the weld metal of the martensitic stainless steel. Due to the development of the tensile residual stresses in the weld metal it shows the tendency for solidification cracking SC. Solidification cracking occurs along the weld centerline due to the presence of such low melting point phases.

So the best way is that we need to reduce the dilution so that the minimum amount of the sulphur and the selenium goes into the weld metal. At the same time use of the austenitic stainless steel filler in form of like say ER 312 having 29% chromium and 9% nickel. This helps in reducing the cracking tendency of the martensitic stainless steels of the free machining type.

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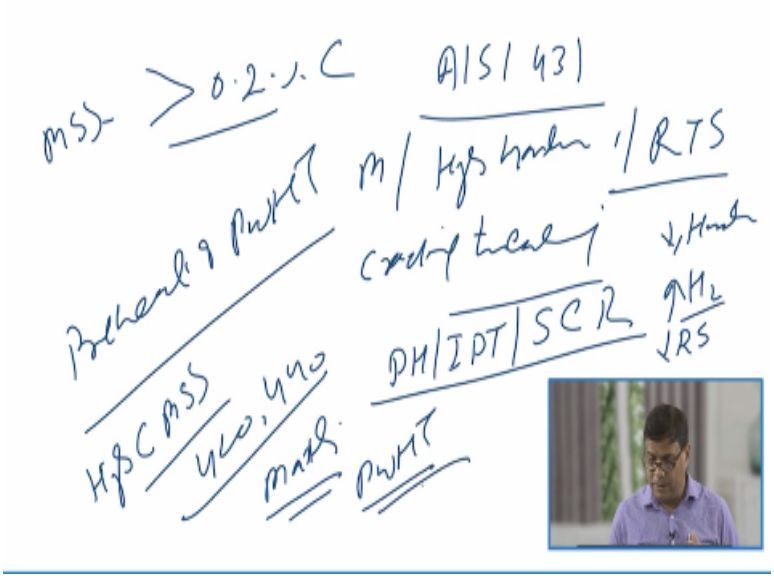

The another precaution related with the welding of the martensitic stainless steel is associated with the MSS having the carbon content greater than 0.2%. So in that case like the stainless steel, martensitic stainless steel AISI 431 type because of the higher carbon content in these grades there is increased martensite formation tendency of the high hardness.

So because of the high hardness and the residual tensile stress formation it will be leading to the increased cracking tendency. So we need to provide the proper preheat and the post weld heat treatment so that the cracking tendency can be reduced. So preheat as well as interpass temperature followed by the slow cooling rate. These help in diffusing out the hydrogen from the weld metal and heat affected zone, it will help in reducing the residual stress formation.

It will also help in reducing the hardness of the weld as well as heat affected zone and that is why it will help in reducing the cracking tendency. But further in case of the very high carbon martensitic stainless steels like 420, 440 and when the matching fillers are used PWHT becomes mandatory to avoid the cracking tendency. Now I will summarize the presentation.

In this presentation basically I have talked about the various fillers, the kind of preheat and the post weld heat treatment which is to be used for successful and sound weld development of the martensitic stainless steel. Thank you for your attention.