Weldability of Metals
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Lecture - 33
Weldability of Stainless Steels - I

Hello, I welcome you all in this presentation related with the subject weldability of metals and so far we have talked about the weldability of the different types of the steels like carbon steels, high strength low alloy steels, quenched and tempered steels, heat treatable low alloy steels and then heat resistant chromium molybdenum steels and the pre-coated steels. This classification is based on the weldability of the materials.

There is another class of the steels which are used mostly for the corrosion resistance conditions or corrosion resistant applications and this is known as the stainless steels.

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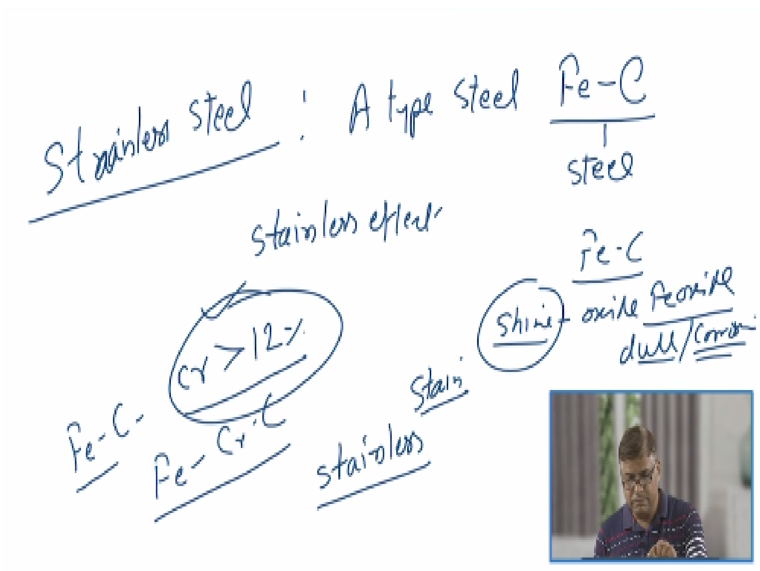

The term stainless steel is given to this category of the steels, stainless steel is basically a type of steel means which is primarily having the iron and carbon along with the other alloying elements. So these two combinations, because it is an alloy of iron and carbon, that is why it is steel. But it is a unique type of steel where the alloying concentration or alloying addition is done in such a way that it gets stainless effect.

Normally, the simple steels which are having primarily carbon and chromium only, these steels they lose their shine due to the oxidation. Iron oxides are formed and which makes its surface dull and which does not look nice also. And another aspect is that whenever such kind of the simple carbon steels or high strength low alloy steels, Q & T steels are exposed to the corrosive environment they tend to get corrode rapidly.

So the shining is lost due to the development of the various stains on the surface of the steel. But in a category of the steel where apart from the iron and carbon when the chromium content is above 12% then steel gets stainless effect. Means whatever steel is developed with the addition of the chromium and carbon in such a way that chromium content is greater than 12% the steel is not subjected to such kind of the oxidation where it loses its shine.

Which means it remains stainless and that is why it is called stainless steel and this happens primarily when the chromium content in the steel is greater than 12%.

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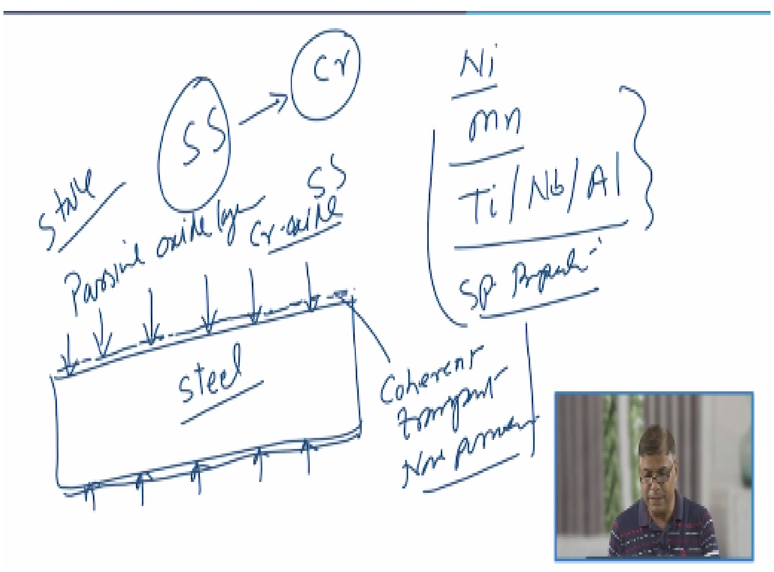

And this can happen means the stainless steels apart from the chromium can have the other alloying elements, maybe in form of nickel or manganese or like small concentration of the elements like niobium, titanium or aluminium. These additions are made to realize the specific set of the properties in the steel so that the suitable purpose using that type of steel can be realized.

So in order to impart specific set of the properties to this stainless steel certain controlled alloying is done. This behavior of the stainless steel is attributed to the formation of the passive oxide layer of the chromium oxide at the surface. So at the surface very thin layer of the chromium oxide is formed which is so thin that we cannot see it and it does not change the color of the steel due to the formation of this oxide.

And this layer is very coherent, transparent, nonporous and due to these properties this oxide layer which is being formed does not allow access of the surrounding to the surface of the steel. And that is why further oxidation or further effect of the surrounding on to the steel is reduced or it is eliminated. So this stainless effect will continue until this passive oxide layer is stable.

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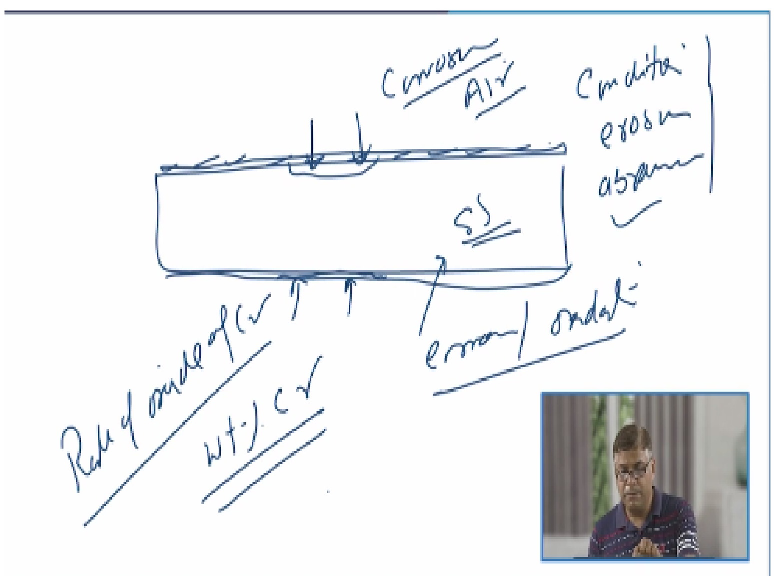

But there are certain conditions, if the steel, stainless steel has been exposed to the such kind of the conditions where this oxide layer will be damaged like erosion or abrasion conditions. So if the oxide layer is damaged, removed then that portion will be exposed to the surroundings and then it will be affected by the surrounding according to the kind of corrosive media which is present.

It may be in form of air or some specific corrosive media for which this steel is sensitive. So if the oxide layer or passive oxide layer is getting damaged and removed due to the conditions for which this kind of stainless steel has been exposed then it will be leading to the corrosion or kind of oxidation as per the environment in which this kind of the steel has been exposed.

The rate of oxidation, means how fast oxide of the chromium will be formed once it is removed or getting damaged, that will depend upon the weight percentage of the chromium present in the steel.

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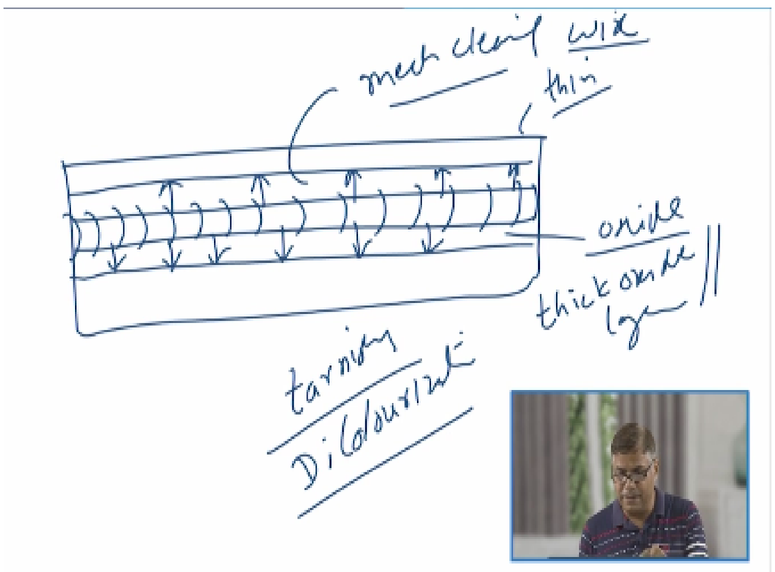

But we must realize another aspect related with the stainless steel that the stainless effect we are getting due to the formation of passive oxide layer which is very thin and almost transparent. So we are not able to see any effect of the chromium oxide layer which is being formed at the surface. But say during the heating or during the welding when the external heat is applied so zones near the weld metal will be heated to the higher temperature.

So this is the vicinity or the area which is heated to the higher temperature. So because of this the stainless steel will be getting oxidized and it will be forming a thick oxide layer on to the surface and formation of thick oxide layer due to the external heating at the surface will be tarnishing the surface or we can say will be leading to the decolorization of the surface.

So in order to restore the shining back, this additional or a thick oxide layer which has been formed next to the weld zone or next to the region whichever has been heated the mechanical cleaning using wire brush or any suitable means, this oxide layer has to be removed so that the earlier shine can be brought back.

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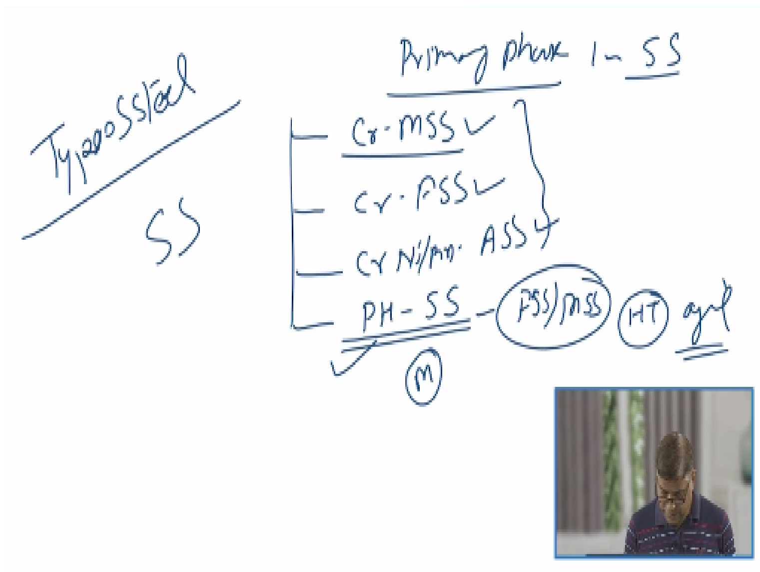

As far as the different types of the steels are concerned, stainless steels are concerned, there are 4 major groups or the classification which is based on the basically the primary phase present in the stainless steel and this classification goes in like this. The chromium-martensitic stainless steel, chromium-ferritic stainless steel, chromium-nickel/manganese austenitic stainless steel and precipitation hardenable-stainless steel.

This can be of the martensitic category or the ferritic category. So FSS or MSS category. In this case we may get the controlled formation of the martensite or some other hardening constituents due to the heat treatment or the thermal cycle being experienced or due to the ageing effect during the heat treatment. So strengthening comes from the precipitate formation or the martensite formation and in all other cases these are.

So there are 4 common types of the stainless steels, martensitic stainless steel, ferritic stainless steel, austenitic stainless steel, and precipitation hardenable stainless steels. Now we will be going through the basic metallurgical aspects related with the stainless steels.

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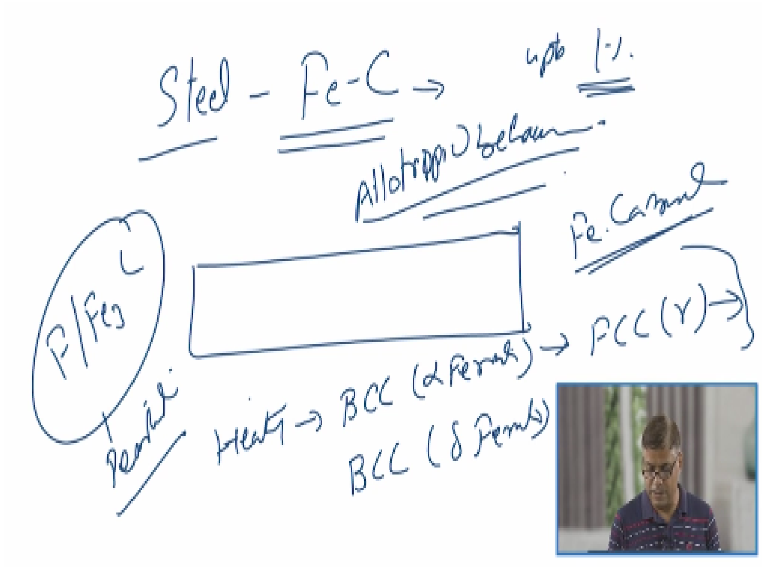

We know that in case of the steels we have iron and carbon and this carbon is up to 1% maximum. Theoretically, the carbon can be up to the 2% but beyond that it is termed as a cast iron where for most of the commercial steels have been developed using the carbon up to 1% and the steel having the carbon up to 1% when it is means the simple carbon steel having the carbon up to 1% when it is subjected to the heating either for melting or during the welding.

When heating is carried out, initially the steel which is having the BCC crystal structure in case of the alpha ferrite will be converted to the FCC crystal structure in form of the austenite and then further heating will be leading to the formation of the BCC delta ferrite in case of the very low carbon steels and thereafter as per the cooling rate the different phases can be formed.

Apart from this steel there will be other constituents like iron carbides in form of cementite is also found. So the ferrite and the cementite mixture Fe 3 C mixture is termed as perlite. So basically the steels show the allotropic behavior where there is continuous change in the crystal structure with the change of the temperature.

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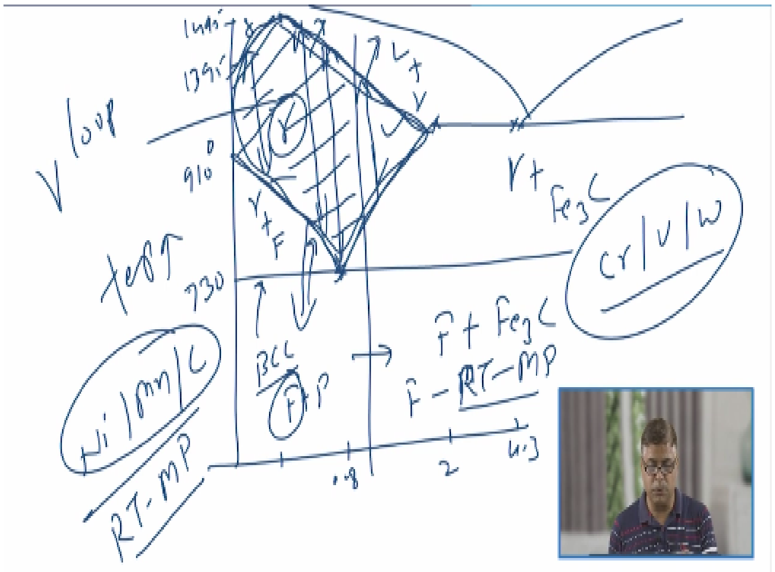

And this typical the variation we can see with the help of the simplified iron carbon diagram like say this is 0.8% and this is 2% and maybe 4.3% different points. This is another point. This is eutectic point. This is eutectoid point. So this one simple lower critical temperature line and this is like say 910 degree centigrade temperature and this is the another line. This is the another line. It will be going like this, yeah.

This is a broader structure. So we say in the Y axis we have the temperature. This is 730 degree centigrade, 910 degree centigrade, here 1395, 1495 like that those temperatures. So if we see initially we have the ferrite plus perlite which is ferrite is having the BCC crystal structure. This is the 2 phase zone where we have a gamma plus ferrite and then gamma. Thereafter we have the delta and this side we have liquid plus gamma.

And here gamma plus Fe 3C. That is the iron carbide. So this is the band where we have basically the ferrite plus iron carbide. So if we notice this, this is the kind of the zone where we get the austenite. So the kind of the temperature range in which the steel is converted into the austenite during the heating that changes as a function of the temperature. So mostly the steels will be having the 1% carbon content.

So this is the kind of the loop which we get. This loop is termed as the gamma loop. Now these boundaries of the gamma loop can move down or these can move up according to the kind of the alloying elements. So there are few elements like nickel, manganese, carbon which will tend to stabilize the gamma phase by moving these boundaries up and down and accordingly the gamma phase will be present from the room temperature to the melting point as per the percentage of these alloying elements.

On the other hand, there are few other elements which will tend to stabilize the ferrite like chromium vanadium, tungsten. These are the ferrite stabilizer. So their addition will be moving this boundary, will be contracting the size of this gamma loop; even it may eliminate. So in that case, when the chromium content and likewise other ferrite stabilizers content is significantly high.

This gamma loop may be eliminated and we may have in that case the ferrite phase from the melting point from the room temperature to the melting point. So there would not be any other phase formation.

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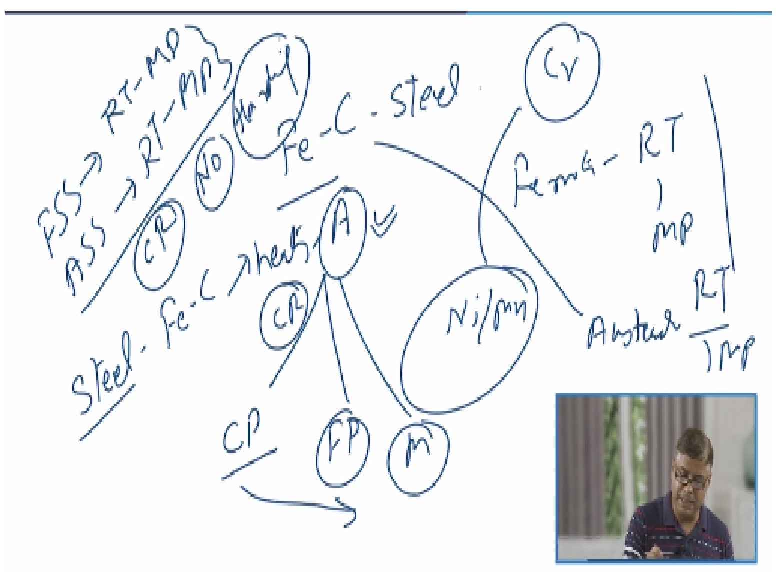

So these are the two situations as far as the iron - carbon systems in steel is concerned. When the ferrite stabilizers are present in large quantity like chromium is in larger quantity then we may have the ferrite throw out from the room temperature to the melting point while when the nickel and the manganese kind of the elements which are austenite stabilizers when they are present in the steel they will be leading to the stabilization of austenite from room temperature to the melting point.

So this is the basic part when we try to see. So the expansion and contraction of the gamma loop is influenced by the kind of the alloying elements which are present in the steel. So now we will be trying to see that you know these steels when steels having simple iron and carbon when subjected to the application of heat or austenite is formed, this austenite as per the cooling rate it may form the coarse perlite or it may form fine perlite or it may form martensite as per the kind of cooling rate which is exposed.

But this kind of the transformation of the austenite into the various phases to get the various combination of the properties will be possible due to the formation of the austenite only. But in those steels where there is no austenite formation or austenite is stable right from the melting point to the room temperature.

So in those cases, whether it is ferritic stainless steel where ferrite is stable from the room temperature to the melting point or austenitic stainless steel where austenite is stable from the room temperature to the melting point. In those cases there would not be any phase transformation whatever kind of the cooling rate is exposed from the high temperature and that is why no hardening is possible in these categories of the steels.

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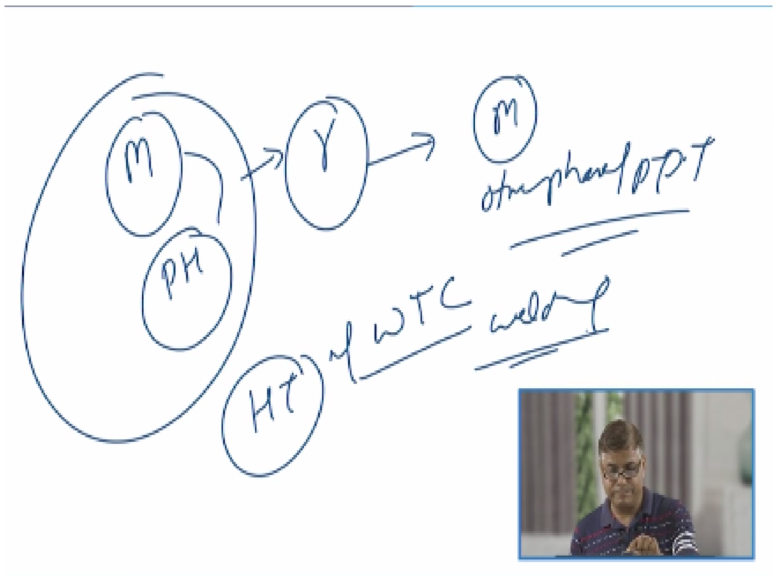

Hardening can be realized primarily in case of the martensitic stainless steels and the precipitation hardenable steels where alloying concentration is such that for a certain range of the temperature we may get the austenite and this austenite can transform into the either martensite or into the other phases or the precipitates which will be helping to enhance the strength. So these two types will be responding to the heat of the weld thermal cycle during the welding. So this is the basics related part of the stainless steels.

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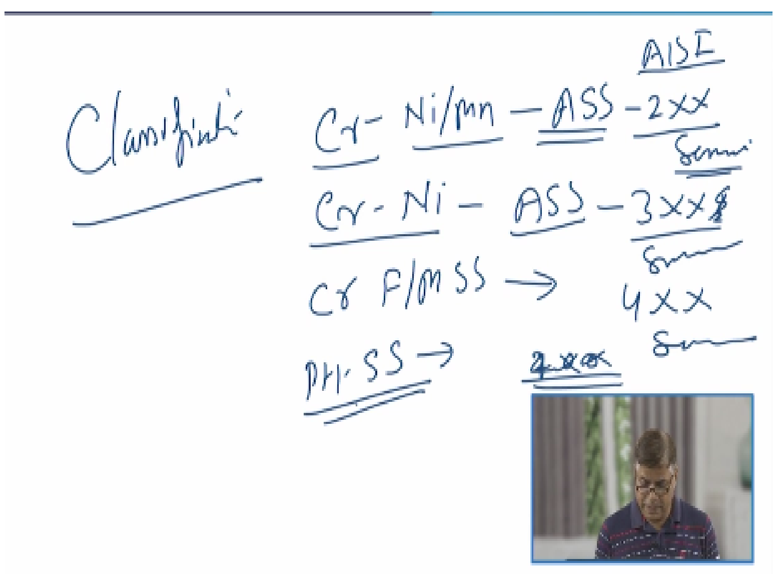

As far as the classification and designation of these steels is concerned we know that the one simple steel having the chromium, nickel and manganese this is a type of the austenitic stainless steel category designated as a 200 series, in a 200 series of the AISI, American Iron and Steel Institute designation of the 200 series for chromium, manganese or nickel combination leading to the austenitic stainless steel.

Then we have the chromium and nickel only austenitic stainless steel for 300 series of the stainless steel primarily for the austenitic stainless steel based on the chromium and nickel. Then there is a chromium ferritic or martensitic stainless steel. This is for both ferritic and martensitic stainless steels we have 400 series of the stainless steel and for precipitation hardenable stainless steel both the ferritic and martensitic classifications are applicable.

But these will be having the specific alloying elements which will respond to the precipitation hardening during the ageing process. So 400 series is applicable for the precipitation hardenable stainless steels.

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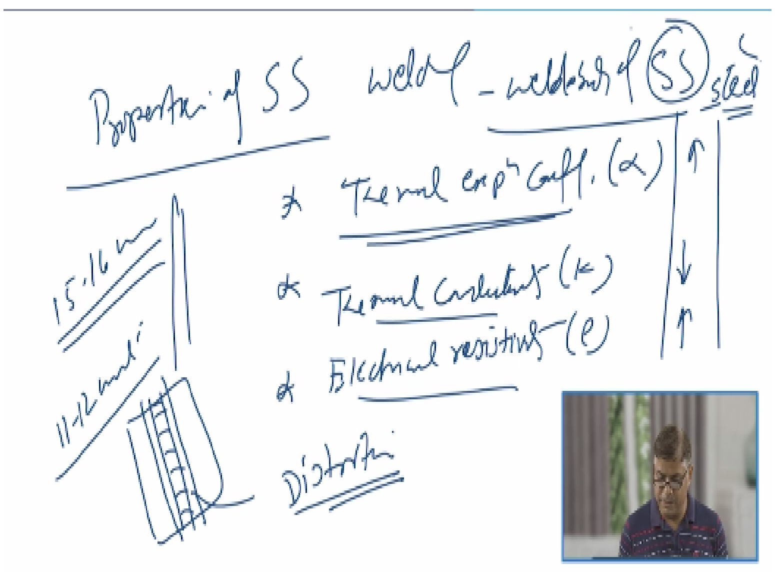

Now coming to the properties of the stainless steels, which are relevant to the welding. So there are 3 main properties which significantly determine the weldability of the stainless steel and these 3 properties are like thermal expansion coefficient alpha. And then we have the thermal conductivity and the last one is the electrical resistivity rho and k.

In general if we compare these with respect to the carbon steels, so for the stainless steel thermal expansion coefficient is extremely high. Thermal conductivity is very low and electrical resistivity is also high. So large variation with regard to the thermal expansion coefficient, thermal conductivity and electrical resistivity of stainless steel as compared to the carbon steel, this difference leads to the greater difference in the weldability of the stainless steel as compared to the carbon steels.

For example, significantly high thermal expansion coefficient like for a simple carbon steel it is normally 11 – 12 units of thermal expansion coefficient. While for the stainless steel it is like 15 – 16 units. So about 40 – 50% greater thermal expansion coefficient of the stainless steels leads to the greater expansion and contraction of the zones during the welding because localized heating is involved.

So due to the higher linear expansion, thermal expansion coefficient of the SS it will be experiencing the greater thermal expansion and contraction during the cooling phase and this will be posing the greater difficulties associated with the distortion. So to control the distortion we need extra care and precaution during the welding of the stainless steels as compared to that of the carbon steel.

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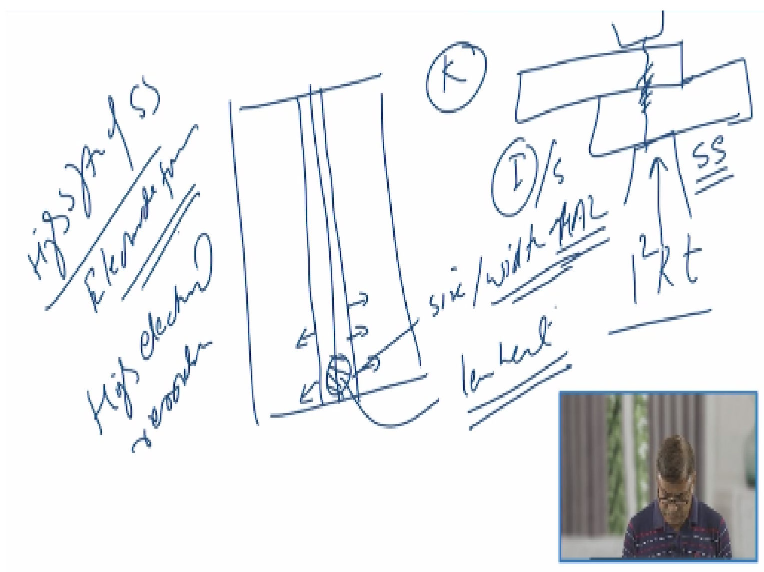

Likewise the thermal conductivity K, thermal conductivity of the stainless steels is very low. So during the welding when the heat is supplied for fusion of the, for melting the faying surfaces of the steel, due to the low thermal conductivity very less heat is dissipated to the underlying base metal and most of the heat is utilized for fusion of the faying surfaces and that is why we require less heat, for less heat to be supplied for welding of the stainless steels as compared to the carbon steels.

At the same time since less heat dissipation to the base metal takes place so the size of the heat affected zone which is measured in terms of the width of HAZ is very limited in case of the stainless steel because not much of the heat is dissipated to the base metal. So less heat input is required, less heat delivery and the less power requirement for welding is needed for stainless steel as compared to the carbon steels and lesser width of the heat affected zone.

Similarly, because of the high electrical resistivity during the resistance welding processes like in spot welding, seam welding when the current is allowed to flow through the components being joined, this leads to the under the given I square Rt heating because of the greater resistance due to the greater electrical resistivity more heat is generated. So we require lesser current and the welding is also means the time for which current is supplied is also shorter.

So the lower current and the lower welding and the supply of the current for the shorter period is needed during the resistance welding of the stainless steels. That is why the weldability of the SS by the resistance welding process is very good. But there is an issue or we can say there is another aspect because of the higher strength of the stainless steels especially at higher temperature we require the greater electrode force during the spot welding or the seam welding so that the required consolidation during the resistance welding processes can be realized.

Now I will summarize this presentation. In this presentation basically I talked about the general properties of the stainless steel and the way by which they can affect the weldability of the stainless steels. Thank you for your attention.