Welding Metallurgy
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Lecture No. 51
Introduction to Weldability of Metals

Welcome to the lecture on introduction to weldability of metals. So, weldability is a very important aspect when we talk about welding metallurgy because ultimately what we need to know is how good or in how satisfactory way the material is to respond to welding and you are going to have the desired properties of the weld.

So, basically that is a relative term. So, you can say that weldability of certain material is better or may be in certain conditions it may be good or so. So, in this lecture, we are going to have the discussion about the introduction to weldability and some introduction about how to measure the weldability, how to have the knowledge about the weldability tests.

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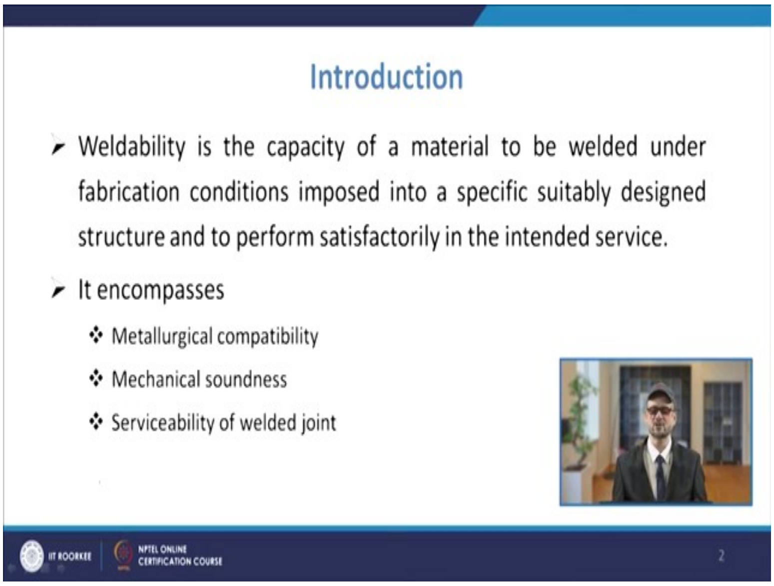

So, coming to the definition of weldability, weldability is the capacity of a material to be welded under the fabrication conditions imposed into a specific suitably designed structure and to perform satisfactorily in the intended service. So, it means that you always have the aim that the material which is welded must be welded in such a manner that it should be performing satisfactorily for the intended service for wherever you are thinking to use it.

So, if you talk about the weldability term, it will be encompassing these following things like the metallurgical compatibility. So, metallurgical compatibility if you talk, metallurgical compatibility means in welding you have the base metal and you have the filler.

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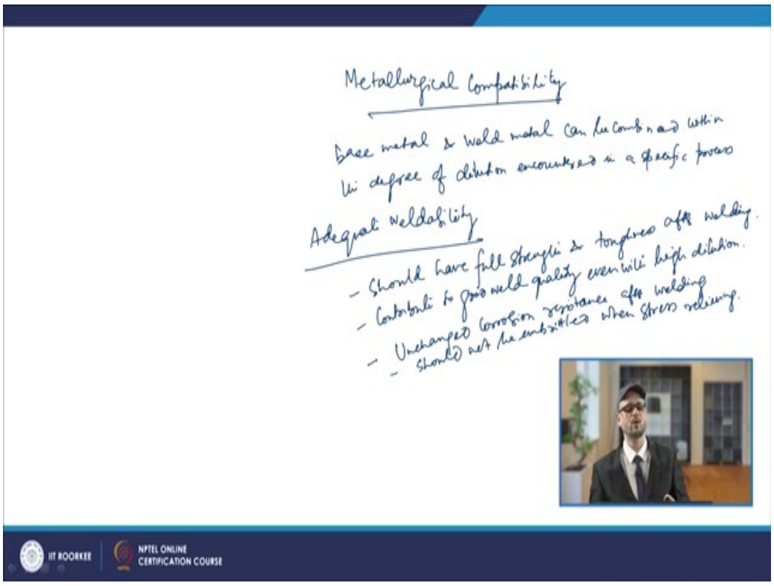

So, metallurgical compatibility means what is the degree of dilution that is possible. So, it means that the best weld metal can be combined within the degree of dilution encountered in a specific process. It means what happens is that many a times you have the base metal and you are using the filler metal and they may not be exactly having the same composition.

So, in those cases, there will be certain degree of dilution and you have that, within that there is a certain limit for a particular process so that you are getting the desired the properties of the weld. Then, the second point is the mechanical soundness. That is when you are talking about the property of the welded joint, so you always aspire to have the good soundness, mechanical soundness of the material that is good mechanical properties without much of the defects which should impair the mechanical properties.

So, it should meet the soundness requirement, whatever the soundness requirement is there, that you should have some tensile strength and some ductility and some toughness or so. So, all these things should be met. Then, the third point is the serviceability. It means the materials should be able to work under the different service conditions. So, the service conditions may be varying from, you may use it at a high temperature or you may use it even at a very low temperature, so that is your, you know, serviceability is there.

Then the structure may be subjected to impact load or may be the under the fluctuating loads. So, whatever is the criteria for the material to be used under those criteria the material must be able to be used under service. So, that is the serviceability. So, it will be encompassing these points. So, what we saw is that this will be encompassing these three points. What we see, in a nutshell, is that when we talk about the adequate weldability of the material, so, if the material has adequate weldability it means it should have full strength and toughness after welding.

So, that is related to the soundness requirement. Then, it should contribute to good weld quality even with high dilution. So, that is what the point related to the dilution that was there. So, even with the high dilution, basically, you must have good quality of weld that can you can get it. Then you have unchanged corrosion resistance after welding. Then, another point is that it should not be embrittled when stress relieving. So, these are the points which should be fulfilled for meeting that the material has adequate weldability.

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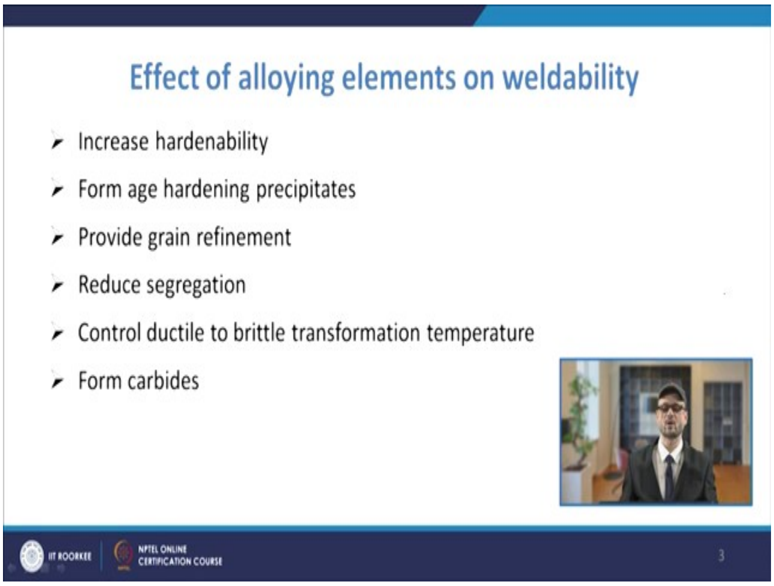

Now, coming to the alloying elements, there are alloying elements which are used in the material. Alloying elements have a say on the weldability of the material. So, the alloying elements have their roles in different ways like the increase the hardenability. Many of the alloying elements which are used they will be increasing the hardenability of the material that can be expressed even in terms of carbon equivalence, that we will see.

Then, alloying elements also are forming the age hardening precipitates, grain refinements, reduce the segregation. They also control ductile to brittle transformation temperature and they are forming the carbides. So, coming to the first point that is the effect of these alloying elements on the hardenability.

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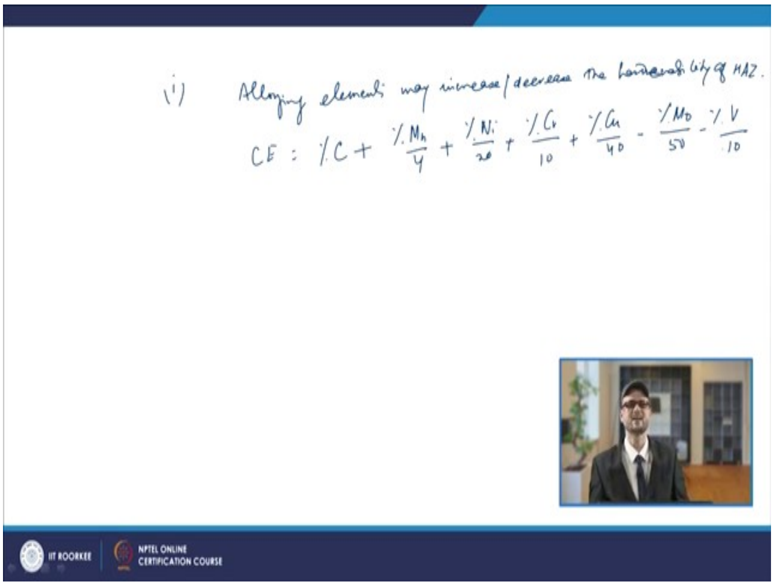

So, the alloying elements may increase or decrease the hardenability of HAZ. So, basically, you have different alloying elements and some of the elements may increase the hardenability and some of them may decrease the hardenability. If you talk about steels, then in steel we normally talk about the alloying elements like chromium, vanadium, nickel, molybdenum, manganese and so on. These alloying elements they can control the tendency of forming martensite.

And so what is happening is that according to that in that perspective these cold cracking also may be now occurring. So, for that a parameter is defined and that is the carbon equivalent and carbon equivalent is basically defined by researchers as %C + %Mn/4 + %Ni/20 + %Cr/10 + %Cu/40 + %Mo/50 + %V/10.

So, wherever you see you will have the positive terms. It indicates that it will increase the carbon equivalent and whichever has the negative term like molybdenum and vanadium we see that they are going to decrease the hardenability. Hardenability is very much dependent upon the carbon equivalent or the carbon content in fact, contribution by carbon in fact. So, we can say that these alloying elements will be there dead.

They will be affecting the hardenability of the HAZ. Then, you have other points like many of the elements they will be forming the age hardening precipitates. We have seen that when we do the age hardening, when we solutionize and then we are holding for some time. So, we get the age hardening precipitates formed and that is because of the alloying elements which are there. Then, many elements they provide the grain refinement.

So, many elements are used to act as grain refiners. By some mechanism they are working as the nucleating elements and nucleation sites and they provide the means to increase the fineness of the grain. So, mostly, apart from certain elements you have mostly the carbide forming elements also. So, you have aluminium, vanadium, titanium, zirconium, and also nitrogen, they act as grain refiners in low carbon steel and carbon steel.

So, they are working as grain refiners. Many a times these alloying elements will be reducing also the segregation. So, that is also one of the role of the alloying element. Then, controlling the ductile to brittle transition temperature. That is also because many a times we know that many metals or most of the metals may be used either in a different temperature environment.

Now, when we decrease the temperature, then at lower temperature even the ductile materials behave in a brittle manner. Now, for controlling that temperature, that also is controlled by the effect of some of the alloying elements. Then the alloying elements also are forming the substitutional alloys, then they also form the interstitial alloys depending upon the size. If you have the substitutional alloy formation, then that is using the solution hardening.

Otherwise, you have the interstitial alloys also and they will be increasing the hardness or the mechanical properties by the lattice distortion or so. So, that way, you have the carbon and boron suppose, they are having smaller in size so they will be used as the interstitial alloys and they will be increasing the strength of the matrix, as we know that when there will be transformation, because of the induced stresses the matrix becomes stronger because of the formation of martensite or so.

So, you have the chances of having strengthening because of these alloying elements. Many alloying elements are used which are the carbide formers. So, that way they improve the properties of the material. Many a times the alloying elements will be providing the deoxidation of molten metal without the loss of primary alloying elements. So, they have basically, you know, the affinity for oxygen more than iron and that is why the oxygen will be taken out, they will be absorbed by them, and they will be taken out of the steel.

So, they will be acting as deoxidizer also in low carbon and medium carbon steels. So, these are normally the role of the alloying elements, and then accordingly all these have its bearings on the weldability of the materials also. So, as we know that when we talk about the weldability we have to see a better way the material is going to behave under welding, how satisfactorily it is going to perform its job under certain specific conditions.

Now, coming to weldability, so basically, you have to assess the weldability, and for that there is weldability test.

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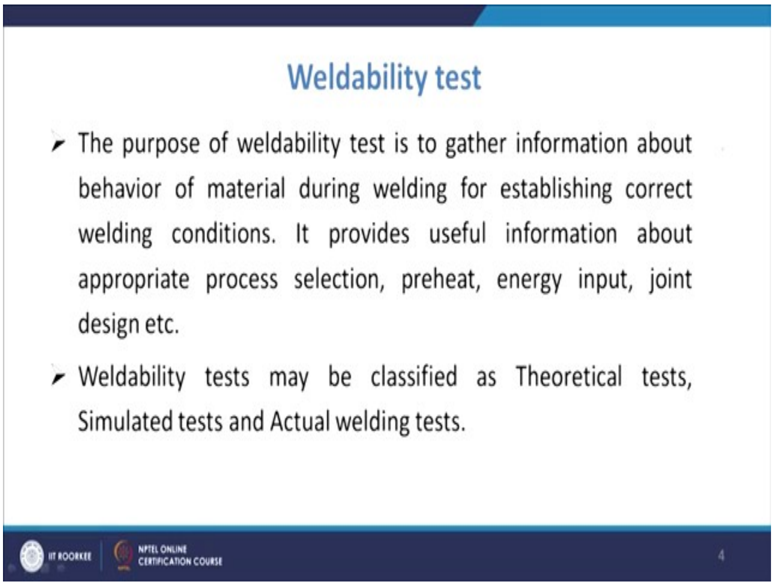

So, the weldability test its purposes to gather information about the behavior of material during welding for establishing correct welding conditions. So, basically, it will be talking about the correct welding conditions which should be there because ultimately when we talk about the welded specimen, especially when you do the welding, then you are more concerned about the weld zone and the heat affected zone.

And you see the changes, more pronounced changes in those zones. So, these zones are going to behave in a different way. They may be subject to increased strength and reduced ductility, reduced toughness or so. So, you need to basically see that under which conditions of welding how the property is going to be affected. So, basically, it will be providing useful information about the appropriate process selection.

So, once you do these tests, then it can give you the information about what will be the most appropriate selection and what should be the preheat requirement. You can do that test with different preheats, and then you can also go for different processes under different energy input conditions. Then, you can also do for the different joint designs. So, that way, you can see how this affects the weldability of the material.

Then, if you talk about the weldability, it can be done directly. You can do the test directly and then check it. Otherwise you can also do indirectly by simulating. Normally the weldability tests are classified as the theoretical test, simulated test, and actual welding test. So, these are the different categories under which this weldability is defined. So, the test is theoretical test, simulated test, and actual welding test.

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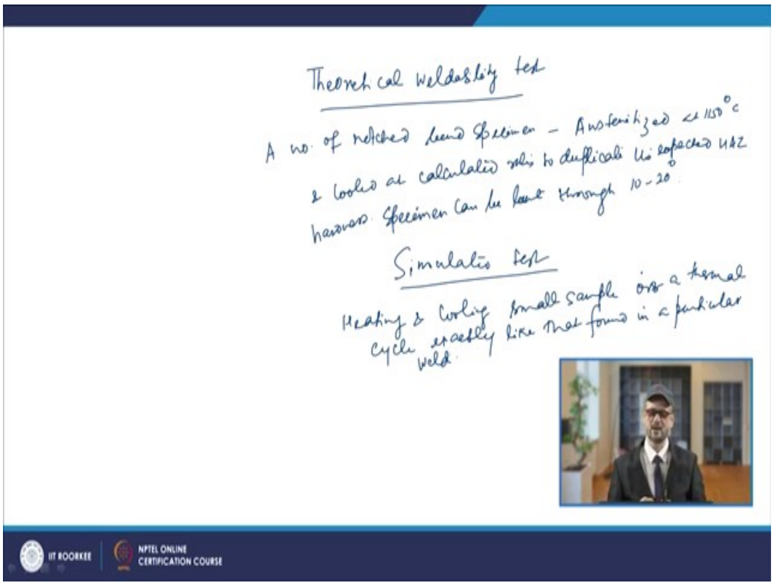

If you talk about the theoretical welding test, now what is happening is, in these cases, as we see that we can have a number of notched bend specimen and that will be austenitized. So, you austenitize them at about 1150 °C, and then you cool at calculated rates to duplicate the expected HAZ hardness.

And then what you do is you try to do the bend test, so you bend them through 10 to 20° and if it is possible to bend them, then they are said to have a sufficient weldability for a particular application or sufficiently ductile. Basically, that is how you do so theoretically you know what should be cooling rates and in that particular cooling rate how it should behave.

So, you are doing the test. Based on that, and if you feel that it is bending, so you tell that it is sufficiently ductile. Similarly, you have the simulated test. What you do is, in this case, you are heating and cooling a small sample over a thermal cycle exactly like that found in a particular weld. So, in that case, as you see, a particular weld which is undergoing that thermal cycle, in that way only you are going to use them to give that thermal cycle to that particular sample, and then you check its properties.

So, that will be the simulated test. Now, actual welding tests, what we mean to know more is about the actual welding test.

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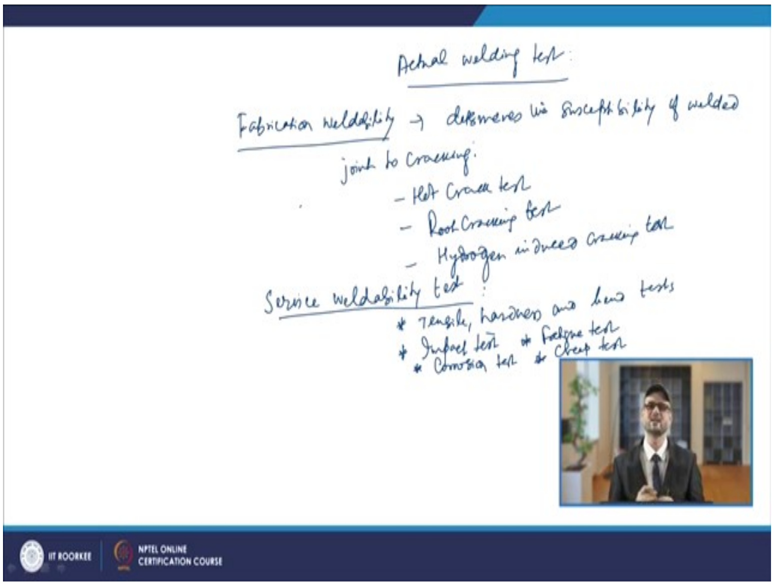

Actual welding test basically will be again of two types; one is the fabrication weldability and another is the service weldability. So, if you talk about the fabrication weldability, in that case you have the hot crack test and then you have the cold crack test or hydrogen-induced crack test or root crack test. That will be determining the susceptibility of the welded joint to cracking. So, that is your fabrication weldability.

So, that determines the susceptibility of welded joint to cracking. What we do in this case is that you have different tests, you have the joint and that joint is subjected to different kinds of tests and we see how much susceptible it is to cracking. For that we are bending or we have the different types of fixtures on which we are fixing the material, we are doing the welding, and then also we are subjecting it to either the twisting or bending or so.

And then we are seeing its behavior, that is your fabrication weldability. And in that category you have the hot crack test. As we know, hot crack test is basically done where the cracking is found because of low temperature eutectics because of sulfur and phosphorus, that we have already discussed. So, in that category, we come across the test like hot crack test, then you have the root cracking tests are there.

And then comes the hydrogen-induced cracking test or cold cracking test. These are the tests which are determining the susceptibility of the welded joint to cracking. It may be under the hot condition, may be root cracking test, or may be in the cold cracking test, as we know that is also known as the hydrogen-induced cracking or delayed cracking, that is cold cracking test. Similarly, another kind of actual welding test will be the service weldability test.

So, this test it will be a measure basically to find out the mechanical properties of the materials because ultimately when you are welding the material you have to use these as far as its mechanical properties are concerned. So, it must meet the requirements satisfactorily. So, for that, its properties should be optimum, it should have minimum amount of the properties which is required for its use in the service.

For that we do the different tests and under that, as you know, we do the tests like you do the tensile, hardness, and bend tests. You can have different tensile tests using the UTM machines or so. On that you do the test and try to have the yield strength and the ultimate tensile strength of the material to know what is its influence on the yield strength of the material.

Many a times the yield strength increases and it may decrease also, an ordinary effect on the ultimate tensile strength, that tensile graph. Then we will also talk about ductility values. So, those values you can get from this tensile test. Hardness you can have the hardness at specified locations and that will let you know the presence of undesirable phases, the hardest parts or so.

So, they will talk about these hardness or micro hardness at different locations. Then, bend tests are also carried out and it will talk about how much you can bend it without rupture. Then, apart from that you will have the impact test. So, impact test basically is very important because in case of welding it is very much expected that the toughness should not be affected. Mostly that is affected because of the grain coarsening or so.

So, notch impact test is done to measure the toughness of the material. So, that impact test is very important. Then, many a times we do the fatigue test. Now, fatigue test also is important because the material which is already under the fluctuating load conditions, now for that the fatigue properties need to be ascertained, the fatigue limit it should not be affected much. So, you may go for the fatigue test.

And apart from that, you have also properties like corrosion test you do. Then, you can go for the creep test. So, all these different tests are required to be done on the material so that you can say that the weldability is not affected or weldability is satisfactory of the material for a particular set of operating parameters or so. So, that is about this introduction to the weldability. Thank you very much.