Welding Metallurgy
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Lecture - 34
Microstructural Products in Weldments

Welcome to the lecture on microstructural products in weldments. So, in the last lecture, we talked about the properties of the heat affected zone and in that lecture we typically talked about the changes in the mechanical properties especially the hardness and the toughness which is varying towards or all along the subzones of the heat affected zone. So and typically we talked about you know the effect of the grain growth.

Because you know below the fusion line and you know as we move towards the heat affected zone, so near that you know fusion line underbead zone. So, there you have the probability of having coarsening of the grains and that affects the properties. Towards the later part, we also discussed about you know the effects which you know which are further to be kept into mind like the material may subject to aging.

So, as we know that aging is a typical type of heat treatment process which normally we refer to the you know non-ferrous type of materials; however, you know steels also are subject to aging and typically we talked about the natural aging behavior of the steels also. Similarly, you know for the austenitic stainless steels also they also undergo the precipitation hardening you know, so that is the through the formation of intermetallic you know phases.

And that is possible you know with the presence of aluminum, titanium and phosphorous type of materials.

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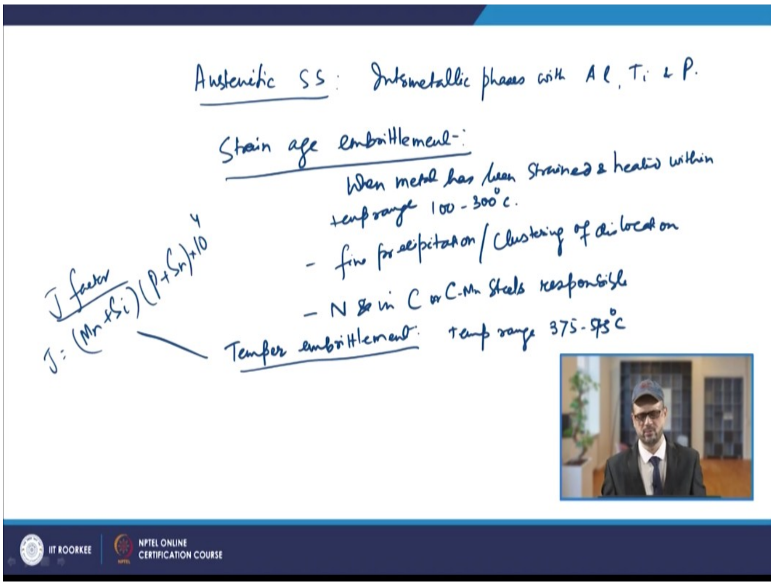

So, even in the you know austenitic stainless steel, so they are also subjected to the precipitation hardening and that is with the formation of intermetallic phases you know and that is in the you know with materials like aluminum, titanium or phosphorus. So, these steels have you know corrosion resistance compared to other you know stainless steels. So, they will be also they become normally brittle when they are you know exposed for many more hours at somewhat elevated temperature like maybe close to 300 ^{0}C.

So, normally what we do is we normally limit their use to the lower temperature range. So, basically we try to you know keep the temperature working temperature somewhat smaller in those cases. Then, another you know important you know property which has to be looked into is the strain age embrittlement. Now, this strain embrittlement it can be you know seen as the first step towards precipitation or aging you know treatment.

So, as we have studied you know earlier that in the strain aging behavior what happens that you strain and then further you reload and then of once it is heated to a certain temperature, then in that case you know all it is left for some time in that case reappearance of the yield point is phenomenon is observed that we had earlier discussed. So, you know strain age embrittlement is another possibility when we talk about these heat affected zone you know formation.

So, it is the possibility when the metal has been strained and heated with to some temperatures, so it is basically when metal has been strained and heated within some temperature range. So, that range is about 100 to 300 ^{0}C. So, basically because of this there are this is associated with the formation of very fine you know precipitation. So, this is because of the fine precipitation or you have the clustering of dislocation.

So, that has been observed when there was microscopy done. So, that was seen that when you are heating to this smaller range, then this strain age embrittlement is also observed. Now, normally the presence of nitrogen or even carbon that we have discussed that is normally responsible for this, you know strain age embrittlement. So, nitrogen is you know and carbon also, so nitrogen and carbon or carbon manganese steels.

So, that is normally responsible for strain age embrittlement behavior. Then, you know normally because of that the ductility is reduced. Now, what happens that the particles which are you know responsible that is carbonitrides or the nitrides. So you know so basically this strain age embrittlement is you know that very important to be kept in mind because that you have to avoid you know the heating you know that process.

Then, another you know property which is further important is the temper embrittlement. So, this is basically the because of the formation of you know unfavorable transformation products and that is through the grain boundary segregation and that is why in this case this is known as the temper embrittlement. So, you know this is again you know the by heating in the certain temperature range.

So, if you have the you know if the holding is there in the temperature range of maybe 375 to 500 ^{0}C, so this is being 575 ^{0}C, so this is basically the tempering temperature range as we all know. So, once you know do the tempering in this range, in that case you have the formation of you know undesirable transformational products and you know that is formed through the grain boundary you know through that grain boundary segregation.

And that basically leads to the you know decrease in toughness or increase in the embrittlement. So, basically you know this is another you know treatment which is or this is another phenomena which occurs in the case of you know that due to the thermal cycling you know treatment because when you are heating, then certain zone are heated to that temperature zone.

And then there is further cooling, so that may lead to you know these temper embrittlement you know conditions. So, basically you know plain carbon steels are highly you know susceptible to this temper embrittlement and but if you add you know 0.5% of molybdenum, it will reduce this tendency and there are certain elements also that increase also the tendency. So, you know that is like antimony, tin, phosphorus.

You know these are you know elements are basically they will be you know increasing the degree of embrittlement. So, then there are also elements which will be increasing that susceptibility you know that is to smaller extent like manganese, vanadium or Boron. So, that way you know your this type of observation is there in certain type of steels. Now, for finding this homosusceptible, it is to the temper embrittlement.

For that, there is a parameter that is J factor you know, so that J factor basically is calculated. So, this J factor calculation is you know based on the value of the alloying elements which are there and you know J factor is basically calculated, so this J will be calculated as $(Mn+Si) * (P+Sn) * 10^4$

So, basically what happens that you have a graph and that graph has on the abscissa you have J factor. So, that J value is there and you know and then you have the fracture appearance you know transition temperature that is also there you know. So, for that the plot is you know drawn and you know accordingly you can see that what way this material will have the will be susceptible towards the temper embrittlement.

Now, it is normally very much you know important when we talk about the vessels in the nuclear power or the petrochemical plants because you know in those cases you know the fracture toughness for ascertaining that you know fracture toughness values. So, in that case this J factor, this parameter is important. So, there it is normally required. So, when we have to design the vessel which is you going to be used in the you know nuclear powers or in the petrochemical sectors.

At that time, you need to you know deal with these you know terminologies. Then, the further you know the another you know terminology which will be important will be the graphitization.

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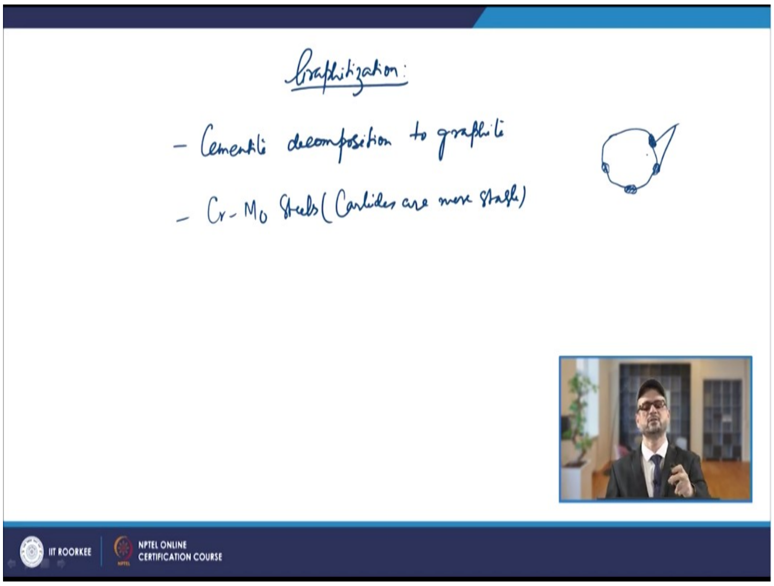

So, what happens as you know that you know in many cases the carbon may be converted towards the graphite? So, we get carbon in different form, we get carbon in combined form, we get carbon in cementite, we get carbon in graphite. So, you know so basically when you have the non-corrosive you know environment, now in that case you know the steel welds may lose the strength that is due to the phenomenon called graphitization.

So, if the steel will be held at some temperature may be something like maybe more than 450 ^{0}C for that you know for long periods of time. Then, you know cementite will be decomposed, so cementite decomposition to you know graphite. So, the cementite decomposition to graphite will lead to basically the decrease in the strength of the weld and you know so.

And what happens that you are ending up with the formation of the graphite globules you know in the low carbon matrix, so low carbon iron matrix. So, basically the breakdown of this cementite to graphite, it is basically you know, it will be promoted by the addition of you know aluminum to steel. So, we many a times we add aluminum to the steel and you know the carbon and as well as carbon and a half molybdenum steels, they are very much susceptible to this defect known as the graphitization.

So, basically what happens you have you know on the grains, you have the grain boundary, so there will be grain boundary carbides formed. So, this way you will have the grain boundary carbide formations along the grain boundaries. So, you know so what you see that in this way you have you know these are the grain boundary you know carbides.

So, these you know this will be because of the you know holding of the steel more than at about more than 450 ^{0}C for basically for higher time. So, that leads to these you know eyebrow type of graphite eyebrow type of structures this is what you get in that heat affected zone. So, now what happens that basically chromoly steels normally will not be affected you know I mean in the sense that the graphitization does not occur in the case of chrome-moly steels.

Because in the case of you know chrome-moly steals, the carbides you know, in these cases carbides are more stable. So, in these cases you know they are not basically you know affected because of you know by the presence of these you know globules of these graphite. So, this way the you know your structures are also changed.

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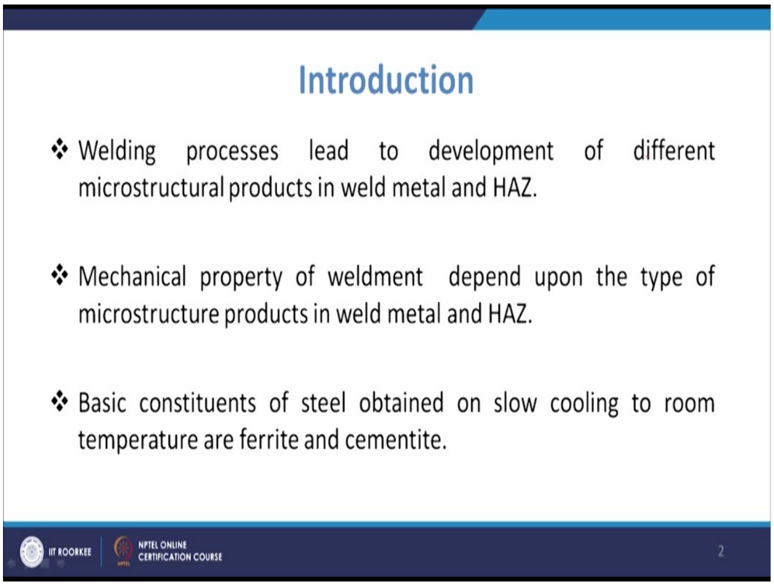

So, what we see that you know the welding processes basically lead to the development of different microstructural products in the weld metal and the heat affected zone. So, as we have seen that as it is subjected to different types of thermal you know cycling, so you have the you know production of different type of microstructural products and these mechanical properties of the weldment will be depending upon the you know type of you know microstructural products in the weld metal and the HAZ.

So, you have different you know basic constituents, which are there phases are formed you know in the you know HAZ and the weld metal zone. So, the different constituents, which are formed are many and normally your two basic constituents which are formed are the ferrite and the cementite. So, if you talk about you know the you know basic constituents so you that you have the presence of ferrite.

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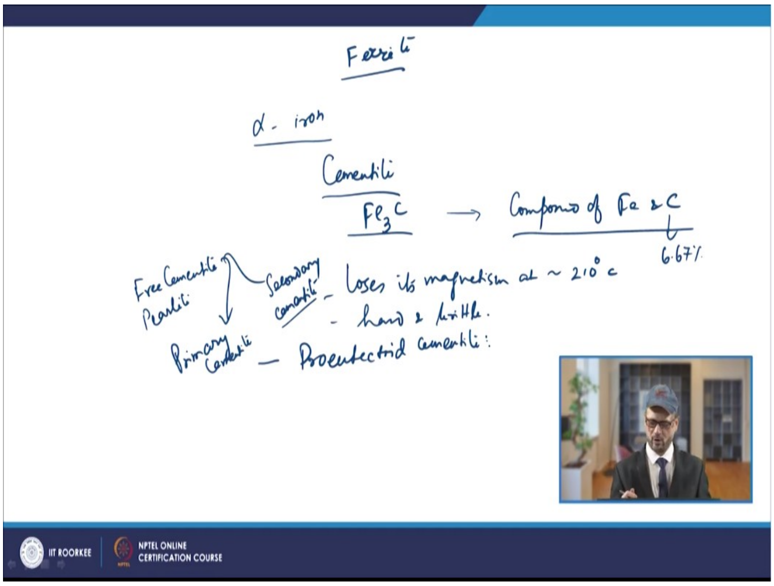

And as we know, that ferrite is in the form of you know it is also known as the α iron. So, you know this is the almost pure iron which is formed you know which is there in its case and carbon can be dissolved you know to form the solid solution ferrite you know in this case and you have very less solubility you know of carbon in the α ferrite at room temperature and it goes to very smaller value like 0.006%.

Its solubility is there at the room temperature and it will be increasing as the temperature is increased. So, at you go to 750 ^{0}C that is you know once you go to that horizontal line of lower critical temperature, so around that it will be going to somewhere close to 0.05% but ferrite has the capability that it can dissolve large number of you know second elements other than carbon to form the alpha solid solutions.

So, that way many alloying elements which we talk or second particles which are there they can be easily absorbed by the ferrite. So, if you look at the ferrite structure, if you look at the weldment structure, then you can easily recognize ferrite. So, you know for that we normally etch with suitable reagent like Nital. So, what you see is that ferrite can be seen as the polyhedral you know grains.

And they are normally regular in shape and size and you know it is normally soft, weak and ductile and also it is magnetic up to the Curie point you know of iron that is about 770 ^{0}C up to that the ferrite is you know magnetic. Now, the next you know basic you know constituent is your cementite. So, you know cementite as you know this is its composition or the formula we write it as the Fe_3C.

So, it is basically the chemical compound of iron and carbon and as we know that you know this is a compound of iron and carbon and we know that it has about carbon is about 6.67% you know and it is formed at about 1500 ^{0}C and it is the hardest constituent you know found in the iron carbon alloy. So, it is extremely you know hard. Now, it can also dissolve a wide variety of elements like manganese and chromium.

So, that way it can have, you can have the complex you know carbides. This cementite is basically losing its magnetism at about 210 ^{0}C, so and it is hard and brittle. Now, the cementite are basically present you know they can be present as free cementite or it will be or it can be laminated with ferrite you know that structure we know that that is formed at a certain reaction invariant reaction we know that eutectoid reaction.

So, there so that in that you have lamellar structure of ferrite and cementite so that way, so there it is known as the pearlite. So, you have a free cementite and you have the laminated structure so that is your combined structure that is not combined, so this is your pearlite or laminated structure. Now, if you talk about the free cementite, now free cementite also are of you know two types.

So, free cementite will be you know either, so free cementite may be you know either it may be primary cementite or it may be secondary cementite. So, when we talk about the primary cementite, so this primary cementite is basically solidifying directly from the melt and they will be occurring in the form of hard needles so that is your primary cementite and you will have a needle type of a structure that can be seen in those cases.

Now, the secondary cementite, so that is you know that precipitates in the solid. So, you know at low carbon content, the secondary you know cementite is formed and that is formed at about you know lower critical temperature that is your A_1 and it will be occurring along the ferrite grain boundaries. So, along the grain boundaries you have the formation of that secondary cementite which is formed.

And it is normally you know this type of cementite that is secondary cementite this is you know encountered in the weld metal which has very low carbon contents. In those cases, you have the possibility of formation of the you know secondary cementite. You also have another cementite that is your proeutectoid cementite. So, you know before the eutectoid temperature.

So, you know again that also is you know it forms in the solid state, so you have you know that is proeutectoid cementite. So, it will be precipitated from the supersaturated you know solid state austenite and you know that way, so it will be and at eutectoid point it will be giving you the pearlite, completely pearlite structure. So, before that you know from austenite it will be you know formed.

So, you know although this ferrite and cementite, these are the two basic constituents which have been cited but depending upon the composition and the cooling rate I mean that you know or the post weld heat treatment which we apply, you know there are different allotropic forms you know, they exist in different allotropic forms and morphologies. So, accordingly they will be influencing that mechanical behavior of the material.

So, you know depending upon the different microstructural you know phase encountered which is there in the you know welding you know the steel are basically are grouped into, so microstructure is grouped into 3 categories again.

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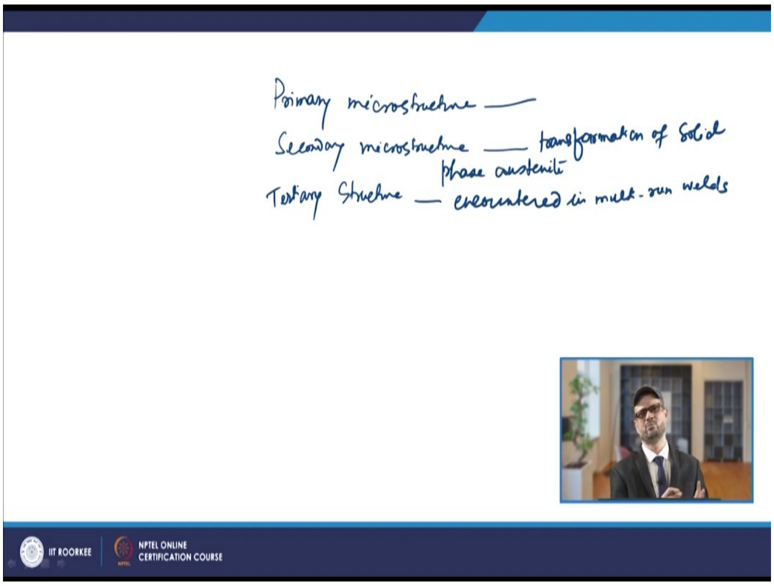

You know so you have the primary microstructure, you have you know secondary microstructure and you have tertiary microstructure and you have tertiary structure. So, if you talk about the primary structure this is obtained by the direct solidification you know of the molten metal and it will be usually resulting in the caste structure, so that is your you know primary structure.

So, as you know in this case you will have the development in terms of the columnar grains and they will be parallel to the direction of the heat flow you know or the temperature gradient as we have discussed about the you know formation of these grains and growth of these grains in the direction opposite to the parallel direction of the heat flow. So, they are parallel directions basically.

And you can also have sometimes the formation of dendritic substructures you know inside the columnar grains and you know this is normally found you know in metals without these phase transformation in the solid state like in aluminium you know primary structure is usually retained you know on cooling to the room temperatures, although you know there may be changes in the substructures upon the cooling.

Now to measure basically you know primary microstructural products are you know which are seen in the case of steel welds that is you know delta ferrite as well as the austenite γ iron, so that is normally there in the case of you know steel welds that is your δ ferrite and the γ ferrite. Then, if you come to the secondary you know microstructure, so that is formed because of the you know transformation of solid you know phase austenite.

So, this is because of the transformation of solid phase austenite okay. So, it will be transforming into different you know solid phases. So, different solid phases may be like you have the pearlite, you have bainite, you have martensite. So, then you have grain boundary ferrite, you have ferrite side plates and all that. So, transformation of this solid phase austenite into all these different you know constituents that is the secondary microstructure.

And if you talk about you know so basically you know you will have different degree of fineness and that will be affecting the mechanical properties of the material and if you talk about the secondary you know microstructure, so you know tertiary microstructure, so that is encountered in normally multi-run welds. So, you know encountered in multi-run welds. So, what happens that you have one you know first run and second run and that way you have successive run of welds is run weld is going on.

So, because of that the previous you know run of the weld which is there, it is further heated to the austenitic zone and then you have the product of different you know fineness that will be formed and that will be affecting the you know properties of the material. So, you know that is because of the normalizing effects because the product which has been there, so that is further subjected to some treatment.

So, that way you have different types of you know structures of different fineness and different properties are formed. So, apart from that you know you have also different as we talked you have the formation of the delta ferrite or austenite which is there a part of the you know secondary structure and we need to understand you know the formation of these or we need to be you know conversant with these phases which are formed you know in weld.

Because these phases, you know by looking at the structure or microstructure, you can have the analysis and you can you know do the proper justification with regard to the properties of the materials. So, this is about you know the different you know structures which are you know observed in the case of welding. Thank you very much.