Welding Metallurgy
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Lecture - 31
Distinct Zones in Fusion Welded Specimen

Welcome to the lecture on distinct zones in fusion welded specimen. So, basically we are talking about the weldments, which are formed by the fusion welding process and as we have seen that when the welding is being carried out, so you have the maximum temperature in the weld pool and then in the transverse direction, the temperature goes on decreasing. So, you will have the different zones which are subjected to the different temperatures.

And because of that you will have the different properties of the materials, so the welded joint varies in metallurgical structure from a point to point with consequential variation in mechanical properties. So, basically when you are you know the weld metal zone which has the maximum temperature, from there as you move towards the transverse direction, so you will have different problem at temperatures to which the material's temperature is raised.

And for that you know the properties are also changed, so there is change in the mechanical properties.

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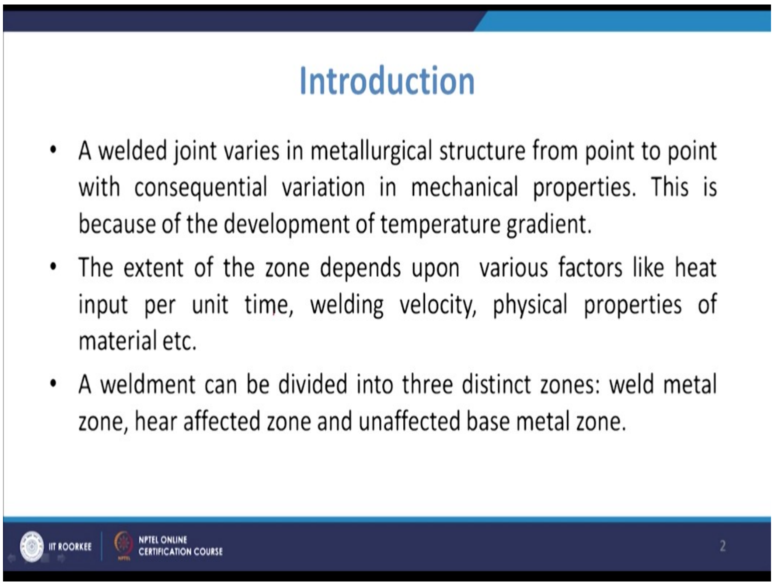

Now, extent of this zone will be depending upon various factors like heat input per unit time, then you have the welding velocity and you have the physical properties of the material like the thermal conductivity you know or thermal diffusivity in true sense you can say, then you have the melting point. So, all these things are also determining that what will be the you know width of or the dimension of that particular zone will be.

So, basically when we talk about you know the weldment, then a weldment has basically 3 different zones as we see that a weldment can be divided into 3 distinct zones. So, first zone is the weld metal zone and then you have so that weld metal zone basically that zone which will be forming the weld bead. So, that is your weld metal zone. Then, the next zone will be the heat affected zone.

So, this heat affected zone is that zone where the properties are affected, the structure is affected because of the heat which is flowing and be consequently the temperature is changing. So, there will be heat affected zone and after that you know to its side, you will have the unaffected zone that is unaffected base metal zone or we call it as the BM or BMZ or base metal zone.

So, you will have 3 distinct you know zones in those cases and you can have you know we can see by graphically that you have basically you know you have the diffusion zone which will be here.

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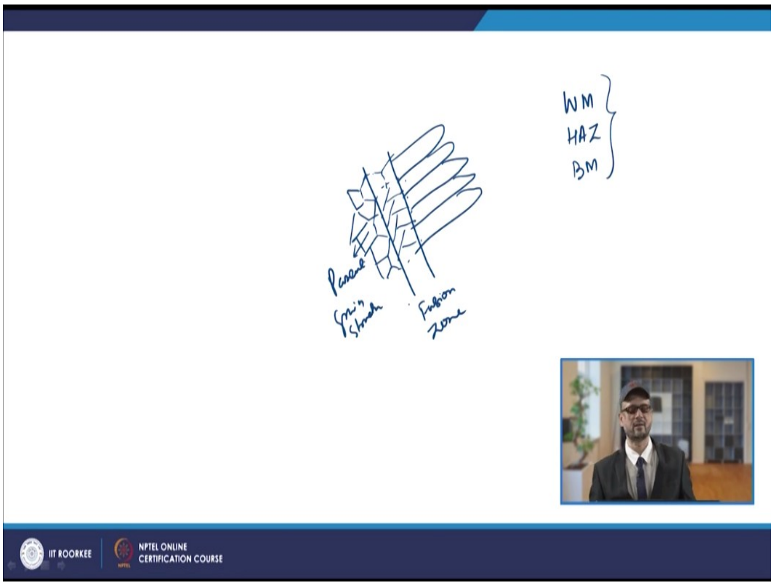

And then you will have so in the fusion zone and you know on this side you will have the grain structure. So, this way these are partially melted you know grains, so and then on this side you will have you know grains you know further moving okay. So, this is your parent metal that is moving in this direction. So, this is your parent grain structure and this zone so on this side also you know some grains are melted.

So, you have you know grains you know melted partially in these cases. So, this zone is known as the fusion zone and then you know on this side you will have the growth taking place, so as we have understood you will have the different you know zones you know different growth or columnar growth of the grain taking place in the direction. So, you will have the fusion phase here and from here the columnar grains will be growing in this direction.

So, you will have so as we discussed you have 3 zones, you have weld metal zone, you have heat affected zone and then you have base metal zone. So, these are you know 3 different zones which occur. Now, in this case, if you have fusion zone so up to in this side up to certain distance, the structure will be changed is likelihood that you know structure and properties also get changed.

So, that is your heat affected zone and then this is your then you have on this this side you will have you know base metal zone and that is unaffected you know zone, so unaffected base metal zone and then towards this side up to in the pool, so you will have growth from this direction also. So, this side it will be you know the weld metal zone which will be here you know in this case.

Now, heat affected zone basically which is here or from this side, so that will have, so there will be up to certain distance, this you know heat affected zone will be defined and that is because of the heating and cooling effect, so for that about it we will be discussing further.

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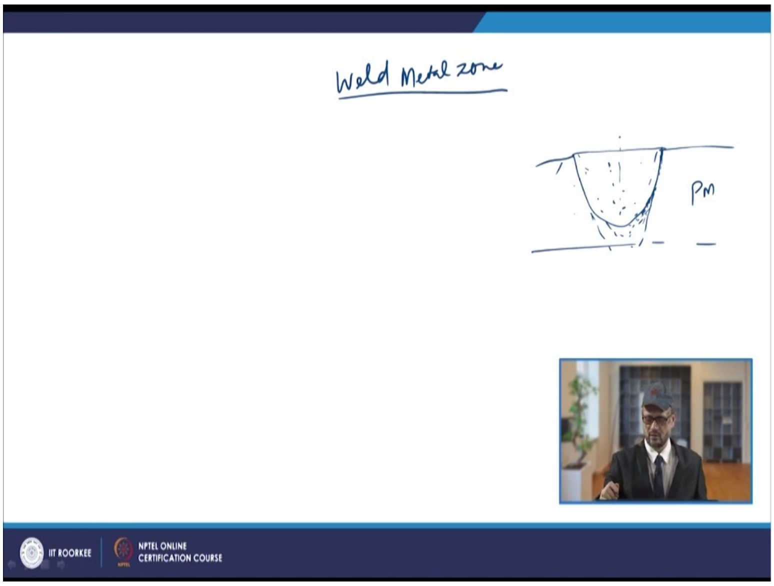

So, coming to you know weld metal zone, so if you talk about you know the weld metal zone, so weld metal zone is basically you know formed by the solidification of the weld pool. So, you know you will have the melting you know, in the central part you will have melting of the original material as well as you have the melting of you know filler metal. So, they are getting melted and that is why it is known as the weld metal zone you know zone.

Now, this is something similar to a cast zone or casting you know you can resemble it to a cast metal because in casting also you are melting the material and then allowing it to solidify. So, in this case also you know you are basically in this zone, you are melting the material. Now, you will have you know melting of the parent material as well as the additional material that is the electrode suppose is there, so that also gets melted.

And then your parent material is also on the sides, so you know so that way you have these material also some part is melted and then your if there is filler material or electrode which is melted, so they all form this pool and that is you know the weld metal pool or weld metal zone it is. Now, in this zone basically when the molten metal is present, now if you look at the temperature on the sides these are the, this is the parent metal or base metal.

Now, there is basically you know high temperature difference between the temperature in the weld metal pool and in just adjacent to it. So, this is basically normally at the suppose the room temperature, so there is large undercooling you know and so you will have the large temperature gradient from this point to this point and so there will be large undercooling being experienced to the metal which is there inside this weld pool.

And you know because of that large undercooling you know nucleation will occur, nucleation will start and then you know once so nucleation will certainly start at the point where the undercooling will be maximum so as we have understood. So, on this point basically you will have the nucleation starting because at this point the liquid metal which is there in this pool it will be in touch with this base metal.

So, you will have the largest undercooling being experienced by the grains which are present here and from here solidification will start and because of the large undercooling faced you will have very fine grains formed here but then what will happen that you know that the heat extraction will go on, so opposite to the direction of heat extraction, the grains will grow in this direction.

So, you will have the growth of grains in the opposite direction and so columnar growth will be there and we have understood how this growth phenomena can be explained basically because you know that there are 2 types of growth; one is your crystallographic growth in the crystallographic direction, another is you know the easy growth direction, so that is your easy growth direction and then you have the growth which is normal to the boundary so because the maximum heat extraction will take place normal to the boundary.

Because you have the maximum area, so you know from there so accordingly your you know grains will be growing from there and your you know grain growth will show that how grain is growing and coming towards the center. So, this way you know since and we have already understood that you have the you know all these partially unmelted grains which are there. So, they will be working as the you know source of nucleation in such cases.

And then they will be you know so from there nucleation will start and then it will further grow towards the inner side of the weld metal pool. So, that is basically this mechanism is also known as the you know epitaxial type of mode or epitaxial solidification or epitaxial type of growth. So, that way this you know weld metal pool is defined. Then, the next zone which is adjacent to that weld metal zone will be your fusion zone.

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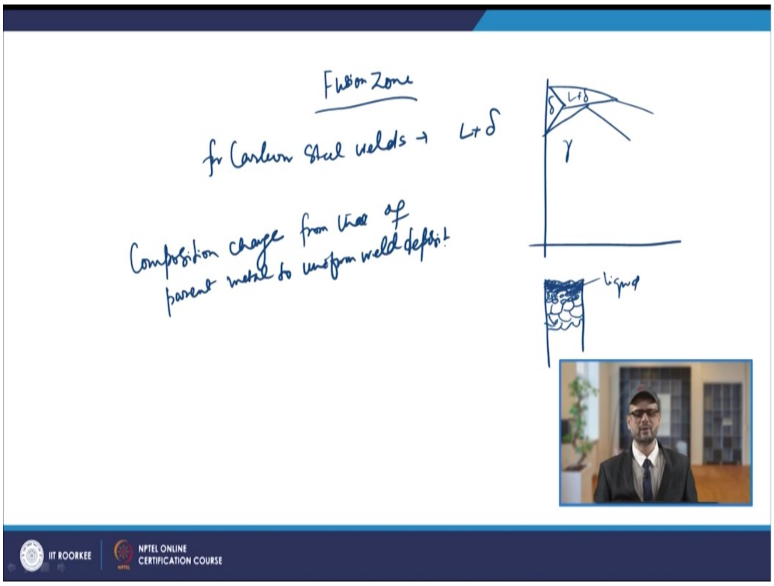

So, if you talk about this, if we have seen in the figure that you have a zone you know adjacent to the weld metal zone, you have the fusion zone. Now, you know you have many terms you will come across like fusion line many a times and but this is normally a zone in which you know the fusion taking place. So, you know it is like you know we also come across the term like fusion boundary many a times.

Now, what is happening that fusion zone is the one; on one side of the fusion zone you have the weld metal zone, on the other side you have the heat affected zone. So, you know now in the case of you know if you talk about the carbon steel welds then the liquid+ δ zone, so for carbon steel welds you know the liquid+ δ you know zone which is there you know liquid+ δ ferrite zone.

So, that zone is basically you know represented as the fusion zone. So, what will be happening you know, normally this fusion zone is quite sharp, so if you try to refer to the iron-carbon diagram. So, as you know you have this is the δ ferrite and then you have this becomes the γ and this is your δ ferrite and as you know that this is going like this. So, you know in the weld metal zone, since the metal is molten, it means practically the temperature is more than the melting temperature of the materials.

It will be higher than that but then this zone which is there where there is liquid+ δ , so this is the zone where there is liquid+ δ, so that refers to that temperature where you have this temperature of the order of liquid plus you know where this temperature is corresponding to.

So, in this zone you will have liquid as well as δ that is your, so there is partial you know melting of the grains, some solid particles and also mostly it is liquid.

So, that is your that is basically indicative of that presence of that zone. Now, in this zone, so you know if you talk about you know other structures also where you see the liquid+solid phase that basically will be the indicative of such you know fusion zone. Now, this zone fusion zone so if you try to look at its you know the figure, if you see the schematic illustration of the microstructure of the fusion boundary zone, so you will have basically this is a completely dark so you have you know here this is completely you know liquid.

So and then adjacent to this liquid, you will have a very small range say, showing and then further you will have at distant places you have these again you have the coarse grains appearing. So, this is basically the you know the liquid+ δ zone and this is you know the indicative of you know fusion zone in such you know cases. Now, what we see that here basically that will be demarcating, this will be the demarcation line between basically, so you have on one side you have certainly that you know so weld metal zone.

But then when it ends because it is very sharp, so when it ends which that is why many a times we call it as a fusion you know boundary. So, then your this heat affected zone starts you know further. Now, in this case you will have you know fine as well as the coarse grains. So, basically it is also you know represented by that line where your composition will be changing from the parent metal to the you know the composition of the weld deposit.

So, basically you will have the composition change from that of parent metal to uniform weld deposit. So, basically you have weld deposit on one side and on other side you have the parent metal. So, your composition will be changing from this to that, so that reason will be basically the you know that will be represented that will be told as the fusion zone, you know in strict sense. Now, after the you know fusion zone, you will have the heat affected zone.

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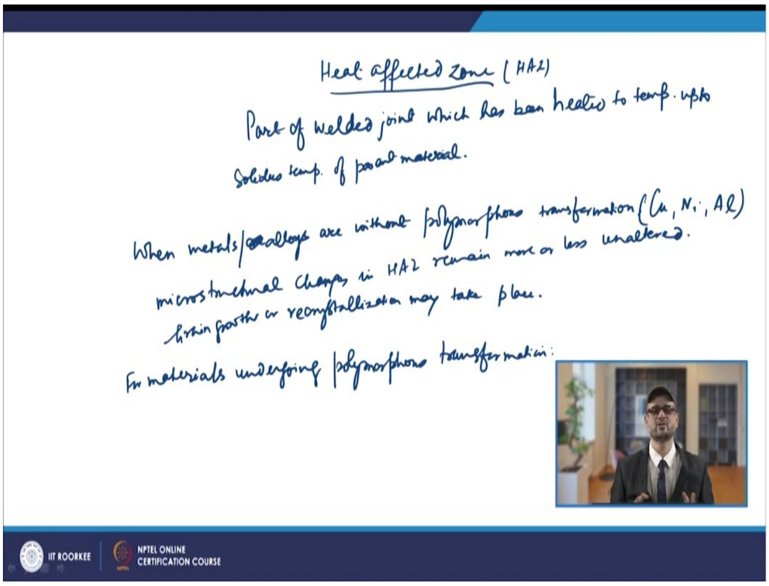

So, once you cross the fusion zone then comes the heat affected. Now, heat affected zone as the name indicates you know in this case, there will be so as we see that you have on one side you have a weld pool where it is completely molten, then you have a fusion zone where on the composition will be changing from the parent metal to the composition of the weld deposit.

Now, after that you have the heat affected zone, so as the name indicates is also known as a HAZ. Now, in this basically you know this is that part of the welded joint where the you know temperature has been raised and it is raised till the solidus temperature because after that you have the solid+liquid region. So, that becomes the fusion part, fusion zone part and then after that even after the liquidus, so you will have the weld metal zone where the phase is completely liquid.

So, that way you have you know so below that fusion zone, you will have the you know the heat affected zone which is formed. Now, in this case what is happening so you know this is a part of the welded joint which has been heated to temperature up to solidus temperature of parent material. Now, you know since you are heating the material to its solidus temperature of the parent material, so you also expect large amount of you know changes in its properties in the properties of the material or microstructure of the material.

So, in the heat affected zone there is a likelihood of you know the you know changing the microstructure, changing the properties of the material. Now, many a times you have basically some of the material where the polymorphous transformation you know does not take place. So, when you have metals and alloys without the polymorphous transformation, so when metals or alloys are without polymorphous transformation, so in those cases you know the microstructure in the HAZ will be not altered.

Because the metal where the polymorphous transformation is taking place, crystal structure basically is changing, in those cases because you have the if you talk about iron so there you have as the temperature comes down you have the initially you have δ ferrite, then it comes to γ ferrite, then γ you know austenite, then it comes to delta ferrite. So, you have at different temperatures you have different you know crystal structures are there.

So, these transformations taking place. So, when the metals or alloys which are without the polymorphous transformation like say for example copper, nickel or aluminum. So, when you do the welding for these materials, so in those cases you know HAZ, the microstructure changes in HAZ is not you know so much of change, so microstructural changes in you know HAZ remain more or less unaltered but that is not the case for you know the everything is not unaltered.

Basically, the recrystallization or grain growth still may take place because the temperature is increased. So, you have you know grain growth or recrystallization may take place. Now, if this is for the materials which does not undergo the polymorphous transformation. For the material which undergo the polymorphous transformation, so for materials undergoing polymorphous transformation.

So, suppose you have you know just like you know steels where these things are very much prevalent. Now, in those cases you have the microstructural changes visible in the heat affected zone and since there is change in the microstructural you know appearance, there is change in the microstructure of the specimen in those regions where it is subjected to the temperature change.

So, ultimately there will be property variation in those you know zones. So, basically what happens that when you talk about you know the this HAZ so it is that zone where the you know temperature has been increased and basically so certainly upper limit is the solidus temperature but the lower limit it may go up to a temperature where it can it has done certain changes you know into the you know into the structure of the material or microstructure of the material.

So, basically if you talk about you know typically for the steels, so in those cases you have the HAZ of steel is basically divided into different zones and these zones are basically one is the underbead zone.

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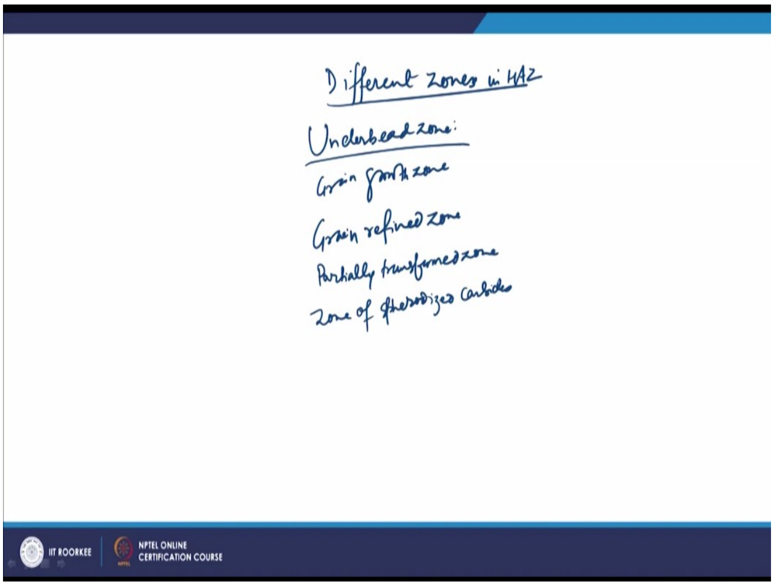

So, if you talk about the different you know zones so in the HAZ, so you have different zones in a sense that as one is your underbead zone. So, this is the zone basically where you know so this is that part of HAZ which is heated beyond the critical temperature of grain growth and you know extends up to the fusion boundary zone. So, just below the fusion boundary zone and this is basically you know the zone where you have this is beyond that critical temperature of the grain growth.

Then, after the underbead zone, you have the grain growth zone. So, it will be basically towards the so if you look for the you know γ region or the austenitic iron region, so in the upper half portion so from there it will extend till the peritectic temperature that is your grain growth zone because in that zone the grain growth is taking place. Similarly, you have the grain refined zone.

So, grain refined zone basically will be that zone which will be towards the lower half you know in that austenitic zone, so that will be from 950 to 1150 ^{0}C. In that zone that is known as the you know the grain you know refined zone. Then, after that you have other zones like you have partially transformed zone and then similarly you have zone of spheroidized carbides.

So, basically the partially transformed zone will be between the inter-critical temperature, so between A1 to A3 you will have partially transformed zone and the zone of spheroidized carbides is basically starting from 550 ^{0}C and it will go till a1. So, even at that temperature also you know when the material is undergoing that thermal treatment, it is being heated that it is likely to affect the microstructure of the property and correspondingly the properties of the material.

So, that is the zone of spheroidized carbides, so this way you will have the different zones and that we will discuss you know in our coming lectures that how these different zones are there. So, basically they can be you know mapped on the iron-carbon diagram and you can have a feel about these different zones on that pertaining to the different temperatures which are achieved.

And then you know depending upon the temperature by some temperature up to which they are heated you know their properties will be also changed. So, these are you know the you know different zones in the heat affected zones because in those cases you know if you are talking about the grain growth zones, so your grain growth takes place and growth of the grain will affect the mechanical properties.

Similarly, you will have you know if you come to the on the lower side you will have the zone where there will be spheroidization of the cementite particle taking place that is as spheroidization process that is also a process of heat treatment. So, there will be some globalization or there will be globules of cementite which is formed because of these you know thermal you know variations.

So, ultimately you will have you know its effect will be there on the final properties of the materials. So, altogether what we have you know studied in this lecture is that you have when you do the welding, so apart from the weld pool, you have basically when we talk about the materials which undergo the polymorphous transformation like iron or steel, in those cases it has strong effect on its mechanical properties.

And so many a times when you do the welding, you need to go further you know for the post treatment you know many a times because if you feel that because if since it is subjected to the temperature variation, so it is like a heat treatment process to it and in these cases you must have the idea that there is a very large you know rate of cooling many a times. So, you may have the development of stresses, then you have coarsening of also the grains that may also take place in certain cases.

Then, you know there are other things also which are likely to happen that we have understood, whichever you know process is bound to follow during the process of solidification, you know they are likely here because that is also in the weld metal zone also it is like the synonymous of a cast specimen where you are putting the liquid metal and then it is allowed to cool in a metallic mould.

So, here basically the amount of liquid is even smaller and it is surrounded by the metallic mould kind of thing. So, in those cases many a times you know that will affect the properties or there will be other associated phenomena’s like segregation and all that and on the other side you have you know affecting the mechanical properties. So, this is all about the heat affected zone in the case of fusion weldments. Thank you very much.