# Welding Metallurgy

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## Lecture – 08
## Continuous Cooling Transformation Diagrams

Welcome to the lecture on continuous cooling transformation diagrams. So they are also known as the CCT diagrams popularly now as we see in our earlier lecture. We discussed about the TTT diagram in that we assumed that transformation is done at or there is transformation at one temperature that is isothermal transformation is there. Now rarely you see that you know such is the case so really it is still it was to a constant temperature and isothermal heat transfer because temperature will change.

So it is normally continuously cooled from austenitizing in temperature to room temperature at different cooling rates. So certainly when you are cooling then in that case you will have different cooling rates from the austenitizing temperature to the room temperature. So if you have to take this you know also this continuous cooling case into account in that case the CCT diagrams will be helpful and CCT diagrams they are depicting the transformation temperature and time relationship during continuous cooling.

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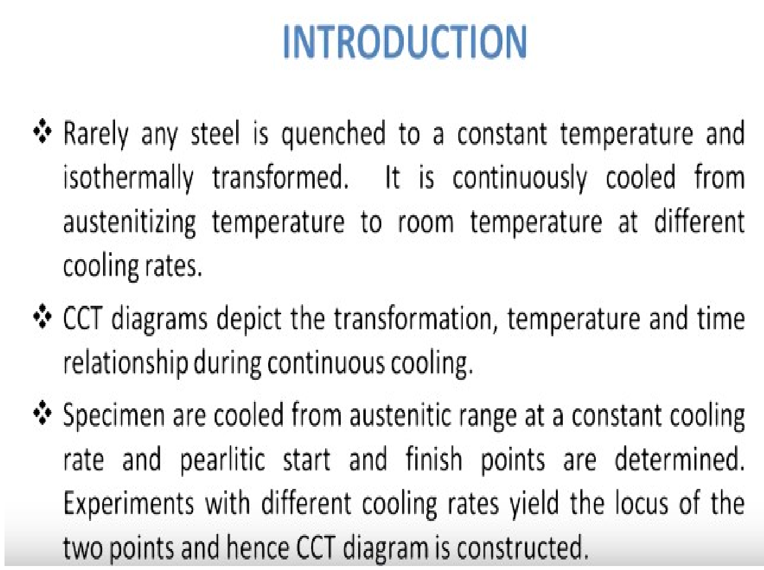

Because there is normally a case of continuous cooling and in that case you need to understand that how the transformation is going to proceed. So specimen will be cooled from austenitic range at a constant cooling rate and in that case you will have the pearlitic start and finish points determined.

So basically again in this case you will have a constant cooling rate and you will be in that you are having these points like when perlite started and when the perlite was finished and in that case. So the same thing will be done here also you will have for a particular amount of time and then in that case what you do is you will have further quenching so you can by knowing the fraction of suppose say martensite because of the presence of austenite at any stage you can understand it.

So accordingly you will have the different points and if you draw these locus of the points then you will have these you know different you know curves that is known as continuous cooling curves. So you know if you draw the continuous cooling curve for the eutectoid steel so that looks like this so as you see in this case you will have.

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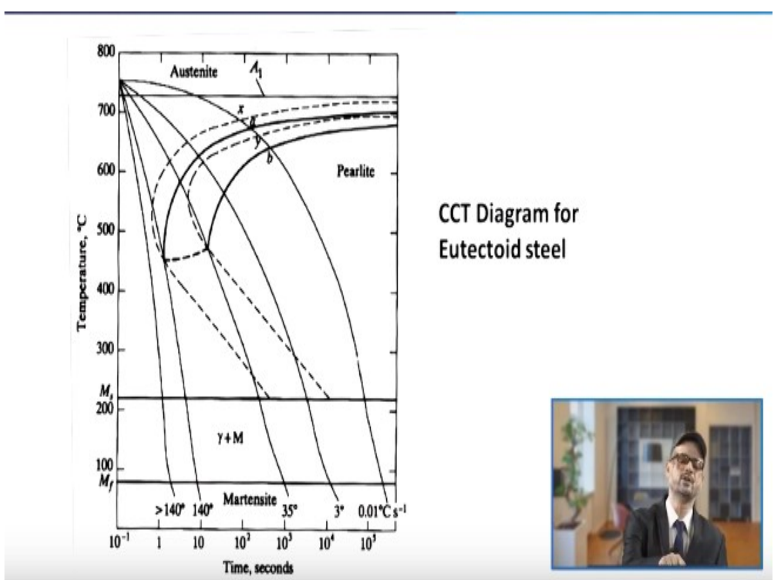


The liquid steel you know I mean steel heated to into this austenitic zone this is eutectoid composition steel. So then from here you are cooling at the different cooling rate the cooling rate this cooling rate is a slow cooling rate whereas this cooling rate is known as this is certainly the other curves are you know for the higher cooling rate than this. So this is 3 ° you know per second similarly this is 35 °C/sec 140 °C/sec and more than 140 degree per second.

Now what you see in this case that you will have you know once you go for this cooling rate you will have these points A and B which are formed and you know what you see that this is basically politics pearlitic start point A and this point is the pearlitic finish point B so they are using the metallographic method and they are outlined now they are at basically what you see is that they are at the lower you know temperature value X and at a later time you know then as per shown by the TTT diagram because the specimen has spent most of the you know time.

So that is cooling time at higher temperature so that is why there is a shift so you see that it is at A and it is at B what you see as compared to that shown by the TTT diagram. Now what you see that with these different cooling rates you will have so if you come to this you know in this cooling rate case at this time. So if you look at this probably $10^3$ this line comes here something close to this.

So in this case at this point this transformation is completely complete for pearlitic start and pearlite finish and then so it will be complete transformation from austenite to pearlite. If you are behind this in that case you will have you know the different transformation. Now in this case you will have now the different zones that will be pearlitic zone so you will have coarse pearlite this side and then further fine pearlite.

Then in the lower side you will have the you know the bainite and all that so you know what happens that if you look at this microstructure this graph you see that a cooling rate of 3 °C/sec if you look at this line that is your 3 °C/sec . So this will give you the fine pearlite so your coming transformation is complete here. So it will give you the final pearlite in in this case when you are you know going for very slow cooling.

So for very slow cooling of 0.1 °C/sec so this is your very slow cooling rate so if you are coming with this cooling rate and in this case you are into this zone where the transformation is complete so this zone will give you the coarse pearlitic structure with 3 °C/sec this cooling rate your transformation is complete here and in this lower zone you will have the fine pearlite structure.

Now if you go for further the increase in the cooling rate now if you go for the 35 °C/sec if this is the line which corresponds to the 35 °C/sec of cooling rate so it will be crossing this pearlitic start. So it is basically crossing this pearlitic finish line this is your pearlitic finish and this is your pearlitic start this you know bold line. So upper bold line is the pearlitic start line and this lower bold line is the pearlitic finish line.

So 35 °C/sec this is crossing that pearlitic finish line near the nose. So it is you know it is just crossing here and it will give you very fine pearlitic structure. So that is because of the very high I mean you know higher cooling rate as compared to the earlier cases and that is why whenever when in normal case we talk that when if you have a higher cooling rate you will have finer structure.

So it is on from here because this is the higher I mean coarse of pearlite region and this is the final pearlite zone. So now if you look at this you know 140 °C/sec of cooling rate is this is quite high cooling rate. Now this is just missing the pearlitic curve so you know and it is also not entering the bainitic zone. So this is in the bottom side you have these this side it is the bainitic zone.

So this 140 °C/sec line so this line is basically missing that pearlitic start curve and this will be you know transforming to all the martensite because there is no pearlitic transformation neither it is further going and being hold you know at this temperature and going into that isothermal transformation zone where the bainite is formed because in the earlier case what we had seen that when you are coming this line when you come past the nose of the C curve heat is coming and then when you are holding here.

Then you are coming in this Zone which is the bainitic zone now in this zone if you are having this 140 °C/sec line. So and if you are continuing through it so you will be getting the full martensite hardened martensitic structure in this case. So you know you must have so that basically defines you know the concept of the critical cooling rate.

So basically this critical cooling rate this is a critical cooling rate because it is just touching the nose of the C curve outer part and basically the cooling rate must be more than this you know for the full hardening of the steel for the full model structure of the steel your cooling rate must be exceeding this value and you know if you know if the steel so in between 35 and 140 so if you it is 140 and it is more than 140 in that case you are getting the full hardening the full transformation from austenite to martensite takes place.

Whereas if you are between 35 and 140 °C/sec then steel will be crossing that pearlitic start and it is not crossing that pearlitic finish you know curve. So what happens in this case some of the austenite will be converted to pearlite not fully so that way what you see and then you also so and then it will be you know part of austenite will be converted to pearlite and you know untransformed austenite will be passing through this bainitic range.

So you know so this bainitic curve we will be so for that this untransformed austenite will be passing through that bainitic range of the TTT diagram and bainitic start curve basically we for continuous cooling will be you know shifting somewhat to the right you know so that very little austenite will be transforming to the bainite. So and rest will be transforming to martensite.

So that way if you analyse this curve you can see that how with what cooling rate what kind of you know transformation product is there.

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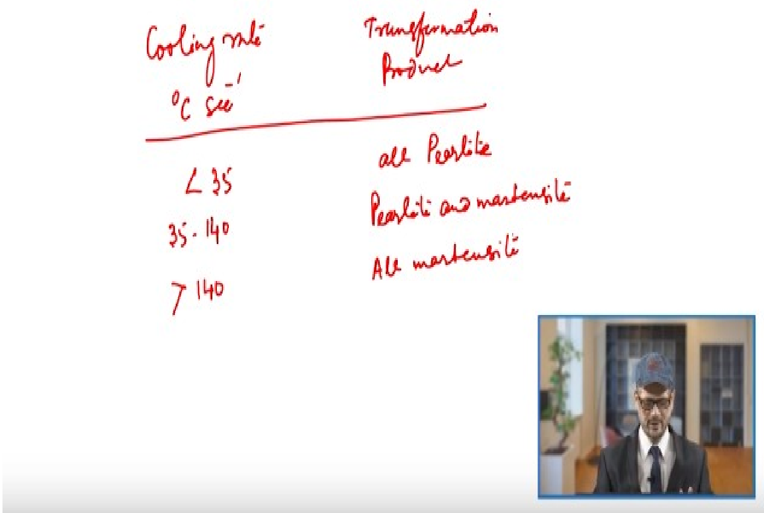


So if you analyse what you see is that if you have the cooling rate you know so if you write the cooling rate and for different cooling rate if you so cooling rate is taken as °C/sec and if you take this transformation product. So for the cooling rate of less than 35 °C/sec what you see that you have all upper pearlitic structure. So that is you know clear from here if your cooling rate is less than this line if you if it the cooling rate is towards this.

So in that case it is passing this pearlitic start and pearlitic finish line so your whole austenite is converted to pearlite. Now if it is between 35 to you know 140 so in that case you will have the pearlite and martensite and if you have more than 140. So in that case you are going to have all martensite structure. So this is how you know these continuous cooling transformation curves can be understood for the you know for the eutectoid type of steels.

We can also understand with respect to the you know low-alloy steels for nickel chromium moly steel. So because in that case what we have seen that these nose of the curves they shift towards right and how you know how can you see that what will be the different type of you know what are the different type of structure will be formed in that case. Now so if you try to draw the continuous cooling curve for the you know nickel chrome moly steels.

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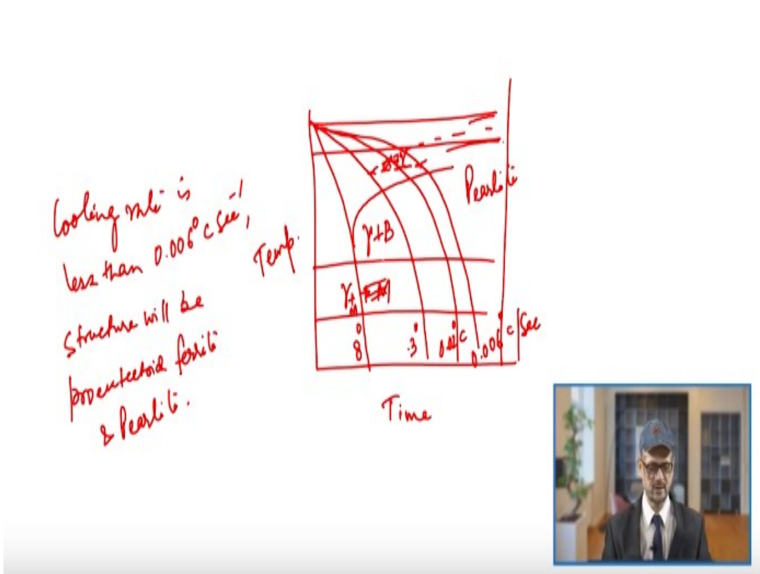


So as we have seen earlier we had seen that when you talk about these you know nickel chrome moly steel so if you take this axis as time and this is your temperature now as you know that in this case you will have you know one line so now in this case what we see that this is your γ+ martensite you know zone and you will have a line that is for 8 °C/sec .

So just you can see that with such a small cooling rate also you are coming in the zone of martensite. Now in this case so this is γ+ martensite here not this now after this so your one zone is going like this now what happens that if you look at the cooling rate. So this cooling rate goes like this now the small cooling rate which is suppose 0.006 °C/sec. Now for this you know cooling rate what you see now in this case if you look at the continuous cooling curve.

So it will and you have another line as 0.3 °C so this will be your 0.3 °C/sec so for that you know small cooling rate in between again you will have another line as the 0.02 °C/sec. So this is the different cooling later what you can see that you have very small values of it is cooling rate and in this at least 8 ° you can see this is coming as the critical value.

Now in this case what you see that here you will have a line that source the different you know transformation lines. So this line will be you know so this line this zone will be α+γ. So what we see in these continuous cooling curve line now in this case you have if you have cooling rate which is less than so if cooling rate is less than 0.006 °C/sec.

Now in that case your structure will be pro eutectoid ferrite + pearlite so if it is soaked in that case you will have this is the α+γ so that γ and this side you have this is a pearlite. So you can see that you will have this α+γ and then if your temperature I mean cooling rate is even less than this you are going to get α+γ and + pearlite.

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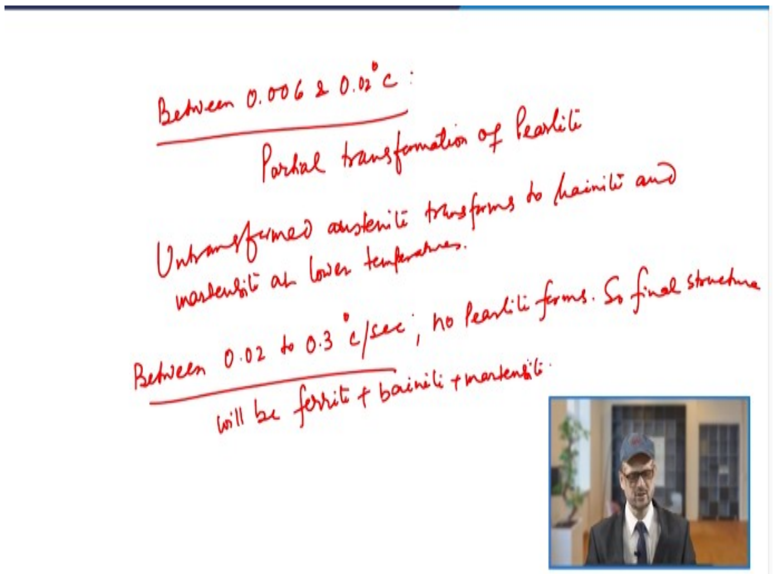


Now if you know further when you go between 0.006 and 0.02 °C. So if your cooling rate is maintained between these two temperatures now in that case you will have a partial transformation of pearlite. Now you could have seen in your earlier cases so you started from 3 °C now you know if you look at this line.

So you started from 0.01 and we amend up to even 3 and that was from 35 that we have seen that partial transformation but otherwise there was complete transformation to pearlite but in this case your cooling rate even it is very small. So that way you know what we see so in this case we see that when you have cooling rate between 0.006 to 0.02 °C then you have partial transformation of pearlite taking place and in that case this untransformed austenite that will be transforming to. So that transforms to bainite and martensite so that transforms to bainite and martensite at lower temperature. So that will be the case when your cooling rate is between 0.006 and between 0.02 °C. Now further if you are increasing the cooling rate you know further so now between 0 point so you are further increasing, so between 0.02 to 0.3 °C/sec.

Now if you look at this line so in between there will be no you know pearlite transformation. So no pearlite forms so the final structure will be ferrite and bainite and martensite ferrite + bainite + martensite because this zone this zone is basically the austenite + bainite. So you will have this gamma you know that you know will be transforming to you know the martensite. So that happens when your cooling rate is from 0.2 to 0.3 °C .

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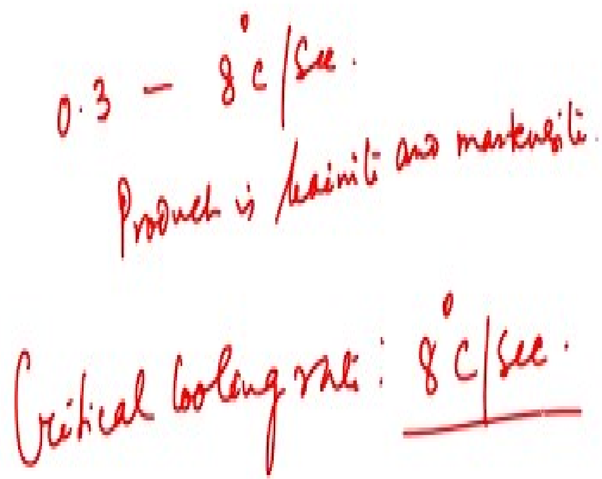


Now when your cooling rate will be a further changed your so cooling rate becomes you know 0.3 to 8 °C/sec, so that was the you know extreme left you know curve. So this was the 8 °C/sec. Now in this case what you see the product is bainite and martensite so what you see that in this steel in this nickel chromium molly steel you are getting bainitic structure and when you are going for continuous cooling.

So but when you have gone to eutectoid steel you have so we have seen that in the case of eutectoid steel you are not getting that easily. So also what you see that the critical cooling rate which was there in the case of you know the eutectoid steel it was 140 °C/sec but in this case the critical cooling rate is quite small that is 8 °C/sec. So your critical cooling rate that becomes to be you know 8 °C/sec.

So this is the difference what you see this is because of the you know alloying elements and this is you know about 20th part of 18th part of the cooling rate what you see what you have to maintain in the case of you know normally eutectoid steels. So that is how the effect of lying elements can be seen on the you know formation of phases and how now you can see with the help of these CCT curves that what cooling rate what we mean what way so what do you see that if you put the if you add the alloy that is why alloy steels have more hardenability.

These alloying elements basically they are shifting towards the right and continuous cooling curve with that continuous cooling also which is I mean in normal case without you know the use of alloying elements in the steel it is very difficult to get the bainitic structure. Whereas in this case in the case of continuous because in the case of continuous cooling it is very difficult to get the bainitic steel you could have got in the case of TTT diagrams.

We look that you have to isothermally hold it and then you get that structure but in this case the you are getting the bainitic structure and also the critical cooling rate is reduced to half it signifies that even yet smaller cooling rate you are likely to have the bainitic and martensitic structures. So that is an advantage you know of the use of alloying elements.

So in a nutshell we should also know that what is the you know role of these alloying elements you have alloying elements and there are different roles of these alloying elements and there are their functions basically so if you talk about the you know function of alloying elements.

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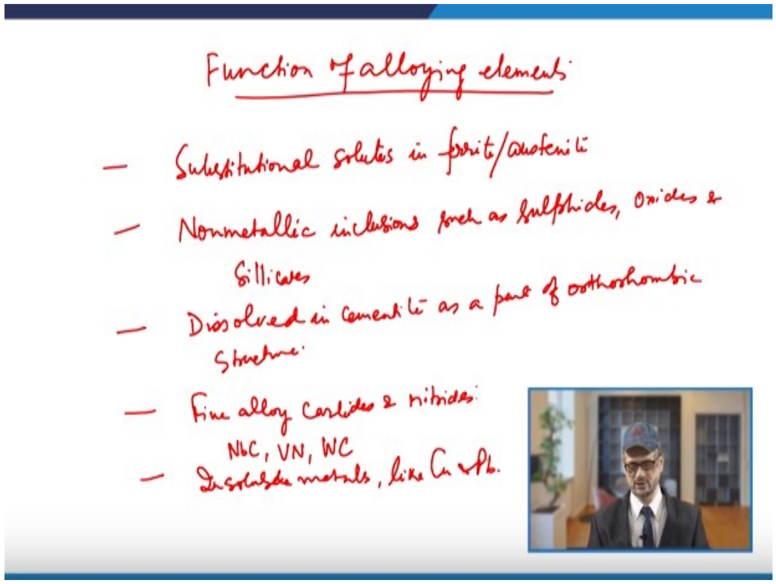


Now as you know that they are used so first of all they are used as substitutional solutes. So you know you have substitutional solutes in ferrite or austenite. So many elements like you know you have the use of chromium or nickel or so they are used as these elements which are used in ferrite or austenite and they will be improving the properties like chromium and nickel if you add into the ferrite you know or austenite.

So they will be improving the corrosion resistance so accordingly so these you know this is the effect of you know these alloying elements there will be strengthening the steel basically. So once they go into that steels they will be strengthening the steel then they are also used as so their function will be like they will be working as non-metallic inclusions. So non-metallic inclusions will be in different forms like you have they can they can be oxide, sulphides and silicates.

So oxides means you can have you know $Al_2O_3$ is there so that becomes a non-metallic inclusion you have you know MnS so that is again another you know non-metallic inclusion or $MnSiO_3$ so magnesium silicate so that is another example of the silicates. So these alloying elements will be working as the non-metallic inclusions then they were they can also be dissolved in cementite.

So dissolved in cementite and they will be cementite they will be dissolving as a part of the orthorhombic structure. So as a part of orthorhombic structure so you have also like you

$(FeMn)_3C$ so that way it is you know it may be formed then one of the very important use of these alloying elements will be that they are present as carbides. So like they are having final alloy carbides and nitrides also.

So like you know normally you have alloying elements which are more carbide forming or nitrate forming elements so you have niobium so that makes niobium carbide you have an vanadium so vanadium nitride tungsten is used tungsten makes tungsten carbide. So that way these alloying elements are normally the carbide or the nitride forming elements so and also like chromium is making $Cr_{23}C_6$.

So that way these are normally the carbide or nitrite forming elements and they provide the strength and then you have also insoluble metals like copper and lead. So insoluble metals so you have like copper and you know lead so this way you have you know different types of you know alloying elements and their roles are different as you have we have understood you know. Now one is one of the function when we talk about these you know CCT or TTT curves.

So in that the very important point is that they normally try to increase the hardenability of the steel increasingly the hardenability of the steel means that basically there is shift of the nose curve nose of the C curve towards the right. So if the shift is towards the right in that case you can have you know full hardening you can have the martensitic structure or you can have the you know better structure with better properties even at a smaller cooling rate.

Otherwise you may have to go for a very large cooling rate for getting the fully martensitic structure. So that is the chief advantage of using these you know alloying elements apart from that many a times you know some of the sulphides or phosphates or insoluble metals they are basically for improving the machinability of the steel and many a times you know these alloy carbides to this.

So they will be pinning down the magnetic boundaries and they will be also you know is basically during the recrystallization and grain growth. So they will be helping in getting a fine size so that is another advantage of these alloying elements and then more importantly again these carbides or nitrites or some carbides like molybdenum carbide or the vanadium carbide.

So they are enhancing that creep strength you know some of the carbides they also increase the you know wear assistance or abrasive assistance so these are typically the effect of these alloying elements and their also effect also is there towards the hardenability of the steel from where we can get the full hardening of the steel you can get the martensitic structure or so. So this is all about the continuous cooling you know transformation curves and some summary about also the use of alloying elements and their functions in a right spirit in the steels. Thank you very much