Welding Metallurgy

Prof. Pradeep K. Jha
Department of Mechanical and Industrial Engineering
Indian Institute of Technology – Roorkee

Lecture – 07
Time Temperature Transformation Diagrams

Welcome to the lecture on TTT Diagrams that is also known as Time Temperature Transformation diagrams. So we studied a bit about the phase transformation and we knew that phase transformation is normally what we have studied is that it is by the mechanism of nucleation and growth and then they were based on that you can also have the expression for the transformation rate which is basically a function of nucleation and growth.

So you will have you know based on that expression further you can have you know you can get the concept of the transformation of one phase to other with respect to time. So with time, how the transformation will you know we will be there. So basically we are interested normally when we in industrial practice or in normal case also we are interested to know that when we are you know changing the temperature.

So, what way other phase will be transformed? How it will transform? At what time, how much amount will be you know transformed. So for that basically there are two kinds of diagrams one is time temperature transformation diagrams and then further we will also discuss in our next lecture about the continuous cooling transformation diagrams. So they are normally known as TTT diagrams and CCT diagrams.

So in this lecture we are going to have the discussion about the time temperature transformation diagrams. So what are these time temperature you know transformation diagrams.

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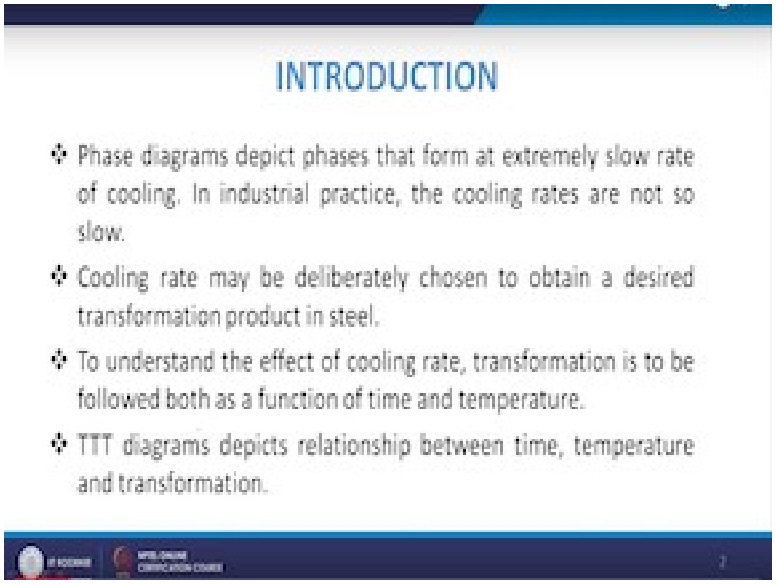

So we discussed about the phase diagrams and and we knew that they are basically they are also known as equilibrium so in that whatever phase we see which is formed basically that is formed at extremely slow cooling rate and they are not very much you know feasible cases because in industrial practice that cooling rates are you know these cooling rates which are there they are not so slow.

So we can have the cooling rate we can choose it deliberately very you know at any value and obtain the desired transformation product in steel. So for understanding the effect of cooling rate transformation is to be followed both as a function of time and temperature. So what we need to understand that when we are cooling then there are two things one is time. So with time how these transformation is being carried away transformation proceeds as well as at what temperature.

So basically when we are you know we are talking about transformation at any point. So we are coming to one temperature and at that temperature with time what will be the transformation. So how the phase will be transformed. So that is basically for that we will in this lecture we are going to discuss about the TTT diagram. So TTT diagram they will that will be depicting the relationship between time temperature and transformations.

So in this case as you know it we will be discussing about you know the time. So you will have on x-axis you have time and on the y-axis you have temperature and then you will have you know so we will discuss that how we can see that how the transformation proceeds so how can we understand about it. Now what we do in this case we are basically heating the steel specimen to austenitic range and then we are quenching into molten bath that is maintained at different temperatures in the paralytic region.

So basically we are talking about any composition suppose so suppose you take the eutectic composition. So you know in this case what we see in the case of eutectic composition that is about 0.8% carbon so the austenite will be converting to pearlite that is a ferrite plus martensite. So there will be pearlite transformation now so what we do is that first of all you have to go into the austenitic zone.

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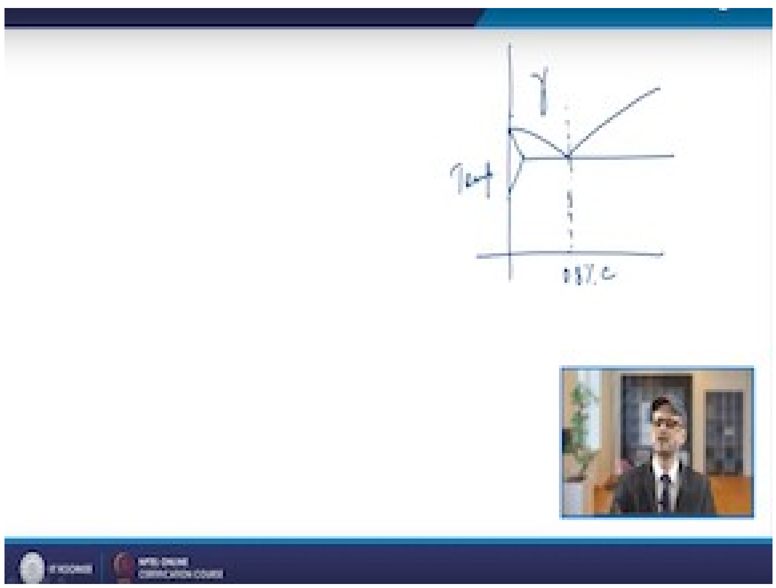

So as you know that you have such is the you know iron carbon diagram. So this is your eutectic composition this is about 0.8% carbon so this is your temperature and now this will be further so in this this zone is the austenitic zone so when the temp so if you talk about this composition so when the temperature will come at this point then it will be converting to martensite I mean pearlite in normal cases.

So this is what you getting this is the composition that is so here you have in this side ferrite and this side you have cementite so mixture of ferrite and cementite in alternate laminates. So that is known as pearlite, so ferrous austenite will be changing to pearlite now what we do is that you are heating that specimen in the austenitic range you are going above 723 °C.

So you are going somewhat above so that whole specimen is austenitized, whole of the specimen is austenite.

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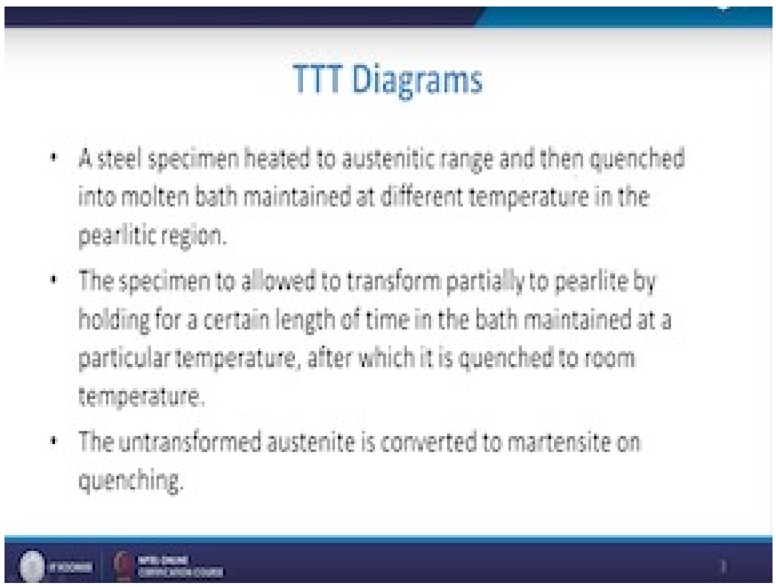

And then we are quenching into molten bath maintained at different temperatures, so what we will do you maintain you know the molten bath at different temperatures below that lower critical so that is something close to 730 °C . So basically you have you heat in this zone and then you maintain it in a molten bath of temperature below this, so you take a particular temperature and at this temperature of the molten bath is maintained.

So that molten bath has this temperature maintained below this temperature. So that this temperature will be taken you know in different set of experiments, so in that you know bath you are going to quench the molten you know this specimen which is there in the austenitic range and since this is a pearlitic range so we are writing the pearlitic range. Now so since you are going to a temperatures you are putting the specimen into the molten bath which is maintained at temperature below this lower critical temperature which is the transformation temperature.

So certainly there will be transformation started now what happens that this specimen will be allowed to transform partially to pearlite by holding for a certain length of time in the bath maintained at a particular temperature after which it will be quenched to room temperature. So what you do is you once you are putting that in the molten bath which is maintained at some temperatures below that temperature below that lower critical temperature.

Then you keep it for some time and then so expecting that there will be transformation to pearlite and then you quench it to room temperature. So that way you will have the austenite which is untransformed suppose there will be some transformation you know after certain time of austenite to pearlite but then after that since you are not holding for infinite time. So after some time you are going to quench it into room-temperature quench it to a bath of which is maintained at room temperature.

So whatever austenite is there if they are you know quenched in quenched at room temperature is so fast cooling in that case austenite will convert to a martensite. So all the untransformed austenite will be converted to martensite on quenching. So transfer so some part if it has to transformed it will be transformed to pearlite otherwise the rest austenite which is not converted so far so that will be converted to martensite.

So at any particular temperature of holding and if you are allowing for different holding time. So you know with different time you will come to know that what really is the amount of you know martensite, so that we basically will tell you that that much was austenite which has been transformed to martensite and if there is you know transformation to pearlite so you will have pearlite and then martensite.

So if there is no transformation it will be only martensite if there is you know suppose 2% of you know pearlite and 98% of martensite it means there is 2% of transformation. So this way you can have you know you can see at any particular temperature you can see that at what time the transformation has started. So that will be 1% line and then at what time the transformation has completed.

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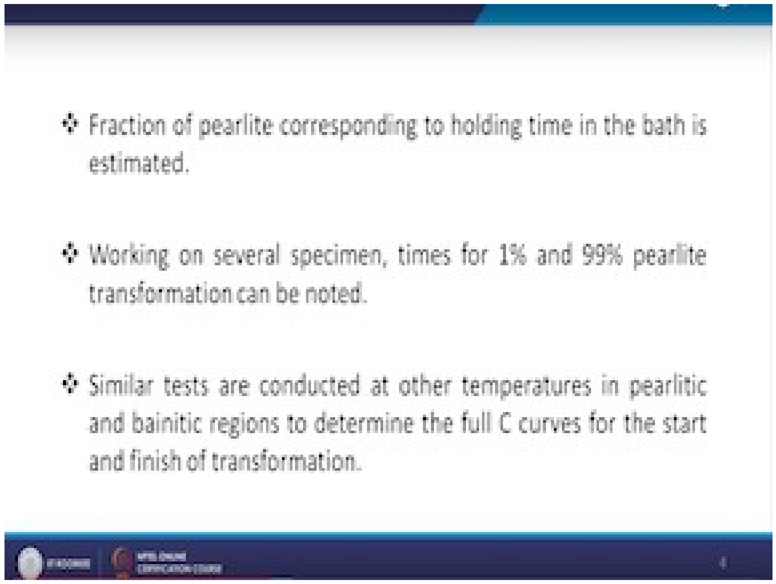

So you normally give 1% as well as 99% pearlitic transformation so that you know that is basically noted and then this will be done at all the different temperatures and accordingly you will have a series of you know points and then you join these lines. So similar tests are conducted at other temperatures in pearlitic and bainitic regions to determine the full C curves for the start and finish of the transformation.

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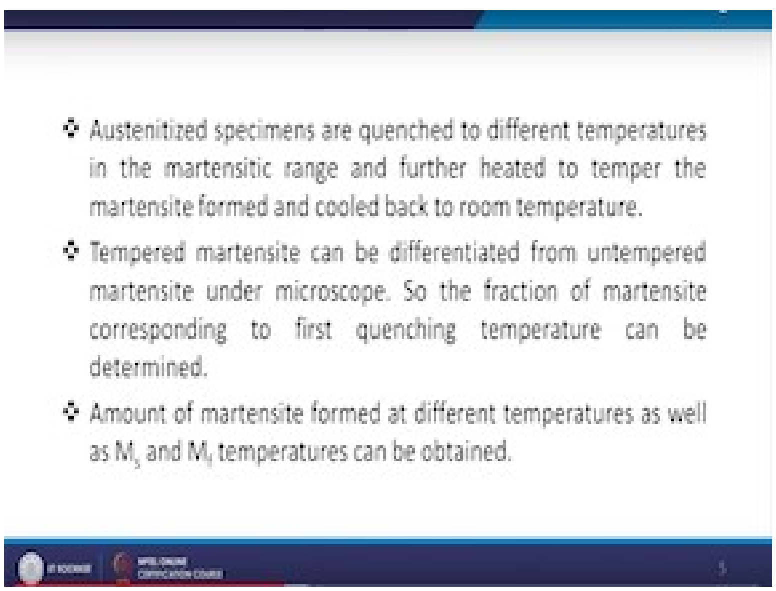

Now these austenitized specimen so there will be quenching to different temperatures in the martensitic zone so that will be different so you know what we will see and now this is how it looks like.

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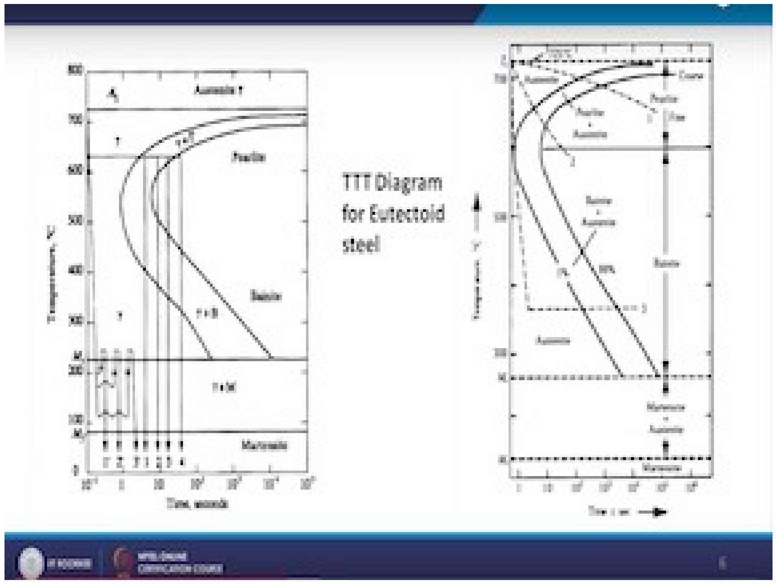

And now this is how it looks like, so what you can see that you will have this is the TTT curve for the eutectoid steel now look at it so this is your 725 °C this is your equilibrium temperature. Now from here you are basically cooling the so suppose you are holding the bath at some point here so if you hold this bath maintained at suppose 720 °C and if you suppose and this is a time so this is in logarithmic scale so this is 10^2.

So you can see that at this temperature somewhere just above or you are going till this time if you are up to this time even if you are coming and you are you know further quenching into the you know quenching at room temperature then you are to get 100% of martensite. Because there is no transformation up to this point, now when you are you know at this temperature suppose say 710 °C you are coming to this time.

So if you are having this time so at this point you will see that these transformation was there. So this line is shown as 1% this is known as 99 %, you know transformation lines. So at this point it will start as 1%, so it is 1% means there will be 99% martensite and here it will be 99% suppose so it is at you see that it is taking large amount of time. So certainly when there is a very less under cooling then for the transformation to proceed you know to get the pearlitic structure.

You will have to wait for you so long transformation takes a lot of time. So at this temperature you will have this point as well as the different points you will get and you will get the 99%

point line also. So this way at every temperature you will have two points you will be getting now you come to different temperature then at this temperature you are going to get this term this line this line so that way as you come down to and initial quenching.

So as you know that you are austenitizing first into the temperature which is above this temperature and then you are first you know quenching in a bath maintained at some temperature. So if you come to this temperature which is a minimum time at which you know the transformation will start and it will end also at minimum time. So that is known as the nose of this curve and then as you go down so that curve looks like this so these curves which you are getting that is known as the TTT curve.

Now in this because this is a this is also known as the isothermal transformation curves because you are talking about the transformation in an isothermal manner. So the transformation is occurring at a particular temperature and that way you are getting this locus of these points and accordingly you are you know drawing these curves. Now these curves will tell you that in what case the you know pearlite will be formed, where the fine pearlite will be found, where the coarse pearlite will be formed where which one is the bainitic region.

So in this case you will understand that when you are basically putting the material you know austenited specimen into a bath which is maintained at different temperatures how what kind of basically the microstructure you can think of. So if you are you know doing this temperature you are putting the here and you are holding and so what you see that in this zone you are getting the coarse pearlitic structure and this is the zone which is for the fine pearlitic structure.

Similarly, if you are going to this zone so that zone basically will be the bainitic reason, now what happens for bainitic reason. What you have to do is if you are coming directly you know you have this you know temperature but you come to this and then you hold it for in this path for some time. So at this you know because it is not it is the past the nose of the C curve so now it is coming here and then if you are holding it so you can have these bainitic structure formed. So you will have coarse bainite as well as the fine bainite structure in these cases.

So basically what you see is that you are going to have you know these two lines. Now what if you are cooling from here directly to this temperature so you are going to get directly the martensite. So basically that is it is basically the critical cooling you know rate so after we go past blue the this C curve. So this cooling rate will talk about the critical cooling rate where you are going to get a 100% martensite in such cases. So that way this is the significance of this you know TTT curve.

Now further if you look at this curve so what you see in this case what you do is you are coming you are going into the different you know temperatures and then you are coming to different temperature here suppose just below MS you are coming this temperature and then you are so you are transformed there will be some fraction of martensite formed and then you are further heating and then cooling to room temperature.

So now what happens in that case the martensite which is formed and then if you are further heating then that will be tempered martensite. So you will have to kind of martensite tempered martensite as well as the untempered martensite and because of the change in the colour because of etching you can differentiate between the tempered as well as the untempered martensite.

So if you select the different temperatures and then you do this process repeatedly so you will have an idea about you know this martensitic start as well as the martensitic finish temperatures that you can get. So this you know curve source so this curve you know this is the one here you are holding here itself and then you are going just below that also so like that if you do so you will have the line for M_s and M_f also determined.

So that is what it is or specified specimen they will be close to different temperatures in the martensitic range and then they will be further heated to temper the martensite formed and then further they are cooled back to room temperature. Now these tempered martensite so they can be differentiated from untampered martensite under microscope. So you can have the idea about the fraction of martensite corresponding to the first quenching temperature you know so that can be determined.

Now also amount of martensite formed at different temperatures as well as M_s and M_f temperatures they can also be determined using you know this curves. So what you see is that when you are coming to so this zone is the gamma zone this is the pearlite zone and this zone is zone, in this zone you will have γ+ pearlite in this upper portion and γ + bainite in this upper zone.

So if you are coming to any temperature here and then you are you know quenching so in that case the γ will be changing to you know martensite and the rest transformed product will be as it is. So if you are coming to in this zone you will have some γ which is transform to martensite and then rest will be pearlite. So and if you are crossing this line in that case all the γ is transformed only to pearlite.

So there is no point there is no chance of having any martensitic structure. So that is about you know that that is about holiday there is **transformation** from austenite to pearlite or bainite or so. Now what we mean to know further that you may have the steel composition other than eutectic also and if you have you know composition of either hypoeutectic or hyper eutectic in that case you know the **phase transfer** formation mechanism will be different and the TTT curves will also be looking somewhat different.

So that can be understood by looking at the you know what will be the change in the TTT curve. So when you have hypoeutectoid steel so that is say less than .8% of carbon so if suppose you are taking say 0.35% you know carbon. So for that you know carbon steel now in that case what happens that if suppose this is the time of 1 second. Now in that case what happens that you know for the hypo eutectoid steel in this range now in this range what will happen that the transformation will be starting from here and say suppose this is your 0.35%.

Now in this case the transformation will start from here and this zone is basically α+ γ so you will have a zone of α+ γ so what happens you will have this suppose you will have another temperature so which will be above the 725 °C and you will have this as 725 °C and this is somewhere close to 800 or so. Now in this case what happens that so it will start from one second and and this will be one minute and this will be one hour or so.

So the the line goes like here so what is there so you are above this temperature you have γ and this zone is basically $\alpha+$. Now what happens that your transformation line moves like this and it will be coming so ultimately you know you have this transformation which is about what we have lined which we have seen earlier that is this line and this region so it will starting line will be this and you have finishing from here.

So this way the lines will move now this will be your α + pearlite because you will have the pro-eutectoid you know ferrite formation so you will have pro eutectoid ferrite + pearlite. Similarly, you will have you know $\alpha+$ + you know pearlite in this case.

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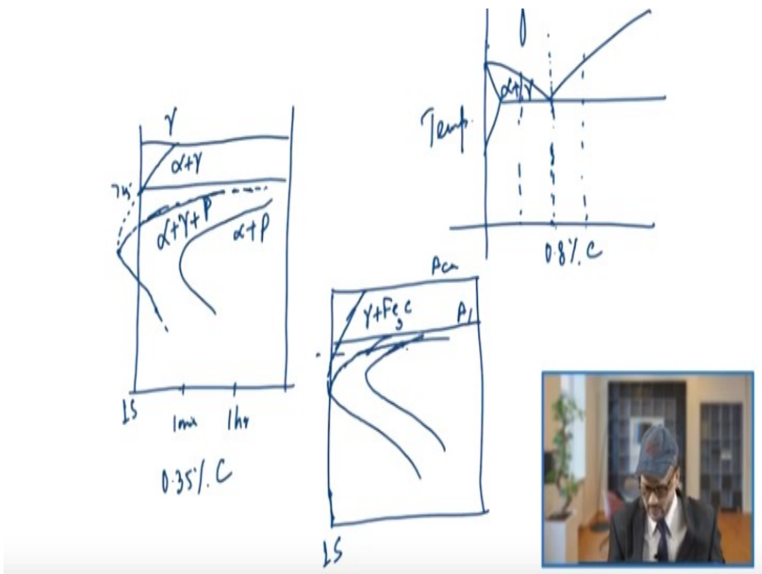

So what you see that in this case this is one second if you look at the you know this point now in this case if you see so this is the here this is somewhere close to one second or even more this nose point is for the eutectoid steel.

Now in this case what you see that this is less than that it is about 0.2 seconds so it is towards that now in this case getting a complete martensitic structure will be very difficult you will have to have very high cooling rate to have the fully martensitic structure. So that is the main difference and also you must be knowing that when you are coming from that temperature in that you know in that case you will have the $\alpha + \gamma$ zone and then once you go below that temperature further.

Then α is already there and gamma will be again changing to γ + so that will be going towards the pearlitic transformation. So that way your transformation will proceed similarly, if you go for the you know hypo eutectoid steels. So hyper eutectoid steel will be towards this line and in this line rather than you will have the cementite on this side so if you try to draw the the TTT diagram for the you know hyper eutectoid steels.

Now in this case what happens if you take this at the 1 second line so you will have again a line and in this case. So this is your A_1 line and you will have so A_{CM} line now in this case what happens that you will have this cementite + . So that will be coming so you will have this will be your γ + Fe_3C and then this line will come and then it will go like this. Similarly, so this line will be from here it will be moving like this and there will be so this will be start it will be starting and then it will be finishing will be like this.

So basically at this temperature if you go like this will be the transformation start finish. So you will have in this zone you will have a Fe_3C + pearlite and this will be γ + Fe_3C. So you know here again you see that this is close to you know one second whereas this is quite early so in this case this hardenability basically can be seen that hardenability is less you know you your chances of conversion to martensite becomes less.

Because you have to will have to apply very high cooling rate then only your you know these lines so it will be you will be getting the whole martensite now the how to you know change these hardenability. So basically with the use of alloying elements you can very well change the hardenability and you can have you know the conversion to martensite full martensite structure so what we do is normally if you go for a alloy steel.

So effect of alloying element is there on these TTT diagrams if you take the you know nickel chrome molybdenum steel. So if you this is a low alloy steel and if you try to see the TTT diagram for such you know steel. So what you see that they will be shift in the you know these curve and the shift is towards the left so if there is shift towards the left. So if suppose this line itself shift towards left so you have more freedom.

So you can have for any cooling that you will have more chances of having the transformation to martensite.

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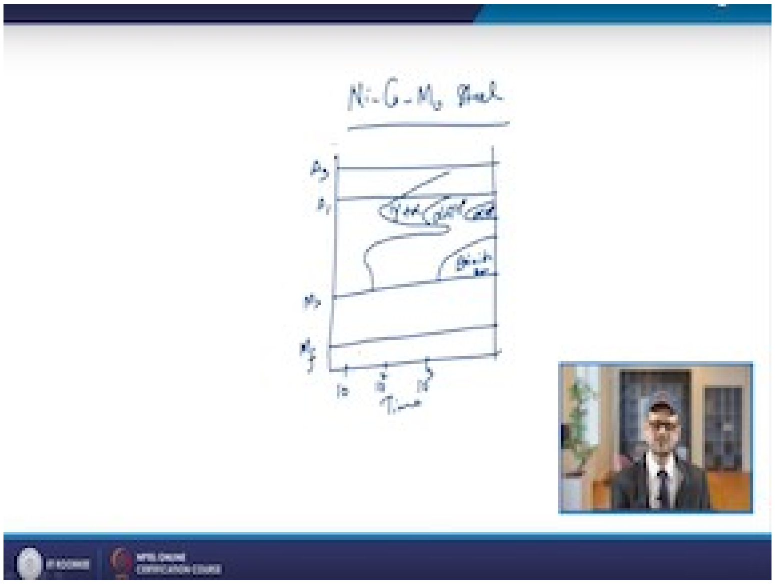

So what happens that for such you know so if you this line is A_1 and this line is A_3 now in this case your you know the N and this is your M_s and M_f temperatures so if suppose this is your M_s and M_f temperature in that case if you try to see the curve the curve you know goes like you know this way. So this way it goes so what you see that and this your bainitic zone and towards you know this side you will have α+ pearlite.

You will have another zone which will be coming here and this will be alpha + gamma + pearlite and you will have $\gamma + \alpha$. So that way now what you see that because of the use of alloying elements now this is your time and and here your if you use you see this will be ten seconds and this will be 10^2 seconds this is 10^3 seconds like that so what you see in normal case your nose was close to one second.

Whereas in this case it is even after this about ten seconds of time so there is shift of the nose towards the right and that basically increases the hardenability and in normal case also you can have the you know formation of martensite with the addition of alloying elements you know and that way it will be affecting these TTT diagrams.

So this is in nutshell about the TTT diagram and we have seen that how these diagrams can be read how by referring to these diagrams you can understand that with certain cooling rate or at what temperature and with what time what amount of transformation will be there. So what will be the different phases which you are likely to get. So basically this kind of you know transformation where you are coming and holding at this temperature and going isothermal transformation here coming so that gives you the bainitic transformers or bainitic phase.

So that way then you come for coming into the martensitic zone so that is about this TTT diagram and we will further read about the continuous cooling transformation diagrams. So that is about this lecture. Thank you very much.