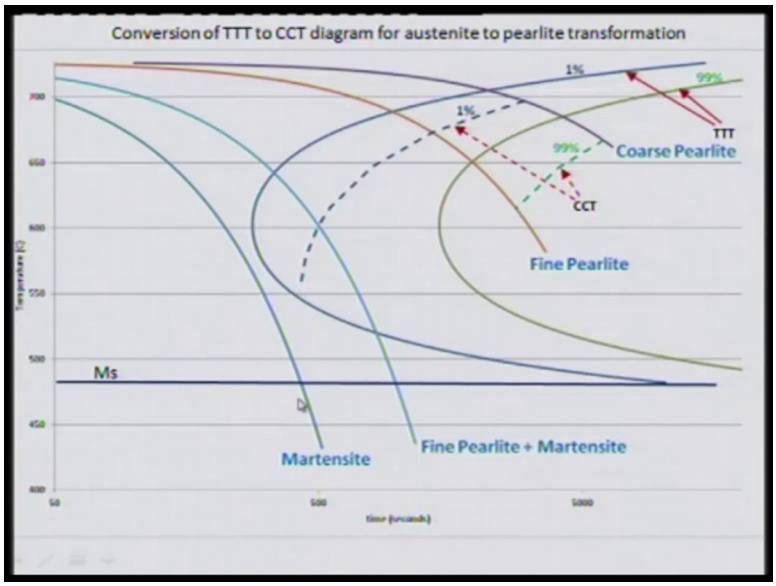
Heat Treatment and Surface Hardening - II

Prof. Kallol Mondal
Prof. Sandeep Sangal
Department of Material Science & Engineering
Indian Institute of Technology, Kanpur

Lecture - 39
TTT, CCT continue and hardenability of steel

Welcome to the second last lecture of this course. In the last lecture we were discussing time temperature transformation diagrams as well as the continuously cooled transformation diagrams. We had seen how we can evolve the time temperature transformation diagram from the transformation kinetics. And we had then seen how we can transform the TTT or the Time Temperature Transformation diagram to the CCT or the Continuously Cooled Transformation diagrams.

(Refer Slide Time: 00:52)



So, here is what where we were in the last lecture, where these solid lines the solid C curves are the TTT curves for a austenite to Pearlite transformation in a steel. And then we had used the principle of additivity to convert this TTT diagram to the CCT diagram which is shown by these broken lines.

So, here we had only done a very small part of the curve on a spreadsheet to show how this principle of additivity is used, here now you see a larger part that this broken line for example, here shows one person transformed if you have these cooling continuously

cooled curves for a sample. So, what this means is that if I am cooling along this path at this point here we would have 1 percent Pearlite formed from austenite and you continue cooling, then at this point here we would end up with 99 percent cool. In the last lecture I had not show this line, but this line has also been now calculated using the same, additivity, principle. Similarly you can look at this other cooling diagrams.

But one of the things that I would like to impress on you that when can this additivity principle be used whenever you have the rate of transformation can be related to as purely a function of the fraction transform and as a function of the temperature. And then we had shown that if the transformation was following Avrami kinetics, then for this system n must be a constant if n is not a constant then that the validity of the principle of additivity is lost and we cannot use that principle.

Now we had also Indica talked about that n is a function of the mechanism of the transformation and here, we have the same mechanism of transformation throughout. So, it would be reasonable to assume that n is constant and only the parameter k of the Avrami equation is a variable and which is a function of temperature.

Now on this diagram already in the earlier lectures you have been told that if you cool very fast like on this curve then you do not touch any of these curves. And hence no diffusional transformation is possible and in steels you end up with a with a line which is called M S line which is the martensitic start line. Therefore, the austenite then directly transforms to martensite.

Now let us just follow each of these cooling curves and we will add use these broken lines as my CCT or the Continuously Cooled Transformation curves. If I am following this particular line which is a relatively low rate of cooling. So, I will start forming Pearlite here and by the time my I reached this point I would have completed almost all of their transformation all of austenite would have transformed to Pearlite.

Therefore, the end product would be Pearlite if I follow this, if I follow this particular curve which is a somewhat faster rate of cooling again, when I reach this point, 1 percent transformation occurs, and by the time I reach this point almost all of austenite has transformed to Pearlite. Then what is the difference between these 2; these 2 cooling curves does it make any difference to the microstructure because in both cases we are getting Pearlite well yes in both cases you get Pearlite, but in one case you will get a

Pearlite which is relatively coarse, which means layers of ferrite and layers of cementite are going to be thicker as compared to the faster cooling rate followed by this path where you would get a much finer Pearlite.

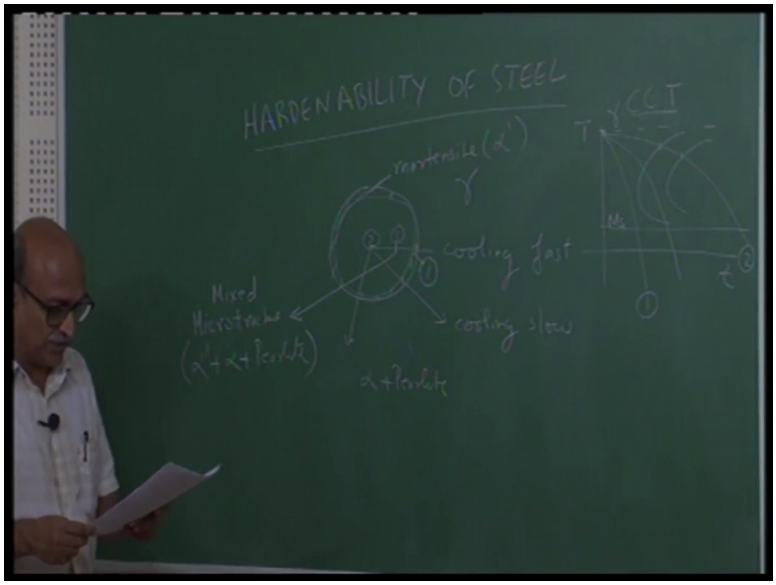
If you want, this now gives you a handle that you can now design a heat treatment where you may want to have a Fine Pearlite, why do you want to find Pearlite well having a having a fine scale microstructure having a fine Pearlite gives you improved mechanical properties in terms of strength as well as ductility, that is why you may want to prefer find Pearlite and then you may want to do a faster cooling to get get a fine Pearlite. Now let us take a look at this third cooling rate, now here what happens is it touches this broken curve broken line which is a CCT curve well this one at this point 1 percent transformation starts to occur and then as we go along some more transformation will keep occurring.

But it never touches this 99 percent it will never touch this 99 percent transformation curve, because it this curve will end somewhere here. So, what would happen in this case well part of the austenite will transform to fine Pearlite and whatever is left when it hits the M S line, then it will undergo a Martensitic transformation and therefore, the final microstructure you will get would be a Fine Pearlite plus Martensite which is a as you know is a very hard phase. So, this kind of a microstructure would give you properties which are very different from the properties when you get fine or coarse Pearlite. Now let us look at this final fourth curve, fourth cooling curve does not cut touch even the starting of the transformation or starting of the diffusional transformation.

And it directly goes below the martensite start line, hence the final microstructure you will get would be 100 percent martensite, and if I just take this microstructure and use it in some application it may not work out for me why it would not work out for me is that this would be an extremely brittle material, and you may then want to somewhat soften it, but tempering it at maybe temperatures of 400 450 degrees centigrade for some time. So, that you get a tempered might martensitic structure which would be hard as well as a little bit of softness has been imparted to it by the tempering treatment. Now with this thing that we now have in place the transformation diagrams, with these diagrams we can actually design a different kind of heat treatments.

But before I really go into the principle of a heat treatment, I would like to I would like introduce and an interesting topic and important topic and which is called as hardenability of steel. And hardenability of steel is directly related to my transformation diagrams as you will see shortly. So, let us try to understand what does hardenability of steel mean to us.

(Refer Slide Time: 09:34)



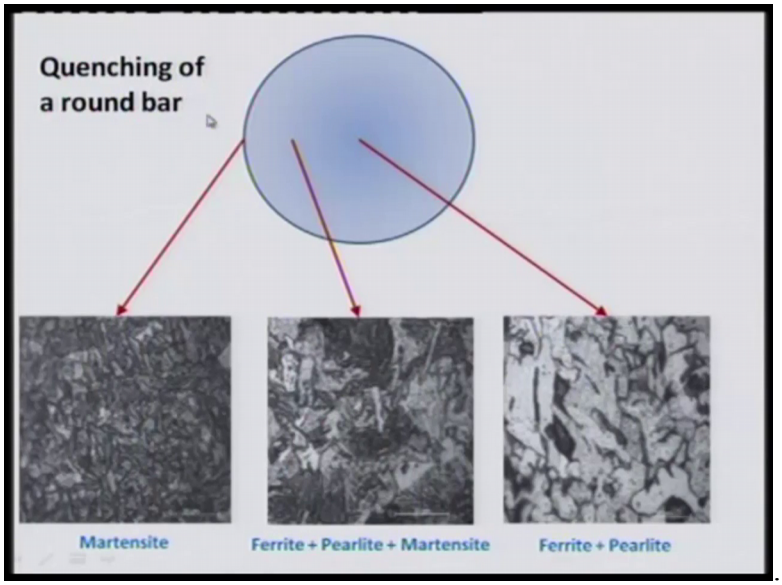
So, hardenability of steel is the ability of steel to transform from austenite to martensite at a given depth when cooled under a given condition, what this essentially means is that if I take let us say let us say I take a round bar I heat this up. So that, heat it up in the austenitic region. So, that I have 100 percent austenite in the steel and then I quench it in some quenching medium.

So, what would happen very clearly the surface regions of the steel? In this region the cooling rate would be very fast. So, cooling is fast while if I go right to the interior depending on the dimension of the rod the cooling will be relatively slow, and if this dimension is large enough then cooling can be quite slow. In fact, you will have all along right from centre to the surface I will have varying cooling rates. Now imagine that I have a CCT diagram for this particular steel for a given composition my CCT diagram may be something like this is the start line this is the end line this is the temperature in the time axis now where the cooling is very fast. So, I am here let us say out here everything is austenite on the surface. So, this if I call it as number 1.

So, this is number 1 that cooling in this surface region is so fast, it does not touch any of these curves. Hence I am going to get martensite here which incidentally can be we use the symbol alpha prime, at the center my cooling may be something like this. So, this is let us say region 2 in the in the interior, here then I am going to get martensite plus ferrite plus Pearlite no sorry there will be no martensite because the it does not martensite start line is here, it simply starts the transformation Pearlite starts to form and Pearlite formation ends and hence at the center I have only ferrite plus Pearlite. Somewhere in between if I call this as 0.3 my cooling could be something like this, here what would happen is I will get ferrite, I will get Pearlite, I will get partly martensite.

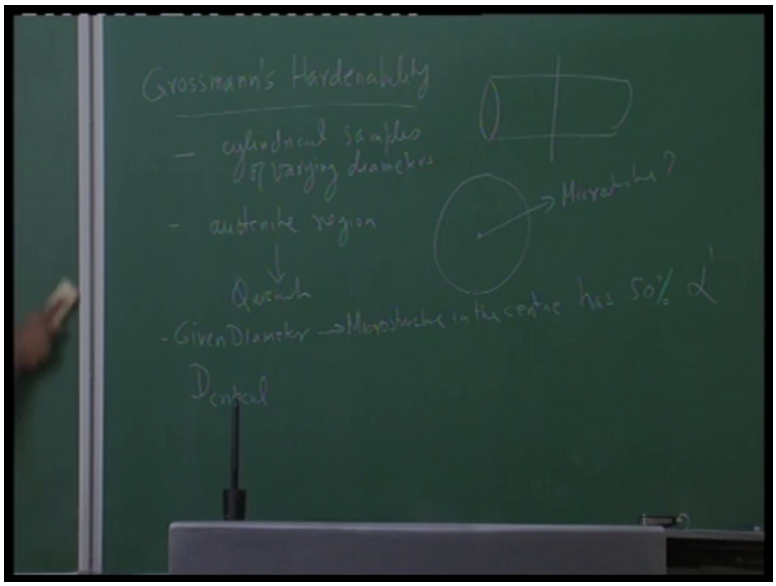
So, I am going to get a mixed microstructure of martensite ferrite plus Pearlite. Of course, if I was looking at eutectoid steel then I will only be getting Pearlite or Pearlite and martensite or only martensite. Now this using this idea, we define what is called as the Grossmann's hardenability.

(Refer Slide Time: 14:09)



And In fact, before I even do this let me just show you, that this is the slide showing quenching of a round bar. So, I have martensitic structure at the surface right in the center I have ferrite and Pearlite and in between I have ferrite Pearlite and martensite. Of course, if my cross section was very small then I may not get such differences.

(Refer Slide Time: 14:43)

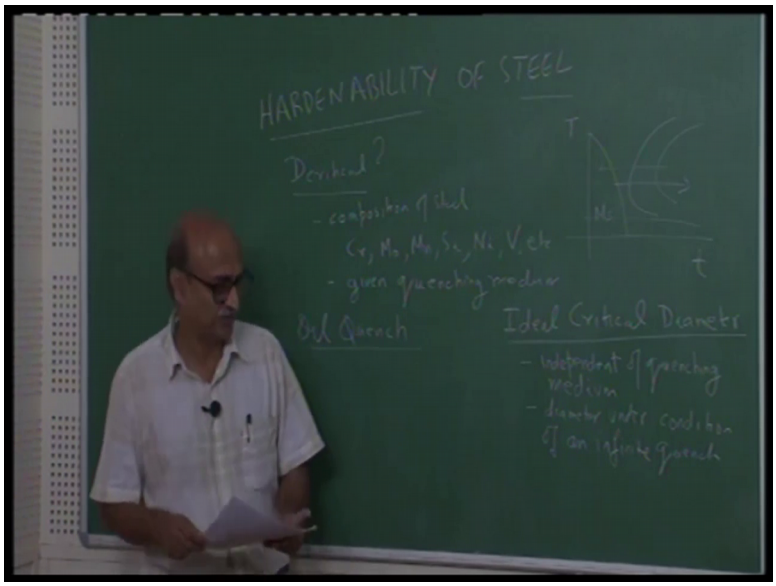


Now using this idea we can determine what is called as the Grossmann's Hardenability and what is Grossmann's hardenability well first of all it uses cylindrical specimens of varying diameters.

I will have several cylindrical samples of different diameters, and what I do I austenitized them. So, first take it to the heated to austenite region from the austenite region you quench the samples, then if this is my sample I take a section in the middle of the sample. I will have a section like this and I look at the microstructure at the center, what is the microstructure here, what kind of a microstructure I have here as expected I should have either ferrite Pearlite or I might have a mixture of ferrite Pearlite martensite if for a given diameter. So, if for a given diameter the microstructure in the center has 50 percent martensite, if it has 50 percent martensite for a given diameter d then this diameter is denoted as the critical diameter.

And that is what defines the Grossmann's hardenability that for a given this particular diameter I will get on quenching 50 percent martensite at the core of the sample. Now this is also not very satisfactory and I will just show you what is the problem with this definition and then we will come up with the alternate definition of hardenability.

(Refer Slide Time: 17:41)



So, what would d critical depend on, what factors would d critical depend on well one is very clear it will depend on composition of steel. So, that is alright in some senses that d critical will tell me whether the steel has a high hardenability or a very low hardenability. In fact, what does it mean by high hardenability; high hardenability means that d critical will be large, low hardenability means d critical would be small.

For example, in what circumstances would d critical be large in terms of the composition of steel well, it depends on how the various alloying elements affect my transformation diagram. If on adding an alloying element that the CCT curves shift to the right, what this essentially means is that it is easy to cool without touching any of the diffusional curves in any of the c curves. For instance I have at some depth I have a cooling rate like this if an alloying element shifts these diagrams to the left, then the for the same cooling rate I will start getting ferrite and pearlite, but for another steel where I have added some other alloying element which has shifted the cooling curves to the right this may simply not touch the c curves at directly go below the martensite start temperature.

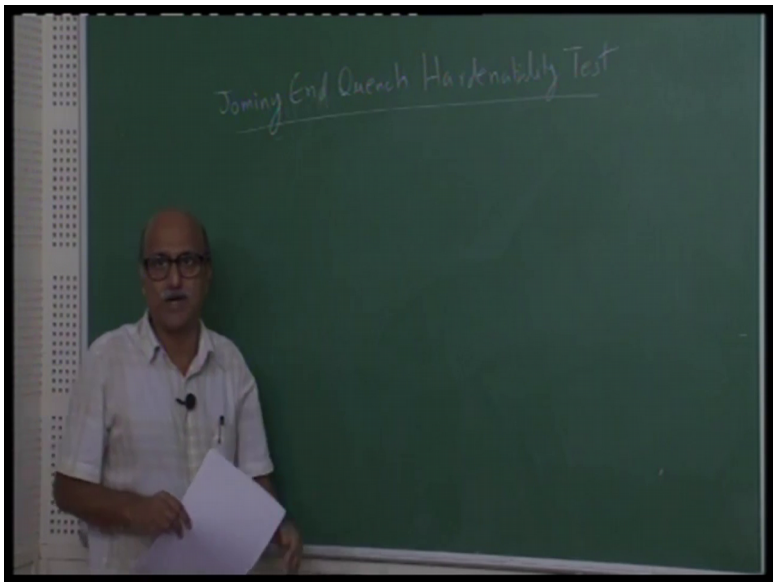
Those alloying elements which will shift these c curves to the right would mean that they would increase the hardenability of steel, and some of those alloying elements which would do that. For example, Chromium, Molybdenum, Manganese, Silicon, Nickel, Vanadium that these elements when added to steel shift the transformation diagram to the right and hence increases the hardenability.

So, this in that sense d critical is a good measure for comparing for different steels, but this are all for a given quenching medium. Now you can you can have other quenching medium which may produce different cooling rates and hence d critical would change. For example, if I do oil quench now Oil Quench compared to water quench would be less severe and hence d critical would become small.

Because these cooling rates are going to be relatively low, on the other hand if I use water quench with agitation then that would be much more severe than a plane quench in still water. So, then also then d critical would become different. In fact, d critical would become larger. If we want to define hardenability in a way which becomes independent of the quenching medium, then Grossmann hardenability, under Grossmann hardenability a concept called the Ideal Critical Diameter was brought in. Now what is this ideal critical diameter, this determines the hardenability independent of quenching medium and this hardenability is defined as the diameter under condition of and what is called as an infinite quench.

And what do I mean with that, what it means is that the temperature of the surface of the sample when it is quenched is brought down instantaneously in 0 time to the temperature of the quenching medium. And the diameter at which under this kind of a quench I get 50 percent martensite at the core of my round sample round bar is called the ideal critical diameter. So, this is one way of assessing hardenability of steels of different compositions. Now there is an alternate way and which is a widely used method of assessing hardenability of steels and which is called as the Jominy end quench hardenability test and let us look at it what does this Jominy test been how it is done.

(Refer Slide Time: 24:26)



So, Jominy End Quench Hardenability Test, the advantage of this kind of a test over the Grossmann's hardenability is that you require one single specimen in the Grossmann's hardenability you needed several samples of different diameters, here we work with only one single sample to assess the hardenability of a steel. So, that is one very big advantage; the other advantage of this is that it has very good reproducibility. Now what kind of a sample do we use first? So, here is an example here is a sample for the Jominy end quench test. So, this is again a round bar this is typically has a diameter of about 25 m m and a length of about 100 millimeters. And what do we do with this well we take this sample of the particular steel for which you want to measure the hardenability and you put it in a furnace to austenitized the sample.

So, that it is 100 percent austenite then you take it out of the furnace and very quickly put it in what is called as a Jominy apparatus, and in the Jominy apparatus the sample is hung from the top and water is sprayed from the bottom. So, that quenching is done at the end of the sample and that is why it is called the Jominy end quench test. So, the heat transfer takes place linearly in one dimensions along this path and slowly the entire sample cool. So, what will happen is you will get different cooling rates, fastest cooling will be near the end and as we go away from the quench end slower and slower cooling will take place and it is best that I show you an actual video clip.

So, that it becomes clear what kind of a test is this.

(Refer Slide Time: 26:56)

So, here this is in the lab out here you see that this is the sample which is being taken out of the furnace after austenitizing and let me just play this clip. So, you quickly take the sample and put it inside this Jominy apparatus.

(Refer Slide Time: 27:15)

And you can see now, water is being spread from the bottom onto the sample and slowly the whole sample is being cooled, but you would have different cooling rates. After the sample is completely cooled you take it out and you can then section it at different distances from the end and look at the microstructure.

Obviously, near the quench end you are going to get 100 percent martensite very far away from the quench and you are going to get a ferrite Pearlite kind of structure and in between you are going to get mixed microstructure. Steels with very high hardenability would have a very large depth up to which martensite would be forming and steels with very low hardenability would form martensite it in very shallow depth from the quench end.

So, this very quickly one single sample] enables you to assess the hardenability of steel. This gives a I gave a quick idea regarding how to assess hardenability of steel, what are hardenability and how to assess hardenability of steel with this we close the lecture and in the next lecture we will look at some applications and some case studies where heat treatment principles are used.