

Principles of Casting Technology
Dr. Pradeep K. Jha
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture – 37
Heat Treatment of Casting
Heat treatment of plain carbon and alloy steel casting

Welcome to the lecture on Heat Treatment of Castings. So, in this lecture we are going to discuss about the heat treatment of plain carbon and alloy steel castings. So, basically we are going to deal with the steel castings in the ferrous group. So, what is the need of heat treatment? As we know that depending upon the suitability of the composition or properties or depending upon the ease or depending upon the requirement, different kind of molding process are selected it may be sand molding, it may be die casting or any other kind of molding process.

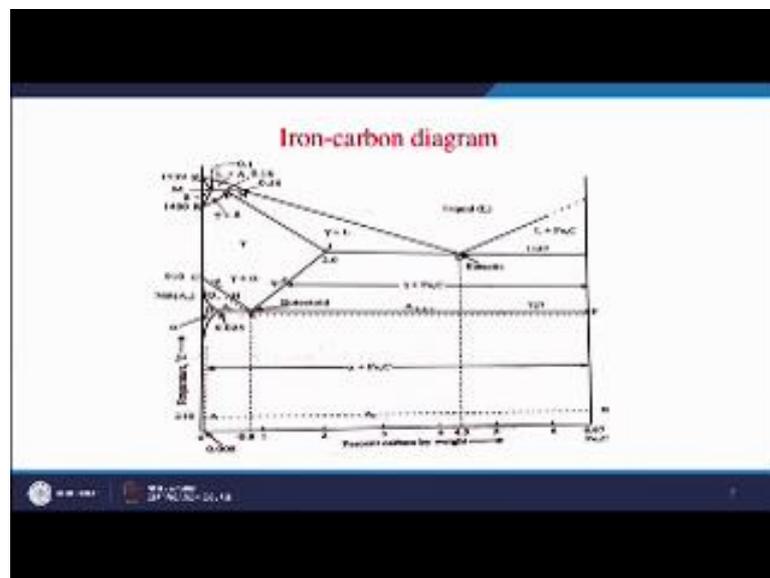
When the casting is taken out, not necessarily the casting has the properties what we desired to achieve. So, what happens that during the casting, there is large amount of gases which are likely to be inside the casting, there are different section thicknesses of the casting and the properties also vary. So, you may be in a position you may not be in position to use this product directly under any application because if the heating rate is not proper or thermal gradient has been quite high, there is large amount of residual stresses which are likely to be inside the casting. So, casting if it is used and if the impact loads are coming into picture and if the toughness is quite low in that case the casting may break so below that strength where it is expected.

So, there are properties which are required to be removed the structure is needed to be seen that you get in the proper phases, proper structure of the material because ultimately that only determines what will be the property of the material and how this material will basically behave, when it is subjected to the different kinds of loading. So, when the casting is taken out in during that process since there is thermally treated, its property changes at many places and there are certain things which are required to be. Certainly in casting normal even we will talk about the sand casting so you have the formation of residual stresses inside the casting because of the fast even cooling or because of the presence of thermal gradient.

You may also need to go for treatments like in which you may get the good hardness of the surface in certain cases; you may like also to get good toughness of the material. So, all these things are to be you know incorporated in the casting product. So, that is done by the heat treatment process. Now so for removing modifying properties and for a stress relieving that there is need of heat treatment process.

Now, as we know that this heat treatment process in that basically there is transformation going on. The material has certain structure certain phases are there and they are basically further reformed they are redistributed, there is formation of one phase at the cost of other or there is morphological changes in that. So, basically it is all going on and that is a kind of transformation which is going on. So, as we know this transformation is normally using the nucleation and growth. So, what happens that in the case of you know ferrous casting as we see, we can see the iron carbon diagram in this cases you have a steel is coming up to this strange of carbon and then you have in the case of alloys it you have different alloying elements.

(Refer Slide Time: 04:44)



So, what happens normally your heat treatment is so when you are talking about the plain carbon steels so your reaction which is primarily taking place that is controlled by this reaction which is taking at this point this is the eutectic point. So, at the eutectic point, you have the austenite in this zone and this austenite basically will be decomposing to ferrite plus cementite. So, that is your eutectic reaction, when it is

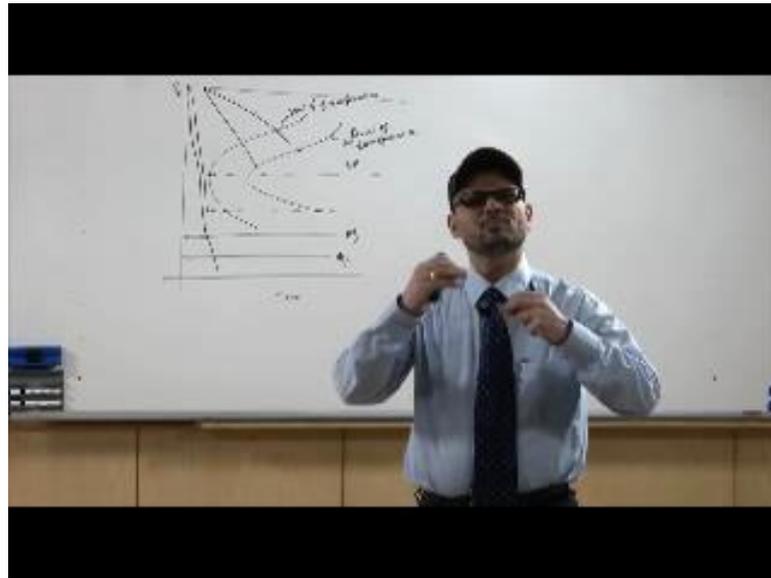
cooling the austenite will decompose to ferrite plus austenite, ferrite plus cementite and when we are basically heating in that case this ferrite plus cementite so that decomposing is pearlite, that will go and change to the austenite.

So, this transformation at this point as well as its transformations at all these places may be below also you have transformation taking place. So, basically this transformation is using the nucleation and growth process and this nucleation basically is on the impurities at the grain boundary that is there on that places the nucleation take place and this way you have first the parent phase and then you have the product phase coming out the parent phase. So, you at the expense of the parent phase, new phases are coming up that is product phases are coming up. So, there is nucleation of one phase from the other and this way at the end you have a different kind of the structure which gives the different kind of properties because all the phases have different you know properties.

Like you have the ferrite which is extremely soft, but then it is not stable at room temperature and in this zone you have cementite in austenite which is Fe₃C. So, you have this which has a brittle deforming properties. So, being Fe₃C you can go in this range and then it has got good plasticity and then further you have so in fact, cementite if it is more it is extremely hard and brittle. So, depending upon also the kind of phase, like you have the formation of martensite that is bcc that is transformed because of the formation of martensite from austenite because of the rapid cooling that we will discuss later; so all this formation of different phases will basically determine the quality of the casting as far as its properties are concerned.

So, what we see is that you have this point or I mean above and below where you have here ferrite plus cementite that is pearlite and then this is austenite, and how this transformation takes place. So, as we know that you need certain under cooling, below which the nucleation take place then after this nucleation there is growth taking place. So, if you take the transformation process normally there is the transformation is time dependent also. So, you have a time temperature transformation graph that is known as TTT curves. So, if you look at the TTT curve it is for its eutectic composition of steel.

(Refer Slide Time: 09:51)



Now what you see it is shown here, now this is your equilibrium temperature and once you are coming you suppose heating this fashion you are read cooling in this fashion, once it touches at this line is start of transformation and this is finish of transformation. So, what happens when you are cooling and the stage is reached, when it touches this line, the austenite will start transforming to another phase so austenite will basically the changing to pearlite. So, pearlite is nothing, but you have alternate lamely of ferrite and cementite, now and when it comes here then this is the hundred percent transformation of austenite to pearlite.

Now if you look at these and if you look at in this fashion what you see is, this is having a line indication in of higher cooling rate. So, what happens when you have a slow cooling rate going on it means this is a time axis. So, for certain temperature drop you are taking this much of time and you are taking the smaller time for this temperature drop. So, what you see is if you take these two lines, the cooling rate experienced or cooling rate given is higher in this line.

Now, what you see is depending upon this TTT curve you can predict what kind of structure you are going to get. So, if you are having a very coarse type of pearlite, it means the material is basically or casting subjected to a heat treatment where are it is cooled very very slowly. So, normally in the case of a annulling, when we do when we cool in the furnace at a very slow rate, in that case if your transformation is finishing at

this point in the upper portions, you see this upper portion were it is finishing it will be normally giving you a coarse pearlitic type of structure. So, this way this is the time temperature transformation curves which tell that, how with time and temperature the transformation gives, because transformation product is a function of the nucleation rate and growth rate.

Now, in this case if you look at here in the case of slow cooling rate, because of the higher temperature it is experiencing for larger time the nucleation is not predominate. In fact, growth becomes predominate and since nucleation is not predominate, the growth process leads to formation of the coarse kind of structure of the pearlite, that is why you get this coarse pearlitic structure when your cooling rate is like this. But if your cooling rate is higher than this line, if the temperature difference is more in the same time in that case you are getting a fine pearlitic type. So, here you have coarse pearlite here you have fine pearlitic structure.

Now, this is called the nose of the c curve. So, if it is crossing through the nose of the c curve. So, this point up to which if it crosses then there is formation of pearlitic structure and depending upon the cooling rate you have either the formation of coarse, pearlitic structure or the fine pearlite structure. Now what happens as we see the next range is the bainitic structure. So, in these cases what happened this is a kind of phase that is bainite. So, it has the different kinds, here you have cementite in the needle shape. So, because of the larger cooling rate and because of being in the lower range, here this is nothing, but the carbide particles are there, but they are in the needle shape imbedded in the ferrite matrix.

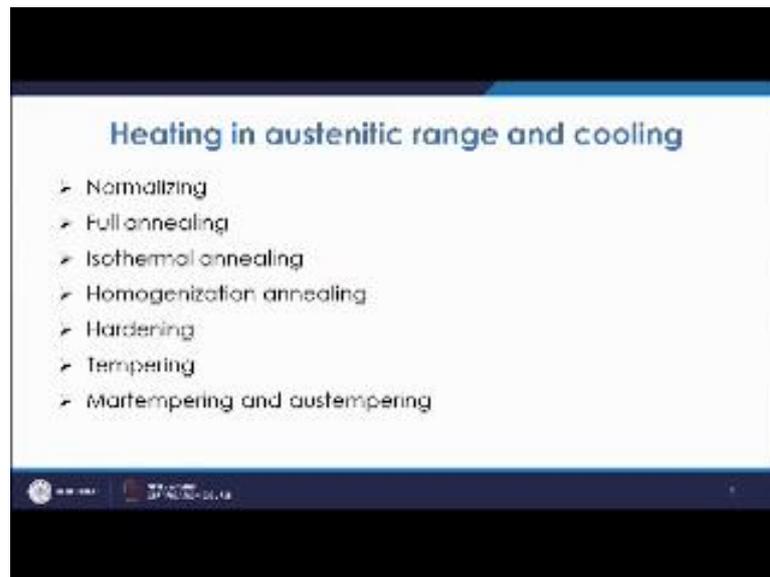
So, that gives better properties in the case of. So, you see in these case you get ferrite plus Bainite. So, you get upper Bainite which is feathery type and this is a (Refer Time: 15:19) type of Bainite that is known as lower Bainite structure. So, you are getting this bainitic structures. Now what happens when we go; so far getting this you have to pass the nose of the c curves. So, once you have the cooling rate which is passing into this line that is known as critical cooling rate. So, basically you are avoiding the transformation of austenite to pearlite and you have two line which is shown one is Ms and Mf as its seen here you have this Ms and Mf line. So, Ms and Mf line talk about martensitic start and martensitic finish lines.

So, what you see is when it goes below this temperature then there will be start of martensitic phase formation. So if it goes passed to the c curve and it passes, here from downward the martensitic will start to form and this is the martensitic finish process. Now what happens for getting that is bainitic structures normally what we do is, we come here and basically here if we hold it at that temperature and go in this bainitic range then there is a process known as isothermal process. So, basically you have isothermal process gives you a bainitic type of a structure, then there is another process that is (Refer Time: 17:08) tempering process because formation of martensite is basically inducing a large amount of stress and martensite phase is extremely hard.

So, and it induces large amount of stresses. So, what happens when you come to this point then you hold for some time? So, you are coming to this point above the M_s temperature and holding and then without going into this range, you are going into this in between the M_s M_f line and a passing this M_f line. So, in that case you are getting completely martensitic structure, but by holding this line at this point for certain time, basically you are allowing the diffusion to take place and having proper homogenization or proper temperature distribution in that case the chances of having large amount of structures that becomes small. So, this treatment is known as (Refer Time: 18:20) tempering process. So, by looking at the different kinds of these phases at all these points and by studying this TTT curves, you can control that what kind of heat treatment should be given so that a proper or a desirable phase is formed and the casting has that kind of properties what you expect.

Now, we should discuss about certain type of process which involves heating in the austenitic range and then further cooling.

(Refer Slide Time: 19:03)



So, as we have seen that the TTT curves show that in what case what kind of phases are being formed. So the process which are based on heating the material in austenitic range and then further cooling, one is normalizing. So, this normalizing is based on the concept that you are heating the material in this temperature. So, this is the A₁ line and this is the ACM line this is normally known as. So, you are heating 50 to 100 degree centigrade above this A₁ this A₃ line or ACM line and then you are cooling in the normal layer so that basically known as normalizing. So, normalizing gives you a good combination of tensorial strength and ductility. So, that is done for the hypo eutectoid steels, where it is heated above this either A₃ line or the ACM line and then further along it to cool in the air; then full annealing.

So, full annealing basically you are done normally for hypo eutectoid steels, so you are going to about 100 degree c above the A₃ line and then you are cooling in the furnace at a very slow rate. So, that process is known as full annealing. So, you are holding in the furnace for some time and then you are cooling at a very small rate. So, normally to give very soft property, to impart the toughness, to impart good merchantability, you give this full annealing treatment, but in this case there may be chances that the structure may be coarse that is there, but otherwise to make it soft and all the material becoming stress free, the full annealing treatment is given.

Isothermal annealing; this isothermal annealing it is done so in this case also you are heating above A_3 or a cm temperature and then you are cooling it at a temperature below this critical line and then holding there for a large amount of time at that temperature, that is why it is known as isothermal annealing. Then this is homogenization annealing, in homogenization annealing what is done is the material is heated in this temperature it comes about 11 to 1200 degree centigrade it is heated there.

And it is also hold at that temperature for large time. So, this homogenization annealing is done to basically ensure that there is no segregation of alloying elements, many a times you have segregation of alloying elements. So, this homogenous annealing in which it is going to higher temperature hold that at temperature and then further cooled in a very slow manner that give basically redistribute this alloying elements and then it also improves its plastic workability. So this way after when we are going to deform the material plastically in stages, in those cases we do this homogenizes annealing in which its deformability or plastic workability increases, so when we go and give this treatment. Then comes hardening, in hardening again you are heating the component above A_3 or ACM line and then you are quenching it into any medium like water, oil or blind solution.

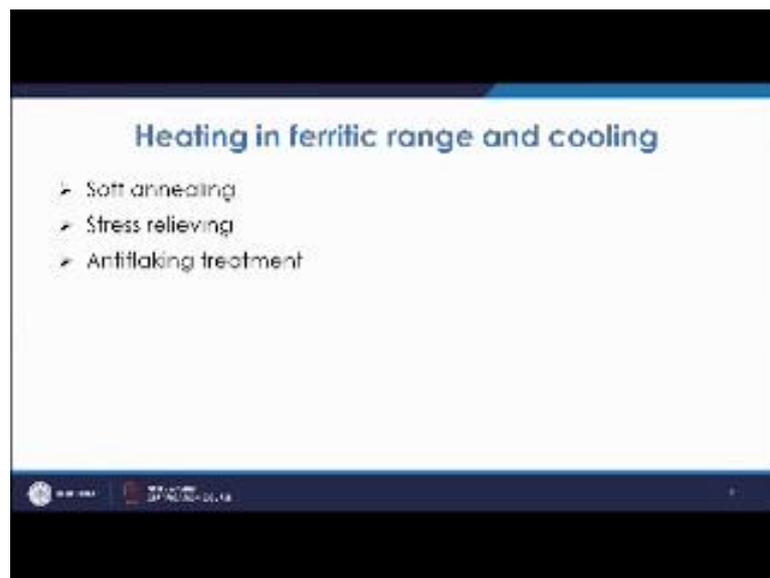
So, what happens this cooling rate is so fast that there is extremely hard surface is achieved and also depending upon the thickness section thickness you will have the formation of hard phases like martensite up to certain depth or the full section being martensitic, that again depends what kind of TTT curve it is, what kind of cooling curve it is in that case? So, depending upon that you will have the formation of phases and you have hard a structure being formed.

So, for increasing the hardness, you go for these hardening treatment in which you are heating them in the austenitic range above 50 to 100 degree centigrade above A_3 or ACM and then you are quickly quenching it into oil water or any suitable solution like (Refer Time: 24:27). So, then after hardening, this tempering treatment is done because if the matersaties formed it is extremely brittle. So, to give some softness to its to make it little tough you give the tempering treatment where you heat to slightly lower temperature 400 to 500 degree centigrade may be the temperature ranges from 200 to even 500 degree centigrade and then you are keeping at that the temperature for sometime so that basically gives some softness in that phase which is a extremely hard

that and that basically makes it somewhat tough. So, this treatment is done to induce the toughness and softness.

Martempering and austempering; so, we have discussed about it in the martempering case you are austenitizing the material and coming back and holding above the M_s temperature and then after sometime again cooling so that all the phases are martensite. So, this because of the holding for certain time, you have enough time to basically make the temperature even at all the positions all the points and then once you are dipping, once you are cooling in between M_s and a reference if the temperature coming, then in that is martensite total martensitic structure is formed. So, this way you get the martensite which is not extremely hard and brittle; austempering already we have discussed where we are holding and going in to the bainitic range, so that is austempering.

(Refer Slide Time: 26:16)



Then there are also certain treatments or process which are based on heating in the ferritic range and then further cooling. So, basically we have talked about the austenitic range. So, we are going above the temperature lower critical temperature line and basically that line also shifted or this zone of austenite also shifted because of the addition of many alloying elements. So, either it may shift towards up side or towards the down side. Now in this case what you do is the temperature is kept below, it is only heated in the ferritic range and there after you do these treatments like soft annealing. So, you are going below this, all this temperature treatments are done soft annealing, that is

basically to remove so, it make it more tough this for removing the stresses so normally you are going.

So, in this case basically this you are holding this around may be heating to 500 to 600 degree centigrade and then keeping at temperatures for a long time. So, what happens this spherical type of carbides are formed. So, that is that induces, the softness and you are having good machinability of the material, similarly you are stress relieving by heating at about 400 to 500 degree centigrade and then holding there for sometime slowly cooling that removes all the residual stresses which are there inside the casting.

Antiflaking treatment this is done to remove the hydrogen which is looked in, basically hydrogen if it is there inside that may lead to stresses that may cause the crakes that is known as flacks. So, because of this presence of hydrogen, these flacks are formed. So, you will have to remove this hydrogen, so for that what you do is you heat and then you have to maintain that temperature for long. Now one thing is that if you casting uses vacuum or some other treatment, in that case this hydrogen can be removed or otherwise in this also you are heating and then holding for a larger time so that the hydrogen which is there that can go out and it becomes hydrogen free.

So, you have different kinds of heat treatments for this steels and this heat treatment processes induce different kinds of material properties, you might have the treatments like hardness to the skin. So, you have the surface hardening, you have many methods of surface hardening like you may have the flame hardening, you may have the carburizing you may have night riding. So different kinds of surface hardening is also carried out many a times so that if you feel that the coarse should be soft and only surface should be hard you can go for the surface hardening methods. So, these different kinds of heat treatment methods induce the different kinds of properties which are required for the casting.

Thank you.