**Welding Metallurgy**
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**Lecture - 18**
**Martempering and Austempering**

Welcome to the lecture on Martempering and Austempering. So these are another two special kind of heat treatment methods. Basically you are giving thermal treatment you know to achieve good properties to the material. So as we know that when we do the quenching, now what happens in the case of quenching when we are quenching from higher temperature to a very low temperature or to the liquid at room temperature.

In that case you have the formation of martensite and as we know that the residual stresses are developed inside and the reason for these developments are certainly because of the differential cooling rate at the center and at the surface. So suppose when there will be you know sudden quenching, in that case the surface will be immediately changing to martensite and as we know that when there is formation of you know austenite I mean martensite from austenite.

So in that case you will have volume expansion taking place. Now the martensite, which has formed at the surface and inside you have steel austenite, you have slow cooling. So basically the stress which is developed basically that is taken care of by the plastic deformation inside in the austenite region. So then what happens that after some time when the inner part also cools, in that case you have further that is cools and changes to martensite.

So again there will be you know, there has to be some accommodation of the volume expansion, but that is not possible because you do not have remaining austenite now, which will take care of accommodating you know the volume expansion, which has taken place, because now you know you have basically you know martensite and martensite cannot accommodate you know, it cannot undergo the plastic deformation, because it is too brittle. It is very, very hard.

So basically that leads to you know the formation of stresses and you will have the residual stresses will be there, which will be stored you know inside the material and that you know these stresses if they are higher you know in many cases that can lead to cracks. So you know so these are quench cracks. So that is how we talk about. So as we know that the residual stresses, which are inside the material, they are detrimental.

And many a times, we do the stress relieving operations to basically get the desired structure to get you know the desired softness inside the material. So basically when you know, so basically there will be gradient of temperature from outside to inside and if you look at the stress distribution you know. So you will have thermal contraction and then so thermal contraction for a steel has certain value like it is LMN * $10^{-6}$ per Kelvin.

So that is your thermal expansion coefficient. So certainly it will have, you will have certain contraction when your temperature is, there is a change of temperature. Now what I was talking, that when we are quenching then in that case you will have the you know residual stress pattern will be there, which will be different you know at the center and at you know the surface.

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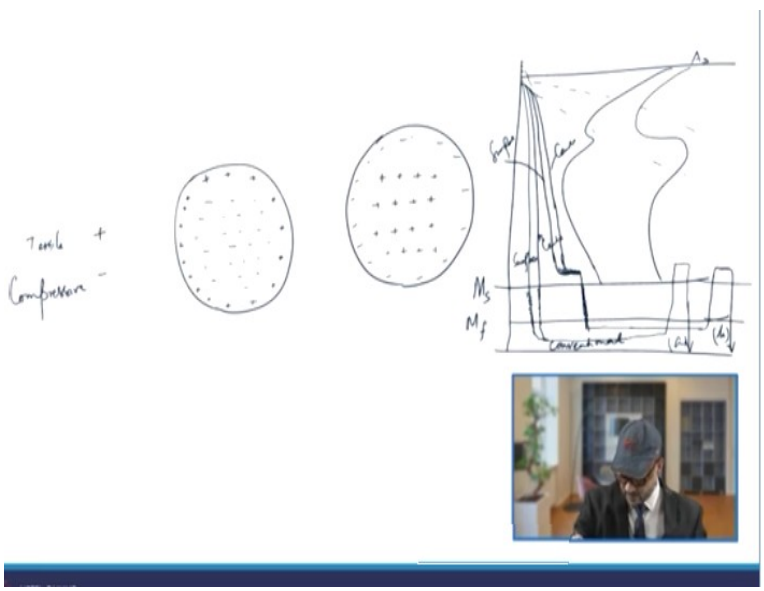

So if you look to the residual stress pattern you know so if you take when you do the thorough hardening, in that case you will have residual stress pattern will be there, like you will have so you will have at the surface this is subjected to the tensile type of residual stresses and inside you know you will have the compressive type of residual stresses, which are developed inside the material. So your positive is basically tensile and the negative is compressive residual stress.

Now when we do the shallow hardening of the material in that case the stress pattern will become like you will have on the surface you will have the compressive type of residual stress pattern. So residual stress distribution will be negative and then inside you will have plus. So it is because you know this is because of the you know through hardening, when you have full hardening taking place.

In that case you will have you know the tensile, compressive tensile stresses real stresses are at the you know surface and in this case you will have compressive residual stresses when you go for the surface hardening. Now the point is that we must be acquainted with this kind of residual stress distribution when you do the quenching and we will also see that we have already studied that there are methods for you know removing these residual stresses and mostly we do it by stress relieving operations or by annealing operations.

And if the stress values are reaching to an alarming level, then that may lead to cracks. They are known as quench cracks. Now once we are you know, so this will be our aim that these the form, now again we need martensite because the martensite is very hard phase. So if you have martensitic structure, then we know that you will have good you know strength properties into it, but then we also feel that because in that austenite to martensite transformation which is occurring because of the you know sudden quenching.

In that case you will have the formation of very hard brittle martensite phase and that basically is detrimental because its ductility is quite less, you will have and also you know the failure will be in a brittle mode. So the austempering and martempering basically are the two methods you know. They are the special heat treatment methods, which basically try to minimize the tendency you know of cracking.

So martempering and austempering, so that is because of the as we know that is you do to the transformation to martensite.

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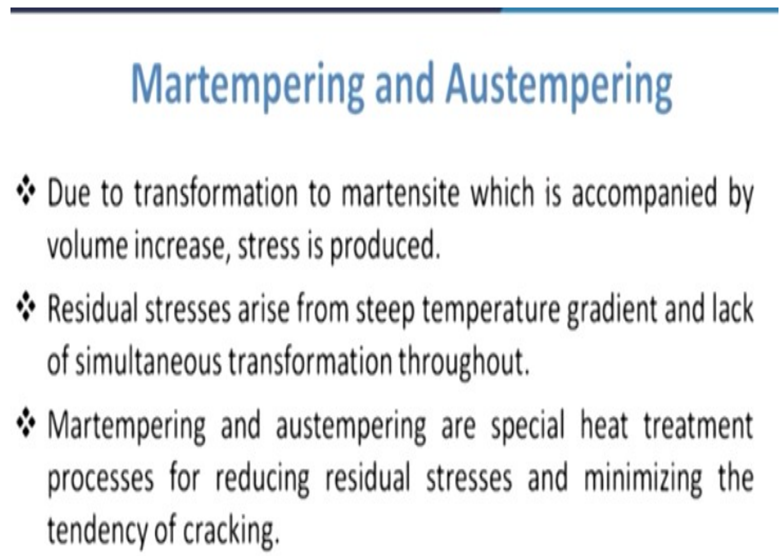


Which is accompanied by volume increase, these stresses are produced and residual stresses, which are arising from the steep temperature gradient, basically you know that is there so steep you know temperature gradient will be there and that will lead to the residual stresses and we also are discussed that since there is no simultaneous transformation throughout, so you will have the you know differential cooling, you will have different rate of transformation.

I mean throughout the domain. So that way you have the chances of the formation of residual stresses. So what we do is that we do some treatment, so that you get the martensitic structure, but the structure is you know not having residual stresses to the large extent, which is basically not desirable. So we have already studied about the process of tempering and that is tempering we know that in tempering we induce you know some softness at the cost of hardness.

So martempering you know also indicates that it takes the name somewhat from the term tempering. So in martempering what we do now, as we know so in the martempering now if we try to refer it to the diagram of you know the TTT curve, if you look at the you know TTT curve in that we have seen that you have this as the equilibrium temperature that is your $A_3$. So you will have this as the $A_3$ temperature.

Now in that case what we know that after that there will be transformation you know started so you will have as we know that then it will go to austenite and pearlite region and then ultimately below that you will have. So you will have austenite transforming to martensite after this temperature. Now in that as you know that if you look at the graphs for say a particular composition of steel now what we see is that you will have some kind of curve.

Which is available maybe because of the presence of alloying elements, it changes it may be you know of different shape also. It may go like this and then it goes like this. So basically it all depends that how what kind of shape you are taking, it depends upon the alloying elements also, how the shape looks like, because that changes that you know these lines. Now the thing is that when you are basically your as we know that when we go to some cooling you know curve like this.

We may have some cooling curve like this, like this. So once it starts you know following this it goes past this line, then we know that this is the reason where austenite is starting transforming to martensite, I mean pearlite. Now you know as you know that when we if you quench like this and if it is your $M_s$ temperature and you know you have one $M_f$ temperature. So martensitic start and martensitic finish temperatures.

As you know that if you go to follow this line, this you know cooling line in that case you are getting fully martensitic structure and this martensitic structure basically is extremely hard so what happens that you know in this case if you come, so that will be normal in conventional way you will have you know 2 kind of you know graph will come and in this process here you will have the formation of martensite taking place in this region.

And then you are coming here and this will be your surface. As you know that you know you have larger cooling at the surface and you have slow cooling at the center. So you have, such way you know the thermal curve looks like. Now in this case, so where the martensite which you are getting by cooling at here so that is you know using the conventional you know quenching process and as you know that you have different cooling rate at the surface and at the center.

So because of this differential cooling rate, you know transformation to martensite is at different times. So you know so that basically you know it will be setting up the residual stresses. Now what we do, that in that case so you know we will be doing some treatment, so that you know you have the martensite formation but there is not much of residual stresses involved. So what we do is now in this case if you and then what you can do is you can go further and then you can further heat and come back.

So this way you can come and get, so you can remove the you can remove the basically residual stresses by further tempering you know and then you are further you know cooling so that is your known as marquenching basically you know that is normal conventional quenching. This is in the conventional you know process not marquenching, that is conventional you know process. Now if you go to the martempering process or also known as the marquenching.

Now in that case what we do is we are not cooling you know we are going to have the cooling somewhat at moderate rate. So we are going certainly past the nose of the C curve and then so it will be so this is for this Center in this line and in this case you will have again further you know cooling. Now again here you will have this as the surface and this will be at the center. Now what we do is in this case we are further holding.

And then what we do is now we are going through this you know this $M_s$ $M_f$ line in between and then further we are holding you know for a large amount of time and then we are basically tempering it and then we are further you know quenching. So this process is so this is A was for the conventional you know process and B is for the martempering or marquenching process. So in this basically you are holding you know this for some time you are holding this specimen at a temperature, which is above $M_s$.

So basically in this case you are not holding, you are just simply you know dipping the specimen in to the bath, which is maintained at a very small temperature, which is temperature below the $M_f$, whereas in the case of martempering or marquenching now this is a quench to a bath, which is maintained at a temperature you know above this $M_s$ and you are keeping it for some sufficient time you know.

This time is to ensure that there is you know uniform temperature distribution inside the material. Now in this case you do not see that uniform temperature distribution because you have differential cooling at the surface and at you know the center, whereas in this case you will have once you hold it for some time, so for sufficient time at a temperature above $M_s$, then the temperature will be uniform throughout and then it will be allowed to go through that martensitic range.

So this is your you know martensitic range and then so this will ensure that the transformation to martensite will be occurring more or less at the same time throughout you know the whole you know sample or so whole part, whereas in this case you cannot ensure that because you have differential cooling you know the surface cools faster than the core. So certainly the martensite will be occurring at different times.

So that basically you know ensures that your simultaneous formation of martensite is there when it passes through this range and in this case you can ensure that there is the minimum amount of residual stresses formed you know and that will be you know giving you the hardness also because your martensite is formed and in this case when you know the cooling rate through this martensite range is basically the smaller one.

Because as you see that the temperature difference will be small, so cooling rate will be smaller in this case, because here the cooling rate is higher, whereas in this case cooling rate when it is passing through the martensitic range it will be smaller. So austenite is also likely to get you know retained because of the thermal stabilization so and further when you are coming so then you are further doing some tempering.

So this process is known as the martempering process and it gives you know the stress free, residual stress free type of the structure you know the material, because you have basically ensured that the transformation from austenite to martensite is occurring at you know at a constant time. So at similar time or I mean difference of time is not more. So that is austempering I mean martempering process. Next process is the austempering process.

Now in austempering process basically what we get is we are getting the bainitic type of structure. So what we do in the case of a stamping process, what we do is we are going again in this case so you will have the you know line coming like this.

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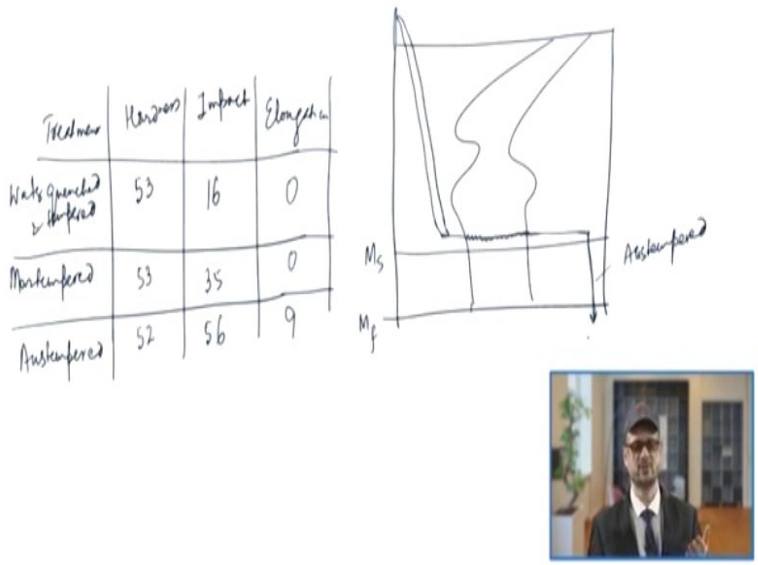


So we can have another you know, so in the case of austempering, basically you know steel is quenched into you know the bainitic bay. So you have a bainitic bay this case you have again this is $A_3$. So as you know that we have some lines, so that way so what we do is, now this is you know after that you will have so this is your $M_s$ and this is your $M_f$. So now in the case of you know.

As we know that we have already discussed that in normal case you are going to have in slow cooling you are going to have the formation of pearlitic structure and when you want to avoid that for because once the line will cross this line once the cooling you know this cooling rate will be such that it will pass through this line. So you will have the formation of certainly some amount of pearlite and that you try to normally avoid.

So what we do is, you will have to have the very fine or the bainitic range in this range you will have the bainitic zone. So for avoiding the formation of coarse pearlite and to get you know the structure, which should be having minimum of the stresses also. So we go for the austempering treatment and we are basically near the nose, we are trying to prevent any transformation. So you know what we do is that where our cooling rate will be such that we are coming here.

So you will have certainly differential cooling at you know the at this point. So we will have this is for the surface and this is for the center and then what we do is we basically you know we are going past the nose of the C curve, but we are not going into the $M_s$ or $M_f$ zone, but we are holding this temperature you know and we are basically passing through this line. So in this line when it is going so and then once you go into this, you will isothermally keep it for large amount of time.

And this region basically this is basically the bainite, so you will have upper bainite and lower bainitic structures. So basically you can ensure that you have a very fine kind of bainitic structure, which is you know form. So you are keeping this until all the structure is transformed you know the transform to bainite and in this basically the cementite, which is basically formed. In earlier case you know that you have pearlitic structure.

In this side you have coarse pearlitic structure, but in this case it is different than pearlite because you know in this case the cementite will be in form of needles and they will be you know very finally distributed. So certainly this will coarse bainite and this will be finer bainite. So you are holding at this temperature, isothermal transformation will take place when it passes through this and then ultimately once you hold it for sufficient amount of time.

Then you are going to you know quench it. So this way you will have so you know you will have the formation of these bainitic structure and this you know type of process is known as the austempering process. So you will have austempered treatment of and you get the very fine type of bainitic structures. Now you know in this case what happens that when you are you can just see that when you do the austempering or martempering, it has basically the effect on the you know the properties of the material.

So if suppose you are giving the different treatment, suppose you have different treatment you know if you have a sample and you can have the water quenched and tempered. Similarly, you can go for the you know martempered structure and you can go for the austempered structure. Austempering you know treatment given martempering treatment given and one is water quenched and tempered that is conventional quenching and then you have to temper certainly.

Because you have to remove the residual stresses. So if you take the use of for a 0.9% you know the steel, carbon steel which is you know treated. So for that basically we are doing so if you go for the different you know properties like if you talk about the Rockwell hardness. So that for the water quenched and tempered it becomes 53 and see scale and this is martempered is 53 and austempered will be 52.

So it will be somewhat less, but you can say that the hardness basically is remaining almost the same you know if you do the martempering or austempering in such cases, but the main difference comes in the case of you know impact. So if you do the impact test, so if you do the Izod impact testing and if you find the you know impact value in terms of joules, then you get the impact value as 16 in the case of water quenched and tempered.

Whereas your value in martempered and austempered case will be 35 and 56. So you can see that you have appreciable change in basically the toughness value or the impact strength of the material as you go to martempering and austempering and austempering gives you very, very you know tough structure. Toughness is quite high whereas hardness is not very much compromised. It has just come down from 53 to 52.

If you look at the elongation, so elongation again you will have changes observed. Elongation while in water quenched and martempered case, it will be almost negligible, whereas in the case of austempered specimen it comes down to comes you know to 9%. It is the elongation is quite increased in the case of austempered. So these materials what we see, they are showing very good you know toughness values you know for the marempered as well as the austempered you know material.

This material treated with martempering or austempering and ductility is maximum. So this austempered treatment gives you the best ductility. As far as you know the looking at the materials property is concerned or the cost is concerned you can see that we are holding this sample for a very long time and then we are you know putting inside the bath. So certainly it becomes you know so now it is a slow process and the certainly it is also going to be somewhat expensive as compared to the other two processes.

So these are austempering and martempering are very much you know practiced you know processes on the shop floor and you know apart from that many a times, we need to have the property to be distributed in such a manner that you know this hardness is required at the surface and core seems is required to be tough. So you have another kind of heat treatment that is known as the surface hardening process or the case hardening processes.

So that is another kind of you know heat treatment that we will discuss in our coming lectures. So this is about these martempering and austempering heat treatment processes, especially for the steels. Thank you very much.