Thermo-mechanical and Thermochemical processes

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Lecture No # 31
Overview of Themo-chemical Treaments

Greetings to everyone, so we are now having a lectures in this course titled thermomechanical and chemical treatments. So, it has got actually two parts. So, the lectures for the more mechanical treatment will be covered you know as a separate set of lectures and I will be covering a set of lectures it will be on thermochemical treatments. So, in this lecture, first of all I would like to give the overview about what is the purpose of you know this topic and what are the topics which will be covered.

So, objective of materials engineer is to develop the materials having a good service life and performance. Right, we should have a component which will have a good service life and the performance. So, the properties of any engineering component whatever we measure or whatever we feel while they are in service, they are dictated by the microstructure of the material being used in this preparation of these components.

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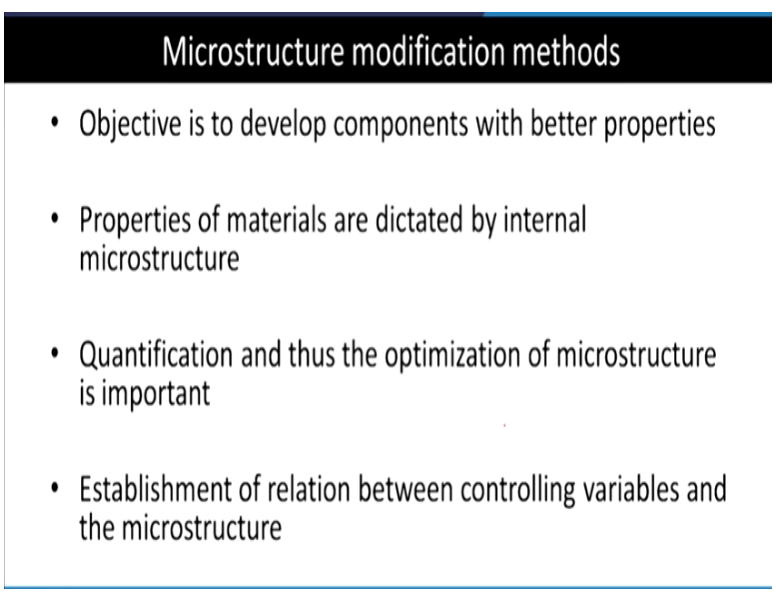

So, our objective is to develop components with better properties. So, in that process, what we want to know is that the internal microstructure. So I hope you all are aware about what is a microstructure. It is like when we look into a microscope and what are the inner details of the material. How the constituents are present inside that would dictate the properties of material.

So, what is important is that we need to know the way to quantify and then you know the optimize the microstructure features which are present in the material. For example, and now, once we know that fundamentally what is the relation between the microstructural quantities and the measured properties, then we need to also find the relationship between these microstructural constitutes and the process parameters.

For example, a component is being produced by forging or by you know the heating it up to some conditions, then we need to find the relation between these properties with these parameters. That is what actually a technical person will be doing while producing the component. So, that is what is actually the important thing that establishment of relation between controlling variables and the microstructure.

So, what are all the things which will be controlling the microstructure and thus the properties of the material. If you look in detail for example, the chemical composition. That means, what we have added into the particular steel. So, what are all the internal chemistry like if we have a steel, how much will be the let us say the amount of carbon how what are the different alloying elements being added into the steel. So, this itself can actually in principle control the properties and next is the phase constitution.

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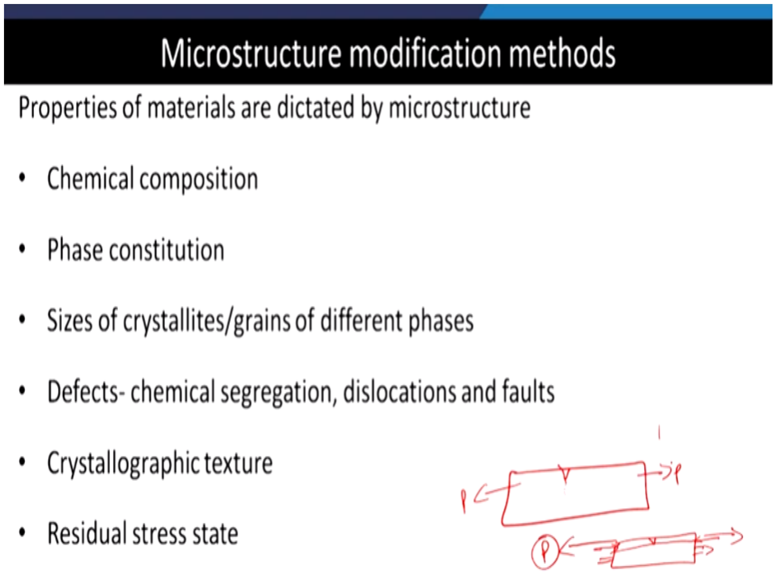

For example, we have a defined chemistry, but by using certain means of controlling the phase transformation, that means, we are not changing the composition. With that we will be able to change the internal constituents. That means, for example, if we consider the steels, like we can control the amount of let us say the cementite or the retained austenite, these things can be controlled and that will also be able to dictate the properties.

And other thing is about being the composition constant and the phase constitution constant, one can also refine the individual grains that means, we can control the crystallite or the grain size, which is known to also alter the properties. So, this becomes one way to tune the properties and then actually the defects engineering.

So, which is not very well established as an engineering method, but still we know that for example, by doing a cold deformation, we can change the properties of the material, right, by introducing defects like dislocations or planner faults. Then we will be able to change the properties. The another aspect is the crystallographic texture, which is also in a very few applications which is possible to engineer this.

So, by because this comes as the crystals are known to have anisotropic properties. For example, if you take a single crystalline solid and if you are measuring the properties along different crystallographic directions. For example, it can be some magnetic property or it can be a you know the strength of the material, then it will show actually the different properties along different directions.

So, in a polycrystalline aggregate, by controlling the fraction of these you know the orientations which are dominant. For example, we have a sample having certain dimensions and now you have a sample surface. Now, with respect to the samples surface, how the different grains in the sample are oriented crystallographically, whether we see all the 100 planes being parallel to the surface not all, I mean majority.

So, that is what actually can give rise to properties which will be different. So, by knowing that what is required and then one can favorably alter the properties by controlling the crystallographic texture. So, the other aspect is we don't do all these things, like we do not change any of the things but we will only change the residual stress state for example, at the surface. We know that most of the failures or any cracks nucleate and start to propagate into the material from the surface.

So, for example, if you have a component right and, on its surface, let us say that there is a defect like this (refer to above figure). And now, if there are no macroscopic stresses acting on this component that means, it is stress free. Then, if you apply the load then there is a critical load at which this crack starts to progress inside and you know we can see the failure. Now, for example, we have a situation where we have already have a residual stress, which is being acting on the top surface.

For example, compressive residual stress acting on the top surface and that is a very thin region (refer to above figure). This is the top surface and remaining portion is feeling a little bit of tensile stress to have the stability for the shape and then in case of the same defect to progress it requires much or the higher effective load. That means, this P will be more than this P. So, that is how actually one can control the failures in components by engineering the residual stress.

So, now actually the most of the failures for example, fatigue, so, where actually the defects from the surface starts to propagate into the material. So, fatigue resistance can be enhanced by engineering the residual stresses. So, now, when it comes to the actual applications, then one can think of two properties, bulk properties of a component and the surface properties of a component.

So, why these things have to be understood separately and engineered the independently or the always considered together in deciding the certain properties. So, the bulk properties mean actually what should be the impact strength of that material being used as well as, what is its formability. That means, you know, if you have a material you want to make some cylinder by deep drawing, then it should have a good drawability.

So, that is the one aspect one has to keep it in mind while choosing the material before you start making a component. So, it should provide a structural stability and it will give a impact strength. That means it should be able to withstand the high deformation energies and it should have a good formability. Having these things set, you will be able to manufacture the component. That once you have a component then you know that the surfaces of the component are actually interacting with the atmosphere.

For example, it can be a certain mechanical load which will be felt maximum by the surfaces first. So, that is where actually the surface properties are important. Then once you have a component we would like that it should have a good wear resistance. So, most engineering components feel the wear with the environment with which they are operating with. So, for example, if you take a gear, the gears are under constant wear and tear right.

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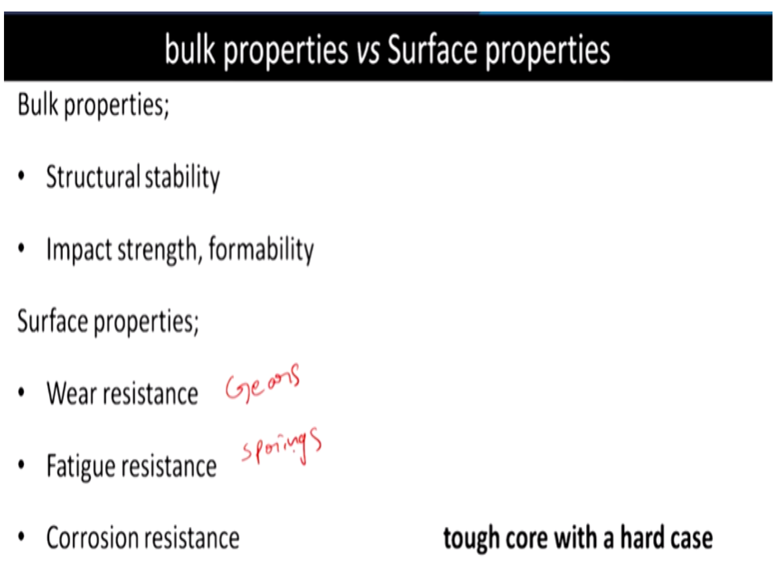

So, we would like to have the gear teethes where you have the loading, so that surfaces of the gear teeth should have highest wear resistance to have a long service life. So, that is one aspect and next is that fatigue resistance. So, for example, a spring and then these springs are under constant variation in the loads they will be operating.

So, they should have a good fatigue resistance because you have a cyclic load being experienced by these springs. So, that is were actually we would like the springs should have a good fatigue resistance. So, this also have to be engineered by the residual stress state at the surface of these springs. So, the other one is the corrosion resistance.

So, because always these components will be in contact with atmosphere, it can be oxidizing or it can be a reducing. So, that is where actually it should have a good corrosion resistance. so that we can prolong the life of the components. So, enhancing these set of properties, the wear resistance, corrosion resistance and fatigue resistance, falls under the criteria where we have a set of methods which are called surface engineering methods.

So, where we would like to change the surface or cover the surface, either we modify the existing surface or by putting a different layer on the surface will be able to get the required properties for the surface.

So, when it comes to the mechanical property related criteria, we want to have a tough core that means if you have a component, the core means inside material should be tough. That means, if you have an impact load, it will not break into pieces. But at the same time, we want to have the skin or case of this component hard so that it can provide a good wear and fatigue resistance.

It becomes usually the strategy for engineering components with a good life and serviceability. So, how we can modify the surface properties? As we discussed, when we engineer the surface properties, then we should also keep it in mind that we have to make sure that the core properties as it is desired should be also engineered or should be retained without disturbing. That means you have a component, by doing the processing methods and the treatments you have fixed its bulk microstructure. It has got a certain composition, certain phase constitution it has got a defined property , for example, yield strength and the impact strengths and all that.

Now, whatever we want to achieve with the surface, when we say the surface it is actually a region of certain depth from the surface that should have a property which is different from the bulk. So, that means, we should be able to only change the property of the surface or we choose the methods such that both being optimized in a consistent manner. So, how we can modify the surface region microstructure.

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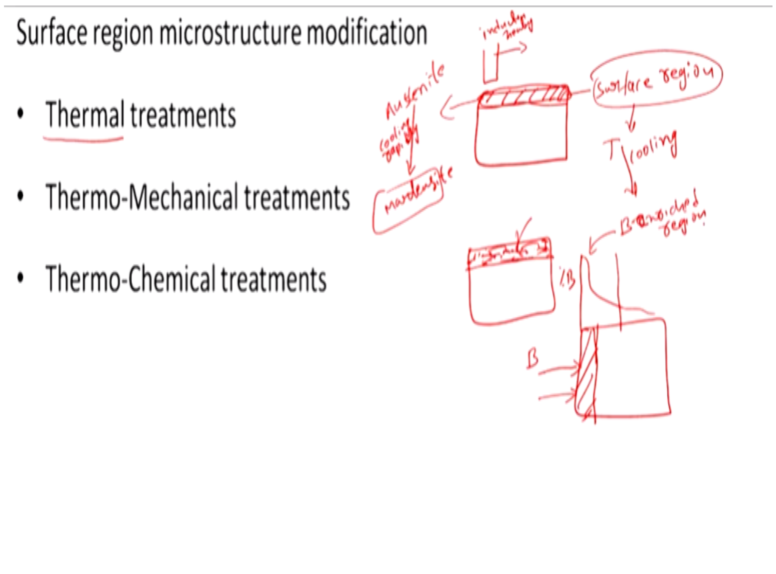

For example, we have a component having certain bulk property and I treat this (refer to above figure) as the surface okay. This is the surface region and now, we want to have a different property only to this surface. So, one possible way is that by using the thermal treatments. Thermal treatments employment, we only change the temperature and the heating and the cooling rate of the particular region of a material and that leads to change in the properties because we introduce a phase transformation.

So, we will be looking at that when we discuss in detail about the different surface treatment methods. So, where we apply only the thermal treatments or the heat treatment, then, we should have a technique by which we can only change the temperature of the surface region. For example only this (refer to above figure) region we want to have a change to different temperature and then we will actually cool it down. So, we want to change the property.

So, you all know about the phase transformations so, if not then I would say that that becomes a basic requirement to follow these kind of courses. So, you have a steel which has got a certain you know the carbon content. It is a medium carbon steel for example, and then if somebody has made a component and then this component has been heated and cooled and then tempered. That means, you have produced a martensite which will be very hard and then you tempered it so, that it has got a optimal values of toughness and the tensile strength.

So, now you want to change only the surface property. Objective is to have the surface which is harder than the bulk. So, then what we have to do is we need to heat up only the surface skin to the temperature where it becomes for example austenite (refer to above figure). So, then after the heating you cool it rapidly, then you produce martensite at the surface. This will be very hard region at the surface, how one can do that?

You can have either an induction heating of only the surface. So, I travel this induction heat source, so that it heats the surface and then produces the required temperature rise and then it gets cool the moment you move the heat source away or you can you have a laser. So, you have a laser beam which is being passed on the surface. So, this will heat up a skin of the material to very high temperature and as it moves away it cools very rapidly.

So, that is the thermal treatment. Other possibility is, you can do the heating as well as by introducing deformation. So, for example, let us think about mechanical treatments. We know that by doing a mechanical deformation, we can alter the properties because we introduce defects into the material that is known to change the properties. So, for example, if we have a sample and the surface region being mechanically deformed and producing the defects and that will have a different kind of properties.

So, it is called as a strain hardening of the material. And now actually what one can do is that you can actually club the heat treatment together with the mechanical treatments and that falls under the category thermomechanical treatments. Okay this will be dealt in detail in the other part of this course, so, that I will not go into the details here. The third possibility is the thermochemical treatments.

So, what we want to do is we want to use the thermal energy that means, we want to change the temperature where heating and cooling of the surface region and at the same time we would like to also change the composition of the material at the surface. So, if you have such a sample and this (refer to above figure) is the surface, I have this region, which I want to change its chemistry. In such a way that that chemistry upon heating and cooling leads to improved properties.

So how we can do that, so, you need to introduce some element for example element B into the surface region, so, that it changes the composition of this region and then when we cool it rapidly, it actually gives rise to a microstructure, which has got the different properties. So, if I plot here percentage B as a function of distance, so, we will see that you have such a profile (refer to above figure).

So, this B enriched region will have a property that is what maybe can be engineered the amount of B and what is the depth that can be controlled. So, this is what we will be discussing in this part of the lectures. So, where will go into the details of so called thermochemical treatments that means, where we are trying to change the chemistry of the surfaces and to change the properties.

So, now when you want to change the chemistry, then you need to choose particular element or a combination of elements which you want to introduce into the surface regions of the material. So, often you see that most popular methods utilize actually the interstitial elements. Interstitial elements mean the elements which are small in size and they can occupy the interstitial voids in the host lattice of the matrix.

That means, if you have a pure iron for example, and you have a BCC iron lattice, and then you have a void being created between these big iron atoms and there are called the octahedral voids and tetrahedral voids.

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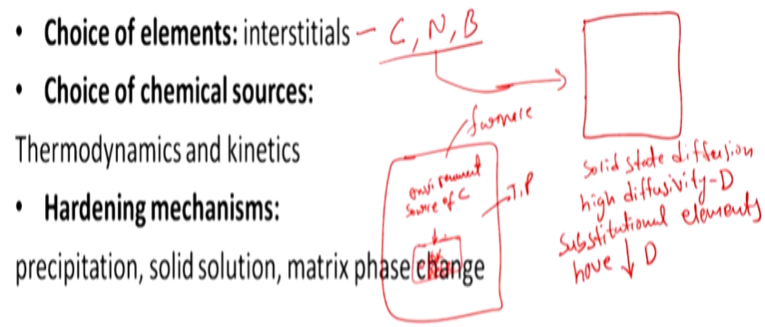

And those regions can be occupied by the small elements, such as interstitial like carbon, nitrogen, boron. One can think of hydrogen too, but it is often known to create a non-favorable property. So, usually these are the carbon, nitrogen and boron being used quite extensively in this kind of interstitial elements. So, another reason why interstitial are favored is, for example, you have a component and you want to feed in for example, these are the elements (refer to above figure) you want to feed into the surface. And then the things which come into picture is the once the elements reach here that involves actually the solid-state diffusion. It is known that interstitial elements should have high diffusivity. It should be the requirement for the elements being introduced into the surface region.

The substitutional elements have a lower diffusivity. So, we want to choose the interstitial elements, which have a high diffusivity that means, at a reasonable temperature in a reasonable time you will be able to diffuse them into the certain depth of the material. So now actually, once you think of like what elements you want to use to enrich the surface, and then one has to know what are the sources for these elements.

For example, we want to use the carbon as an element being diffused into the surface region in order to modify their surface region chemistry. Then we need to have a source that means whatever the source which supplies the carbon and then that has to be chosen by considering the thermodynamics and the kinetics of that particular source when it tries to equilibrate with your work piece.

For example, how this works is that you have a furnace and then you place your work piece and then you need to create here the environment and this will have a source of let us say carbon and then this should provide the carbon and then this carbon will come to the surface of this work piece and then can diffuse inwards. So now this entire process in order to choose the particular environment or the source of this element requires that at this given temperature and pressure, what are the thermodynamics of this source and how the kinetics of this transfer of the element from this environment into the workpiece that has to be taken into consideration. So, that is about the choice of chemical sources and now actually for example, if we consider our objective is to enhance the mechanical property of the surface that means, we want to harden the surface.

So, we know that there are different hardening mechanisms, okay if you have a material if you want to make it harder. So, there are different ways to do that one is called precipitation hardening that means, you want to have a another second phase being present as a particles and which are dispersed in the matrix and these particles have a higher the mechanical properties then you create actually so called precipitation hardening.

So, the entire composite material that means, you have a one phase with dispersion of the second phase within that, that will have a different property that is called as precipitation hardening and other possibilities solid solution strengthening. For example, if you have a pure iron austenite and if you keep on adding the carbon into it depending on the amount of carbon, we can increase the hardness of the material, that is called solid solution strengthening.

Another way is that you change the entire surface region material into a new phase that means, you to a new compound. For example, if you have a iron surface or a steel surface you change that to some other compound like a cementite or you know the iron carbide or iron nitride or iron boride. So, when you change that then you also change its property. That is what is a change in the complete phase of your material.

So, now I would like to talk about actually, one model example by which I want to explain how the different things can be realized by using different treatments. So, before we go further, I would like to summarize what we have discussed until now. So, we have discussed about what is the importance of controlling the microstructure of the materials and what are the parameters which actually dictate the microstructure and thus the properties of the material.

And now, then it comes to the engineering components, so, we need to understand that it requires certain level of bulk properties and certain level of surface properties in order to be able to provide good life and serviceability. So, that means actually we need to have a surface modification methods or how we can change the surface properties. So, in that context we have discussed about thermal treatment, thermomechanical treatments and thermochemical treatments.

Then the purpose of this lecture is about the thermochemical treatment. And then we have discussed about what are all the elements can be chosen in order to change the chemistry of the existing component surface. So, there we saw that interstitials would host good source because they are small in size, they can diffuse faster and that means in a reasonable time and at a reasonable temperature we would be able to reach a certain depth of the specimens surface being modified.

So, with this now, I would like to move on to the next lecture, where I want to first explain two very popular thermochemical surface treatments. These are called carburizing and nitriding. That will be the part of our next lecture.

Keywords – Thermochemical treatment, surface properties, interstitial solid solution.