Heat Treatment and Surface Hardening (Part–1)

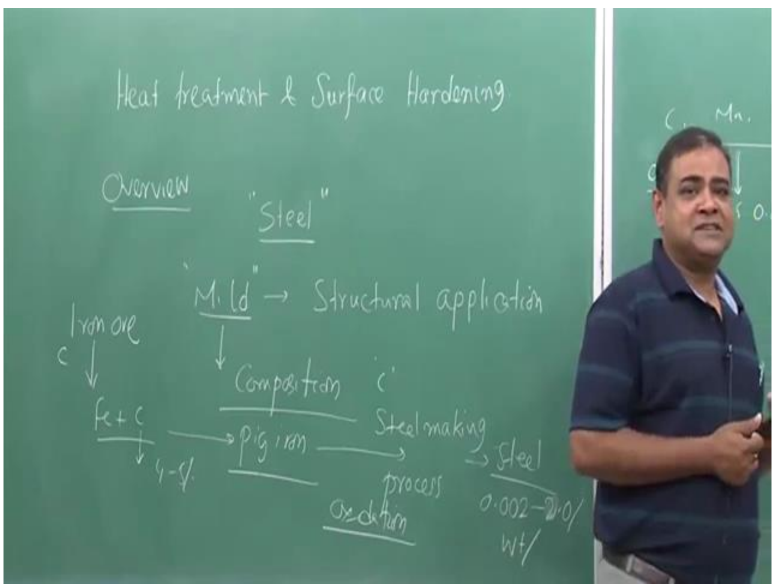
Professor Kallol Mondal
Professor Sandeep Sangal
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Lecture Number 25

Nucleation Rate - 2

Hello everyone let us start our course Heat Treatment and Surface Hardening. And in this course, we will be discussing the principle of Heat Treatment and Surface Hardening as well as its thermodynamics and kinetics associated with it. And in addition, we would be also taking some engineering alloys to see that whether those principle are useful in deciding our time and temperature cycles in order to have a particular material for a particular application and we will be two persons taking this course, the first ten hour of lectures myself will continue and then next ten hours of this particular course will be taken by professor Sandeep Sangal.

(Refer Slide Time: 02:10)



And today is the first lecture and in this first lecture we will just have a kind of overview of this particular course. Now coming to the overview of this particular course, now question arises the why we should study this course. In order to answer this if we would like to take some examples of existing materials and let us see how we can change its properties as well as structures in order to have some particular functions to be made and then in fact finally we would like to see our performance which would be sufficient to have this material in use for a longer duration without any problem.

Now whenever we talk about any material, it can be either metals or alloys or it can be composite, it can be ceramics, or it can be polymers, now in this particular course, we will be mainly concentrating on metals and alloys and whenever we talk about metals and alloys, immediately the metal and alloy which come comes in to our mind is steel. And in fact if we consider the gamat of use of different materials in our engineering applications, we would see that at least 70 to 80 percent of applications considering that considering the fact that we are leaving in the modern society still it is steel.

Of course there would be n number of variations in the steels starting from a very low carbon steel to our simple mild steel to high carbon steel and in between we have a kind of advanced steels like interfacial free steel, which is popularly known as IF steel and then we have HSLS steel, which is High Strength Low Alloy Steel, micro alloyed steels then exotic steels like maraging steel which are used in a very very sophisticated applications like aerospace applications.

But if we take steel, we would again see that out of all the varieties of steels we have mild steel which is very common and in mild steel we generally use in structural applications. And whenever we talk about structural application we talk about common structural applications, now let us say pipeline, it is a kind of variation, it is a kind of category which falls under a mild steel category. Then we have, for example we have a let us say reinforced bars many of those reinforced bars are manly used, mainly under under the category of mild steel.

Then let us say we want to make a grill structure for a house, for our house, and the grill material is mainly mild steel, now that is what mild steel you find everywhere in common applications we have mild steels. Now whenever we talk about mild steel, then we need to see that what constitutes mild steel. Now whenever we talk about constitutions, we talk about compositions, we talk about compositions and if we (tik) about think about iron, now steel is nothing but alloy of iron and carbon.

Now 100 percent pure iron, of course the cost wise it would be very high cost, but the application wise it will not of much of engineering use, because it cannot withstand much of load during applications. But whenever you put carbon in it, it has a positive effect of that carbon, it becomes steel. Now where from this carbon comes and also whenever we talk about steel, we cannot get rid of carbon fully because the production root of steel is actually stemmed from production of iron, from iron ore by the reduction of, by the reduction process by carbon or hydrogen you can reduce that.

And then once we reduce, because that carbon is used during reduction which is very popularly known as blast furnace process. The product is nothing but pig iron and this pig iron is coming from iron ore and reduction by carbon, then you are getting iron plus carbon and this carbon content would be a very high, and now that is basically nothing but the pig iron and the carbon content it could be 4 to 5 percent carbon.

Now that material, the pig iron, if we have a very high carbon content its strength, its ductility is very minimal because it becomes brittle material. Now from pig iron, we use steel making process to form steel there we simply reduce the carbon content from pig iron. How can we reduce? We use oxidation process. So the steel making process is basically oxidation process, where we oxidize carbon to reduce carbon and then when we oxidize carbon, it forms carbon monoxide or carbon dioxide that evaporates out.

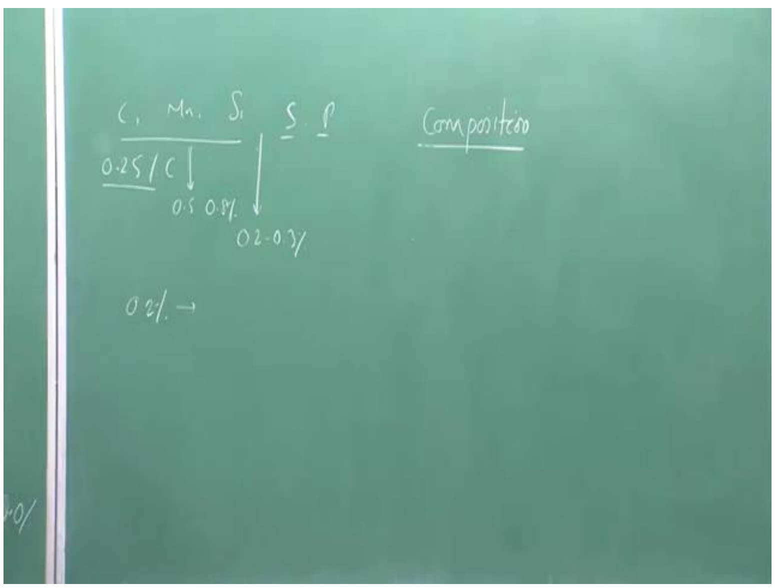
And in this process, we definitely lose a carbon, lose some iron in the form of iron oxide but finally the left out material is steel, where the carbon varies from 0.002 to 2.0 percent and this is in weight percent. And whenever we have carbon in this range, we call it a steel which is nothing but the carbon iron alloy and the carbon stays in the interstitial position. And that interstitial positions are nothing but in crystal structure if we see, we have interstitial voids, which are nothing but octahedral or tetrahedral voids. And there we have carbon.

So now we have a steel and interestingly if we consider the steel production from pig iron when you are getting steel it is oxidation process, but when we are talking about iron ore, there we are having reduction process. So reduction process gives me pig iron and oxidation process gives me steel. Now from this discussion we see that composition is a factor, because if we change carbon from very low carbon to very high carbon, the difference in the properties would be at a very low carbon steel becomes very very malleable.

The malleable means, it can be taken into form of plates or it can be very ductile, means it can be drawn into wire very easily. And why it is, it can be drawn into wire very easily? Because its ill strength as well as tensile strength are on the lower side and the percentage elongation, that means when you draw weight that time the kind of elongation uniform elongation you can provide to that particular steel would be very very high.

Now if we consider two percent, okay coming to this particular low carbon one, as we increase carbon content its strength increases but consequently its ductility decreases. So that means, it becomes more and more harder and harder, but its ductility becomes lesser and lesser. So that means we have some variation in properties with the function of carbon content. Now whenever we have different percentage of carbon content, at the same time we also come across other alloying elements during the processing of pig iron as well as iron ore and which leads to manganese or silicon content in the steel.

(Refer Slide Time: 12:20)



So mainly if we consider mild steel, the mainly we have carbon, manganese and silicon, these three elements. Carbon generally in case of mild steel, its maximum its 25 percentage, 0.25 percentage carbon, manganese it can be 0.5 to 0.8 percentage, silicon could be 0.2 to 0.3 percent depending on different varieties these (pro) these material can vary a much, but can vary little, but this one always stays around 0.25, if it is more than 0.25 that will not come under the category of mild steel.

So if we take 0.25 percent carbon maximum, we can term it as mild steel. If we at the same time we do not have much of other alloying elements like vanadium, titanium, chromium all sort of stuffs, those are costly alloying elements. Now when we talk about these alloying elements, forget about these other alloying of course there will be sulphur, phosphorous but we always take care of this sulphur and phosphorous, we try to maintain these composition of phosphorous concentration of phosphorous and sulphur to be minimum because those elements are not beneficial elements in terms of properties we want from this particular steel.

Now coming to only carbon, if we let us say zero point carbon percent, and then we try to see k what sort of structure it generates we can easily come to know from a particular pictorial graph which is called phase diagram. Phase diagram is nothing but the equilibrium diagram of different phases appearing at different temperature and if we change the composition and this phase fraction would change as well as different phase might appear.

Those phase diagram part we will talk in third lecture, but if we consider this particular composition part only and this composition part if we consider, we can see that if we change composition, we can change its properties. We are getting little bit of idea from this composition. So composition is one of the major factors we must consider, okay. So now coming to, whenever we talk about a material, we le let us first see what are the parameters we should look at in order to see whether do we need time temperature variation to get a different properties or not, whether we would get it or not.

Now from this discussion it is very clear that composition is a factor which controls, from our discussion it is very clear that it controls the properties. But at the same time it also controls the structures, for example if we consider 100 percent pure iron if we can make okay, which is very difficult to form 100 percent pure material is very difficult to form which will come across during a thermodynamics consideration of alloy formation, we would see that it is extremely extremely difficult to form 100 percent pure material because there is this culprities nothing but entropy part.

(Refer Slide Time: 16:10)

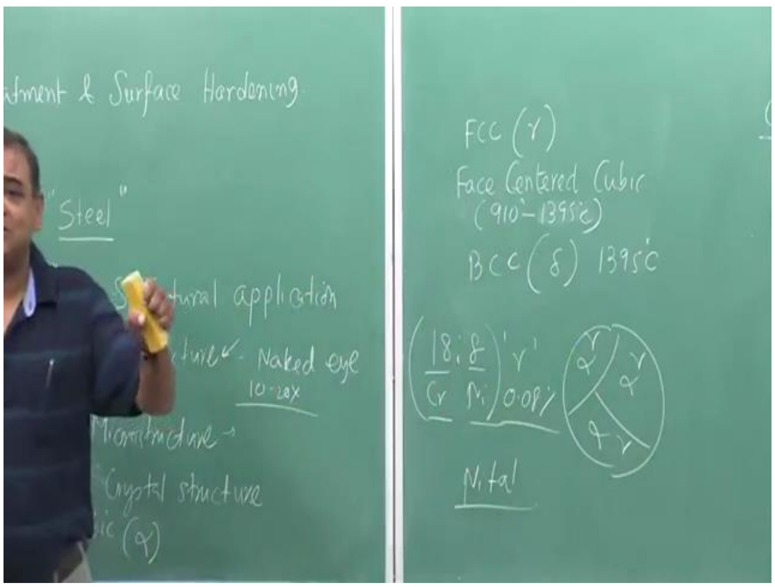
The entropy of mixing, this allows us to form 100 pure material okay. But if we for example, let us say 0.0001 percent carbon steel which we can consider as the pure iron, and in the pure iron we have some structures and this structures could be either it could be macrostructures, it could be microstructures, it could be micro, it could be crystal structures. Now different structures they are would be other structures also we are not getting into the atomic structures because iron, pure iron is also consisting of huge numbers of iron atom, we are not going into that iron atom because we would be only concentrating on these particular two structures.

And this macrostructure some time would be very important when we talk about a surface preparation that would come in the macrostructure group and whenever we talk about different structures, if we consider this these two, these two can be considered as a structure which can be seen in naked eye. That we can consider as a macrostructures, naked eye, and the magnification we can go up to, let us say 10 to 20x depending on the power of the human eye. But whenever we talk about microstructure, some structure it will be inherent in this (particu), in any material and that structure we cannot see with a naked eye. We need microscope.

And that microscope it can be a very small magnification, small magnification I meant to say 50x, that means we can blow it up by 50 times or it can be a very very high magnification we can blow it up to a million times, okay. That means we have entire range of microscopes, for example optical microscope where we can go up to 200 to 2000x that means 2000 times we can blow it, blow the material, blow it up or we can use a sophisticated transmission electron microscope we popularly, we popularly know it as TEM okay, transmission electron microscope where we can Blow million times. Now this microstructure changes with composition at the same time crystal structure also changes with composition.

For example, if we take pure iron at room temperature, the pure iron structure is BCC, which is nothing but body centered cubic, body centered cubic. Now if we take this pure iron temperature to more than 910 degree Celsius, we have a different structure what that structure is called FCC, which is called face centered cubic, face centered cubic.

(Refer Slide Time: 19:40)



Now these are the two basic structures what we have in pure iron, there is one more structure which is called BCC again but that forms beyond a temperature of 1395 degree Celsius which is called again BCC.

Now the question is which is again body centered cubic, but if we consider room temperature below 910 degree Celsius we have BCC, that time it is called alpha and this time which is beyond, which is called delta beyond 1395 degree Celsius. And this one appears between 910 degree Celsius to 1395 degree Celsius if we consider pure iron. Now whenever we talk about these structures, we must consider that these are solid states structures, solid structures as well as during that time we are fixing the pressure at one atmosphere.

If we change the pressure as well as temperature, we can come across other structures iron which could be 8 cp also which is called hexagonal closed pack structure. But for our application, we would be happy with this BCC and this FCC. Classic example, mild steel if we consider the iron what we see that is nothing but the BCC and stainless steel or the popular stainless steel which is (consi), which is called a 18:8, 18:8 stainless steel, where eighteen percent is chromium, eight percent is nickel.

So the stainless steel what we see in our common application, for example wash basin is a classic example of 18:8 stainless steel. So there we do not abstain and in case of stainless steel, the stain is nothing but the rust, because iron always forms rust if it come in contact with moisture as well as oxygen and that to are amply available in environment. So if we have moisture as well as oxygen, then they can form rust which are nothing but again iron oxides or hydroxides.

But in case of 18:8 stainless steel we do not form those oxides or hydroxides, that is what surface remains is very shinny and it does not corrode okay. So there is a term called corrosion, the corrosion does not happen in case of 18:8 stainless steel. So that is why it is called stainless, there is no stain. Now in this case, the structure is nothing but gamma which is nothing but FCC which is also called gamma phase. So that means, we see in case of pure iron if we change the temperature we are coming across different structures, which is nothing but the crystal structures.

Now if we try to see the microstructure, in case of pure iron the microstructure if we consider BCC microstructure, the microstructure contains like this, which are are the grains of alpha and this are grain boundary. So this kind of structure we would see if we see under a microscope, but how can we see under a microscope? We have to polish it and polish it in such a way that we can see our face on the surface of that poly surface, and then we have Ech it, age is nothing but the electrochemical reaction with an acid which is normally used nitric acid, that acid solution we call it Nital.

And that Nital if we dip that particular poly surface, mirror poly surface and then allow it to react for some time and then if you take it out and see under an optical microscope, you will see a grain structure like this. So these are called grains of alpha and then these are called microstructure okay. So now that means we see crystal structure, we see microstructure. And now we see that if change composition from no carbon to a little carbon, we have the carbon content this of the, for example in case of 18:8 stainless steel carbon content is 0.8 percent if we take commercial stainless steel.

So if you see that with little carbon content but if we increase the alloying elements, that means we have composition we can see that our structure changes from BCC to FCC. That means as we have told that if we change the composition, we can have change in structures, we can change, we can see the change in structure if you change in crystal structures. And now when we change the composition from gamma to alpha the microstructure would be almost similar like this, but only thing it will change to gamma.

So the microstructure almost remain same, but the crystal structure changes from alpha to gamma, so that means we see that the composition is one factor as well as there is one factor which is intricately associated with the composition that is called structure and that structure could be crystal structure or microstructure, we can change both depending on the change in composition okay. So let us stop here for the first lecture, and we will continue this topic in our second lecture. Thank you.