Heat Treatment and Surface Hardening (Part–1)

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Lecture Number 02

Case studied in reference to Material Tetrahedron T/t information and processing

Okay, so let us begin from where we have left in our last lecture, in the last lecture we talked about composition and associated structure in one of those materials which are called steel.

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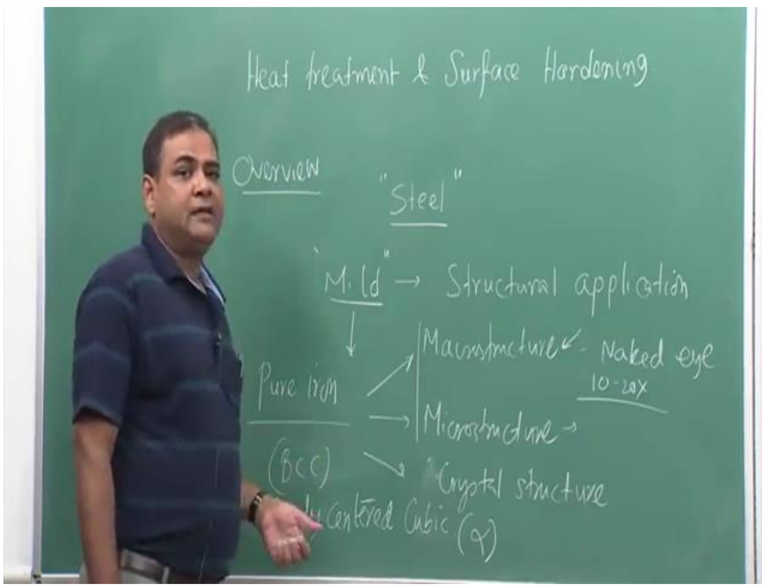

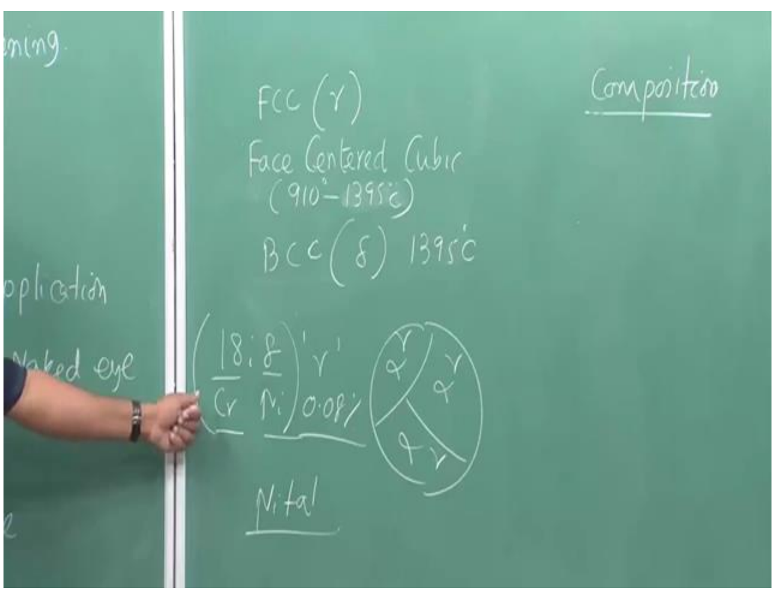

And in the steel we talked about mild steel and in the mild steel we then talked about pure iron and then as we change the temperature we see that different structures are appearing, which are basically nothing but the crystal structure and if we change the composition, for example we have talked about gamma iron, which is nothing but 18:8 stainless steel which is, which has a crystal structure of gamma or FCC.

And then later on we saw that the how the microstructure looks like, and in the microstructure can be obtained by eching in Nital and seeing under optical microscope.

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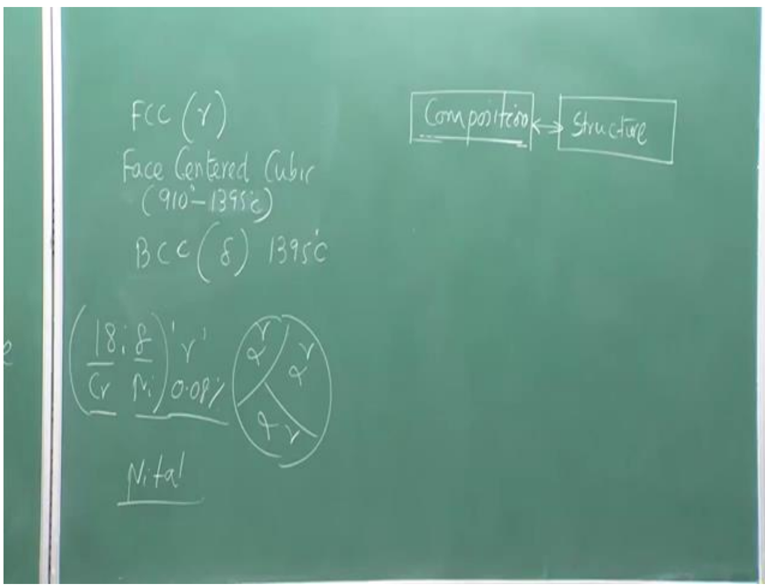

Now that means if we see composition and then we see (pra) structure they are intricately related. Now when we talk about composition and structure, then finally if we have a combination of composition and structure, we are getting some kind of properties in that material.

And the properties in the form of either tensile properties or chemical properties or functional properties we can change those properties if we change composition and structure. For example the example is here which is 18:8 stainless steel microstructure looks almost similar, but there is a change in crystal structure and there is a change in composition. And in pure iron we do not have chromium and nickel, but in steel we have chromium and nickel, high amount chromium and nickel, this 18 percent which is actually a weight and 8 weight percent.

18 percent chromium and 8 percent nickel. But the carbon content is pretty low which is 0.08 percent, but there structures are different but interestingly there properties, if we consider the tensile properties, here it will be higher than normal iron, but the purpose of making stainless steel is different, the purpose of making stainless steel is to have a stainless properties, that is why we are going for high amount of alloy, because the chromium and nickel they are very very costly alloy elements.

And this costly alloy elements are added in order to have this stainless property or extremely high corrosion resistance. So, so that means we are changing the (cor) microstructures, not the microstructure, we are changing the crystal structure and associated composition change and getting some particular property which is high corrosion resistance.

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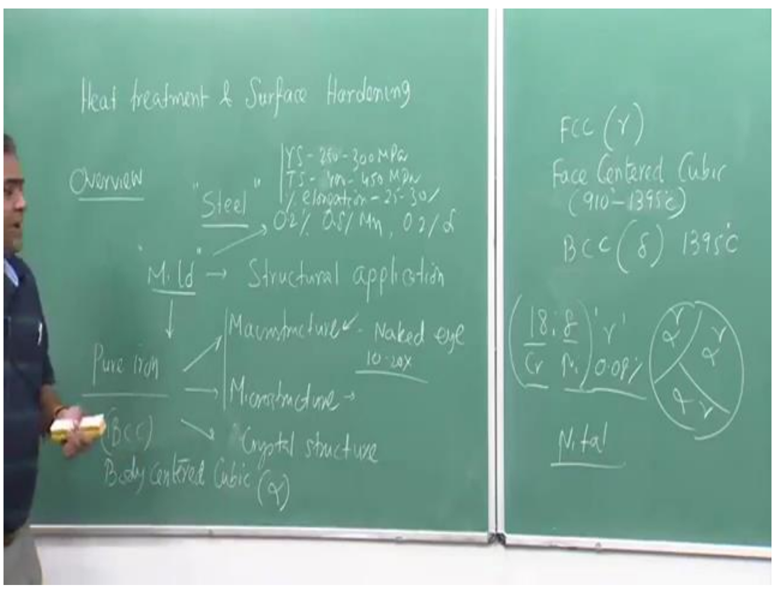

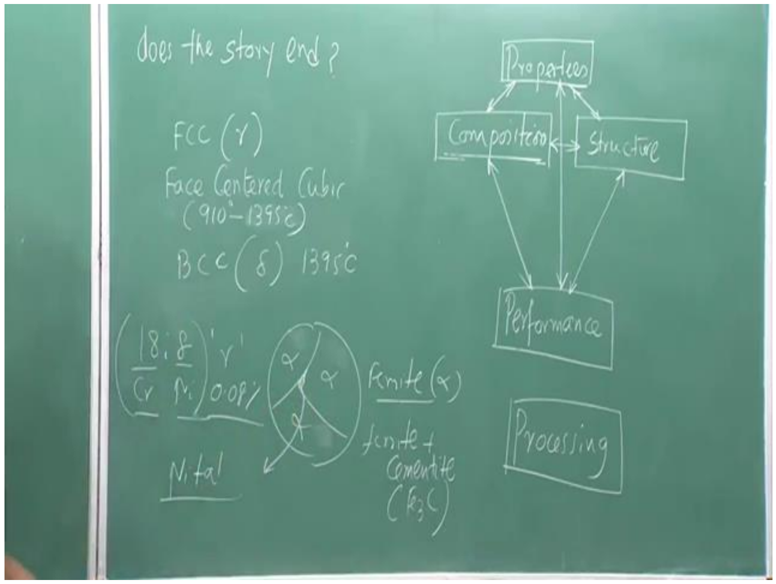

Now, if we consider mild steel, and let say I am considering the carbon content 0.2 carbon and 0.8 percent manganese and 0.2 silicon and in this case, we get normally the properties we get yield strength around 300, 250 to 300mpa.

Tensile strength of the about of 400 to 450 mpa, and percentage elongation 25 to 30 percent. Now this is the property we get. And what is the microstructure? Microstructure if we consider the same microstructure it will be same as alpha which are called ferrite, now once we have iron carbon alloy that time we call it as ferrite, this grains are called ferrite grain and that means the ferrite is also alpha but now these alpha contains interstitial carbon. So that means this ferrite is nothing but alloy of pure iron and carbon.

Now if we have two percent carbon as per the phase diagram we will talk about that phase diagram later, we will see that it contains perlite too of the order of close to about twenty percent perlite, twenty to twenty five percent perlite depending on the carbon content, we will also talk about how to find out the (car) perlite content and that is decided by a (())(05:40) construction in the face diagram. And in that case, the perlite around forms around the triple point. So this triple point we have perlite.

And this perlite is nothing but the phase mixture which are ferrite plus cementite, and the cementite formula is Fe3c which is the cementite, and ferrite is nothing but the solid solution of carbon and pure iron. Now this is the typical microstructure we get, and the ferrite is basically the alternate lamilise, lamy layoff ferrite and cementite. Because of this cementite presence, the cementite is a very hard phase, its strength increases, but whenever strength increases, strength increases means yield strength, tensile strength both increases compare to a lower carbon steel.

If we consider 0.1 percent carbon steel of the same composition other things are same, this silicon, manganese all are same, but if carbon we reduce by 0.1 percent, then its strength, that means yield strength and tensile strength both will reduce but associated change would be elongation would increase. But if we talk about increase in carbon content, (th) these two value increases but this one would decrease. So that means as we increase carbon without changing other alloying elements we have change in the tensile properties.

And that change in properties have coming due to change in microstructures. Previously we talked about change in crystal structure, not much change in my crystal (str), microstructure but here, we are talking about change in microstructure, but the crystal structures remain same. That means the ferrite is same ferrite alpha iron and cementite is same as you can see. But only thing is, that the content perlite changes. And as we go higher and higher carbon, the content of perlite increases as well as the strength increases but the ductility decreases.

So that means we see here the effect of microstructure, but at the same time we are seeing change in properties. So that means, if we have composition and structure both are counter related, both are interrelated then we also see the property is also inter related. So the property if we change the composition without changing the microstructure, we change have the change in properties. That means structure remains same, but that means the microstructure here composition changes, property changes.

Now on the other hand, if we change the composition, similarly the microstructure is changing but the crystal structures are same, that means crystal structure of cementite is a rhombohedral and then verities simple BCC, they are also in change in properties are take place. So that means if we see properties, you see this is interrelated, this is interrelated. Interestingly, we are seeing that composition structure both are interrelated, composition properties interrelated, structure and properties that two are also interrelated. So that means, all three are absolutely bounded together.

Now what we get out of it? We get something which will be useful for our particular application, is it? So that means whenever we talk about applications, we always talk about performance, and for example in case of stainless steel, the performance comes how long it would remain stainless steel, is it? Now similarly in case of mild steel, how long it will withstand the load? So (th) that way we finally trying to see the performance.

So that means, we have performance which is also related to the properties, that means finally the performance is given by what? The properties, so the properties is giving the performance and the properties is related to structure and composition and in order to get a particular performance we need a particular property, so these two are also inter related, is it? So the performance composition, structure, properties these four terms we have already seen these two are, these three are inter related, now this is inter related with this, can we not say that these two are also inter related.

Now we get composition, we get structure, we get properties, and we get performance. Does the story end there? Now, if we can answer that particular question, does the story end there? Does the story end there? Answering to this particular question takes us to the different world of change in properties with the change in processing, okay. And that processing, if we see processing, if we change the processing without changing composition, we can get different properties and accordingly we can have a different performance.

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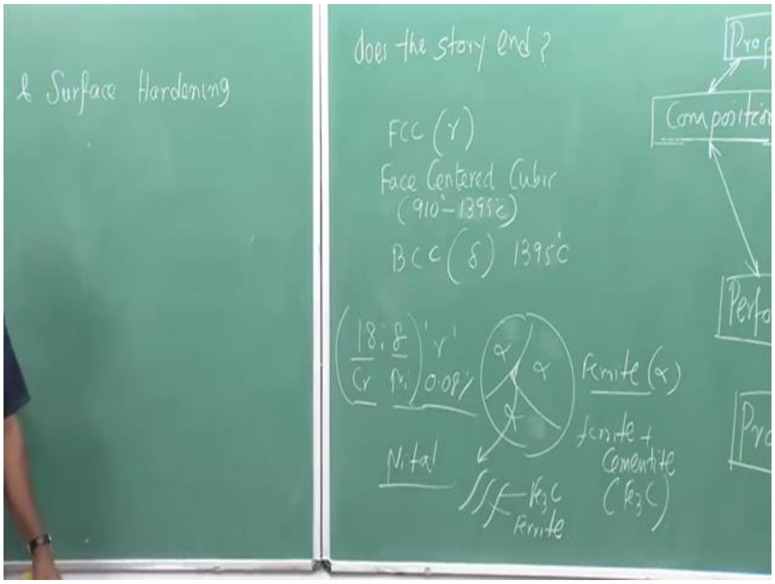

Now we should see how we could do it? Okay, now whenever we talk about processing, let us talk about mild steel or let us say, first let us talk about mild steel and then we will have three examples, one in mild steel, one in this particular stainless steel, the other one is very very popular aerospace material which we call as a duralumin. Once we talk about duralumin immediately the things come into our mind, comes into our mind is basically nothing but aluminum copper.

So we will have discussion on these, we will have discussion on mild steel, we will have discussion on this how we can change the processing to change the properties without change in the composition. So now we are fixing one term which is the composition. Now, let us come to the mild steel I am removing all the thing now. Now in the mild steel the kind of structure what we have seen is this, now if we blow it up, this one, if we blow it up again we will see the structure is like this where these are Fe3c and these are ferrite. And this kind of structure we generally get, if we cool it very very slow.

Let us say we take it to a temperature about thousand degree Celsius and hold it there for half an hour or forty minutes or so, and then cool it slowly, now how slow we can cool.

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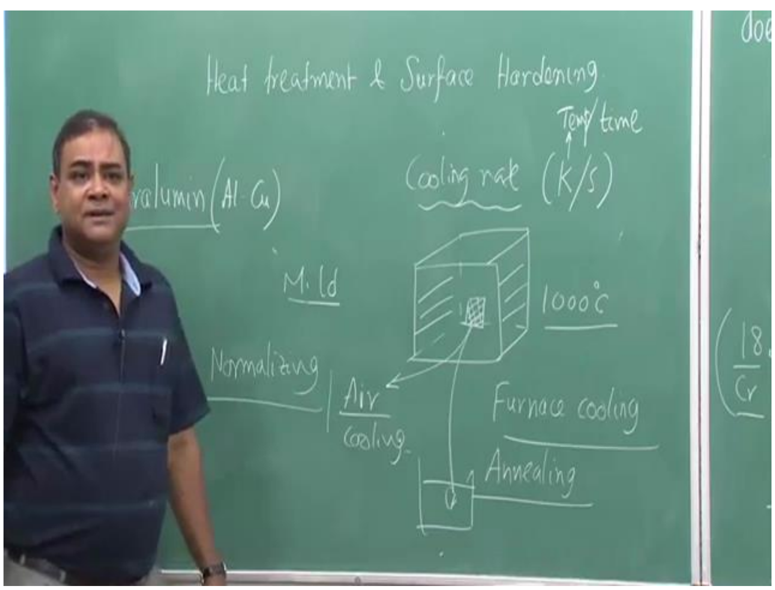

Now the question is whenever we talk about how slow we can cool, we have to measure the cooling rate, that means the degree temperature reduced by unit time. So that means we have a term called cooling rate, which is nothing but Kelvin per second. Now let us say I want to cool it very very slow, that means absolutely slow, but how slow we can go?

One practical process is, let us say I have take, I have taken the particular sample in a muffle furnace, muffle furnace is nothing but a box, and around that box we have heating rods or coils and that heats the material with astation here, this is the material let us say. Now let us say I have heated it to thousand degree Celsius the furnace temperature is thousand degree Celsius and there the temperature fixes. So that means temperature does not change.

Now once we have held it for forty minutes or so, if we put the furnace off, then it will and also the doors are closed, so that means it will cool very very slowly and that time we call it as furnace cooling. And this furnace cooling is very very slow cooling and that time we also call it as annealing or furnace annealing, specially the furnace annealing. And if we see the furnace annealing, if it is a very very slow process we can say that it is falling pseudo equilibrium process, it is not completely equilibrium, but we can say that it is a pseudo equilibrium and in many books you will find that it is basically very very slow cooling it is equilibrium cooling.

And that means if we have this kind of cooling, we will get the structure as is predicted in phase diagram because a phase diagram is basically called as equilibrium diagram. But now let us say I open the furnace, I leave it there, would it get the same cooling rate here what we have achieved here? No, it will have little faster cooling because the previous case the door was closed, the heat loss was very very slow, but once the door is open so that means it is getting access to open atmosphere and the heat can be loss very quickly and the temperature can drop quickly (())(17:41) quicker than this furnace cooling when the doors are closed.

But if this material is taken to normal condition that means normal air we just take it to outside, the furnace it will cool much faster. So that means if we take it to air, that time it is called air cooling you will later know that this is called normalizing. So that means, here also we are getting a bit faster cooling rate compare to the conditions where the doors are open and this is much faster compare to the furnace cooling where the door is closed.

Do you think in these three conditions structure would be same? I am talking about the microstructure because the crystal structure would not change, where it would have same structure as BCC, cementite would have the same structure. Now only change would take place is the microstructure and the microstructure would get finer and finer. So that means if we consider the distance between this two as d, as we go higher and higher cooling rate, these distance between two lamel is would decrease.

So that means, the perlite become finer. Now once this becomes finer, it strength increases. Now that means here the strength would be lowest, here the strength where the doors will be open, strength would be little higher but here it would be much higher than this. So that means I have a change in microstructure by changing in cooling rate and whenever we talk about cooling rate, we are talking about temperature, we are talking about time.

That means we are changing temperature and time, to come across this change in microstructure as the microstructure is getting finer and finer because of higher cooling rate, we are getting higher and higher strength, and of course the ductility will reduce or the elongation will reduce. That means we are changing in properties. So that means if we fix the composition, if we fix the structure, we get some properties even after that we have a window of opportunity where we can change the processing condition and change the properties in the same material.

Let us say in some application we need little higher strength and little lower ductility, we do not have to go for higher (comp) composition change, we only have to go for time and temperature variation, we get the properties as desired and accordingly I can have my performance or the desired performance. So that means processing is here, in the cooling rate. Similarly if we take this material to thousand degree Celsius and then immediately I have a oil bath which is maintained at room temperature and I dropped it immediately.

The sample becomes very very hard and the reason is there not only change is the microstructure, as well as the crystal structure changes, we get a different structure which is called Martensite, Martensite and the Martensite is a phase which is BCT structure Body entered tetragonal.

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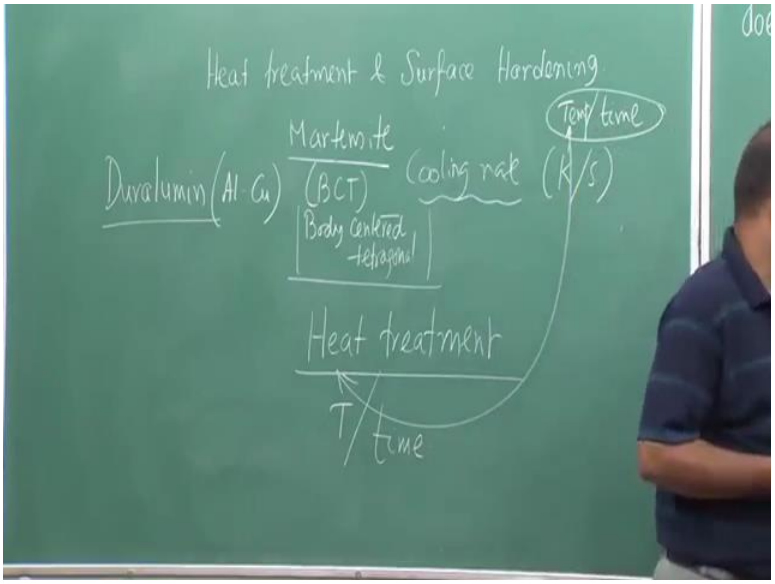

Body centered tetragonal, on whenever this phase arises in steel, the steel becomes very very hard. For example let us say a cutting tool a plain carbon steel cutting tool, our interest there the structure is the tempered Martensite and once we form Martensite, the sample becomes very very hard, once the sample becomes very very it ductility goes down.

That means it becomes little brittle, but if we take this Martensite to little higher temperature around 500 degree Celsius, these Martensite tempers and then forms a phase called tempered Martensite, that time it incorporates little bit of ductility, of course the strength reduces a bit. It does not reduce much, it reduces bit, but its ductility enhances so you can incorporate these properties into a cutting tool so that we can have longer performance.

So that means you can again see time and temperature. If we change these time and temperature on the same composition, we can get different properties as desired in order to meet the performance of that material in (app) practical application. So that means now what is this temperature and time? We talked about in many cases, we talked about heat treatment and heat treatment is coming from temperature and then treatment time, how long? How long will you heat it? Though it looks simple, there would be many many complications, but my intention here to tell that it is not only composition and structure to get the properties.

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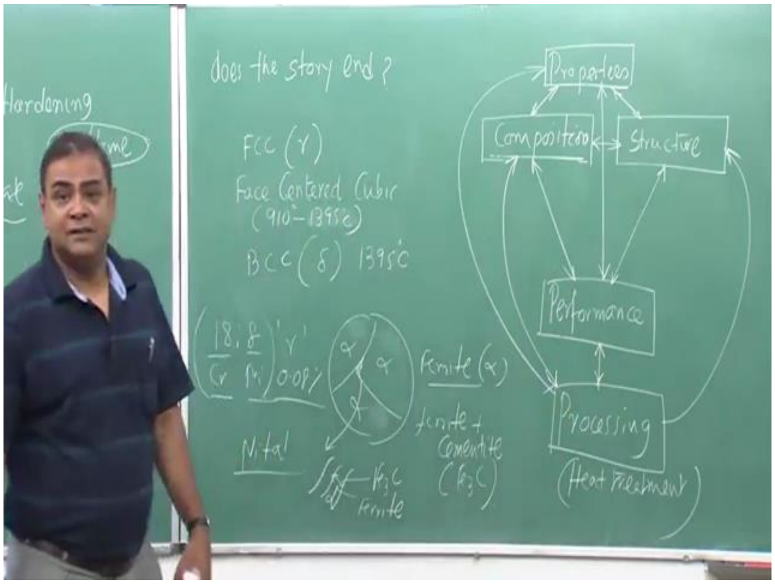

Rather there is one more way where we can have huge number of changes or large number of changes in the properties as well as structure is the processing. And heat treatment falls under processing, heat treatment fall under processing. So that means here we see the processing changes the properties, processing changes the structure, composition changes structure, processing also changes the (pra). Composition will decide the processing we will talk about that which composition, for example in case of cutting tool we need to get high carbon, and that higher carbon will be immediately taken to Martensite, it would be tempered in order to incorp a little ductility in it without losing much of (duc) hardness or strength.

And then we can get the cutting properties. So that means composition and processing this is also intricately related, structure is intricately related, can we not say that processing is also related to performance, is it? So now, we have discussing all this in order to get to this. But do you know what this, what is this? This is the basics of materials development. It is basics of material development and if you have gone through little bit of material scores, you have come across one particular diagram which is called material tetrahedron.

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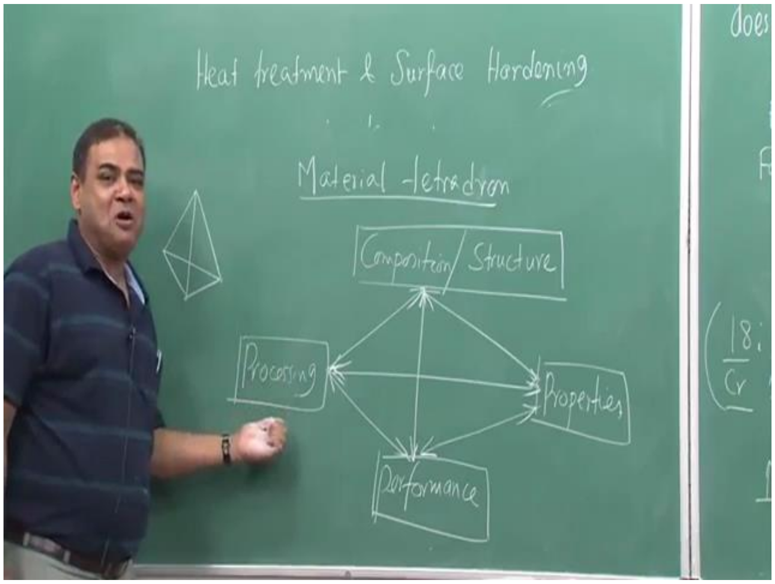

I am sure that you have gone (acc), come across this particular material tetrahedron, if we see that diagram, these two are inter related, these two are inter related, these two are inter related, these two are inter related, these two are inter related. So it forms a tetrahedron, this is a material tetrahedron and heat treatment falls here. So we will be talking about processing all the time and while processing, we will come across several terms.

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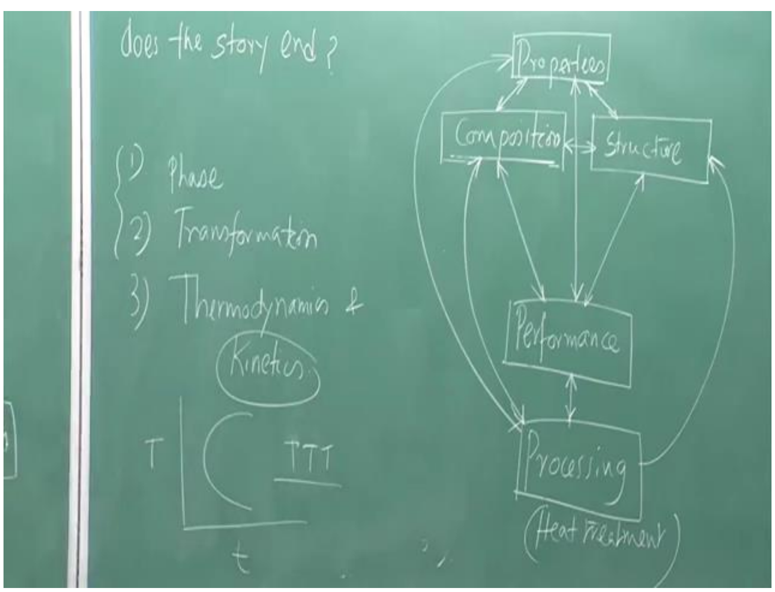

If we see this particular discussion, I can give some of those keywords what we have to come across, 1) is phase, 2) is transformation and when we talk about phase and transformation, we would be talking about thermodynamics and kinetics.

Because whenever we talk about phase, because of change in processing we will have to consider the transformation, so that was the phase transformation and once we talk about phase transformation, we need to see whether we could form that particular phase as per the free energy consideration. And once we see that that phase formation possibility is there, we need to see whether actually that phase would form or not that would be decided by the kinetics and finally once we see these all those three things, we get to a particular diagram t, t, t. And this t, t, t diagram would tell me what sort of temperature time information you need in order to get a particular set of properties from a particular material in order to meet up desired performance.

So let us end here that final aim would be to see phase transformation thermodynamics and kinetics in order to decide time temperature information to get desired performance. Thank you very much.