Basics of Materials Engineering
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Lecture – 54
Phase Diagrams (Introduction)

Welcome back. The next module in this course is phase diagrams. In this course, we have first looked at the crystal structure of crystalline materials. Then, we have looked at different kinds of defects in materials and how the defects lead to certain mechanical properties. We have discussed how one measures the mechanical properties and the different kinds of mechanical properties that are of interest from design perspective.

After estimating the mechanical properties, we have spent some time understanding the failure theories. How the materials fail and based on the failure theories, how do we go about designing certain machine components, right? However, we have discussed designing pretty simple components like beams and so on.

The detailed design of several machine elements will come in the next course on design of machine elements. And once having done that, if you remember in the very beginning, we have discussed the concept of PSPP diagram i.e., processing, structure and performance and product, right? So, in that PSPP diagram, the first one is processing, which will give us certain crystal structure.

In this module, we will see how processing helps us in obtaining the structure of our interest. Phase diagrams is a module that gives us more understanding about the development of the structure of a solid material, when it is cooled from the liquid state.

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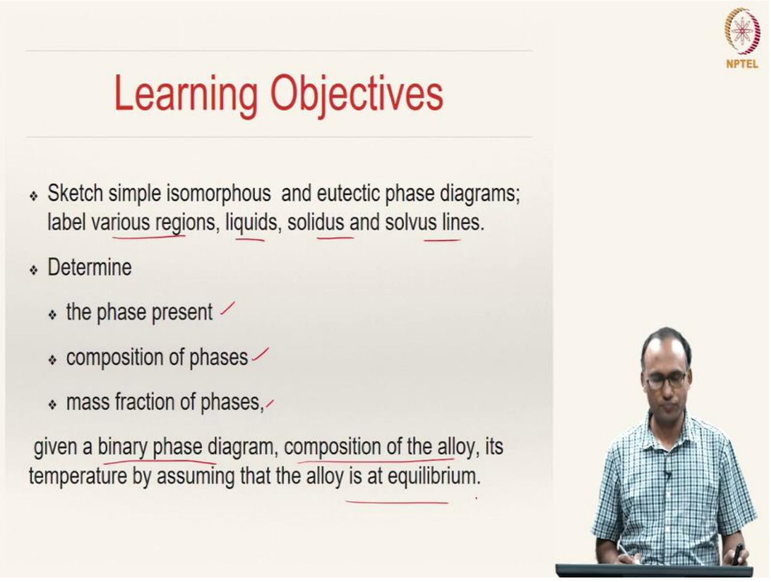

The learning objectives of this module are: to be able to sketch simple isomorphous and eutectic phase diagrams. And we should be able to label various regions such as liquidus, solidus, solvus lines single phase regions, two phase regions and so on.

In various regions in this phase diagram, we should be able to determine the phases present, and their compositions and the mass fractions or weight fractions of those phases that are present in a binary phase diagram, given a binary phase diagram and the composition of the alloy and its temperature, by assuming that the alloy is at equilibrium.

In this course, we will be only focusing on binary phase diagrams. What do we mean by a binary phase diagram? We will discuss in a moment.

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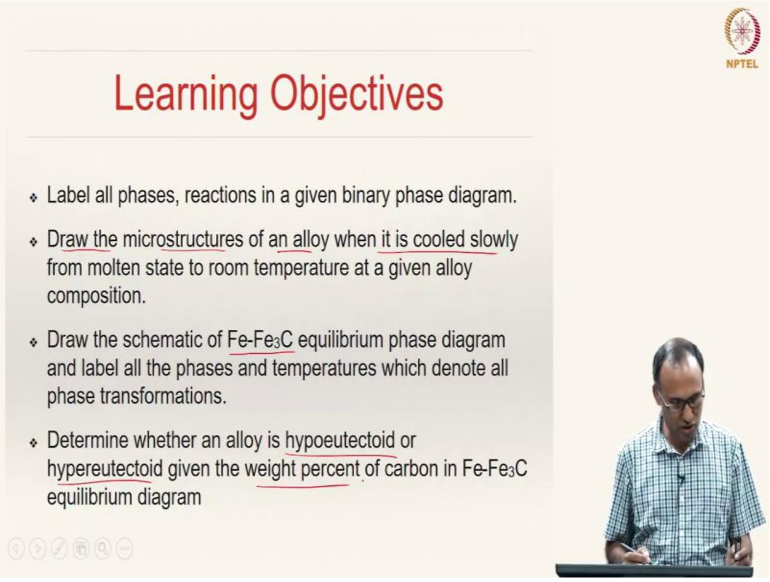

We should also be able to label all the phases in a given phase diagram and the reactions that the liquid or solid goes through, when it is cooled down from the high temperature to room temperature or low temperature. And then, we should also be able to draw different kinds of microstructures.

When we say 'draw the microstructure', we actually mean the schematic representation of the microstructure of an alloy, when it is cooled slowly from molten state to room temperature for a given alloy composition.

And then, once we understand this aspect of identifying different phases, calculating the weight fractions of each and every phase and so on, we will spend time on understanding a specific phase diagram of interest, primarily for engineers, i.e., the iron - iron carbide equilibrium phase diagram. Iron-Carbon phase diagram is of extreme importance, particularly for mechanical engineers, because most of the components or machine components that we work with are made of steel, which is an alloy of iron and carbon.

Hence, we will spend a significant amount of time of this course understanding the iron - iron carbide equilibrium phase diagram and the discussion thereafter. We should also be able to determine, given a composition, whether an alloy is hypoeutectoid or hypereutectoid, given the weight fraction or the composition of the alloy.

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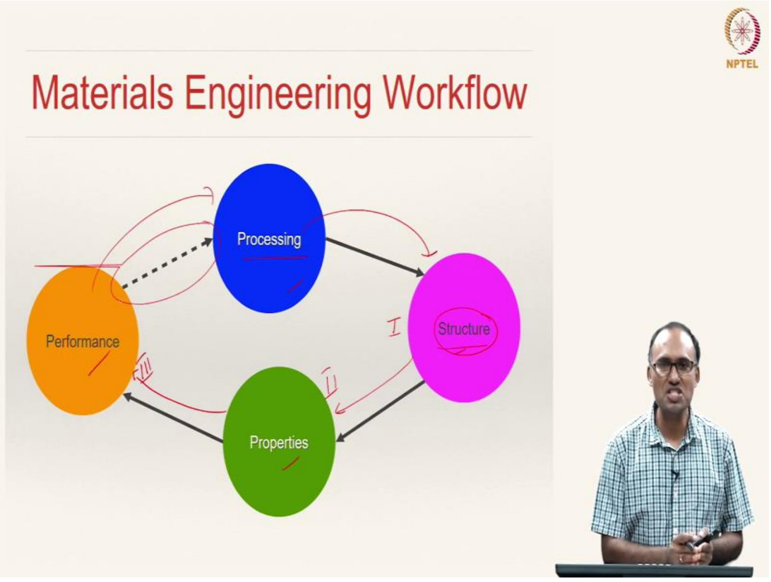

This is the materials engineering workflow, where we have discussed the PSPP diagram: processing, structure, property and performance. However, when we have drawn this diagram in the beginning, we did not have this dashed line; this is something that I have drawn to try to make some sense out of this processing. As we have discussed, we have started here, our journey of this course started by understanding the structure.

From there, we understood the mechanical properties, which strongly are a function of the underlying microstructure or underlying structure of the solid. Having understood the properties, we have discussed the failure theories; and then based on that, under a given loading condition, what is the factor of safety or whether the component will withstand the loads that are applied.

In other words, we were trying to understand the performance characteristics of the component, given a particular material being used as the basis for making the components.

So, we have also, in some sense, we looked at the performance. We know that a particular structure of a material is obtained by taking a specific processing route. So, the processing is the key, which will give us certain structure, right? And that structure in turn, gives certain properties. Those properties are responsible for the performance.

If the performance of the component is not up to mark, we need to enhance the performance and then, that input can possibly be given back to the processing and we can change the processing route in order to get a structure that would give the required performance.

In that sense, although it is not a closed loop, this dashed line can sort of be thought as a feedback from the performance step, to improvising the processing step. The phase diagrams module primarily discusses the processing part of the PSPP diagram.

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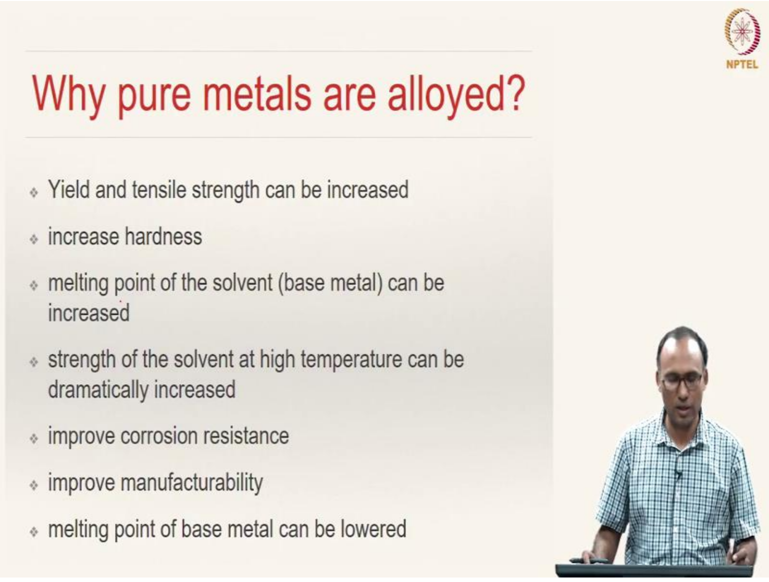

Most of the materials that we use in our daily life are not pure metals; they are almost all the time or many times, alloys. The question that we need to ask ourselves is the following: why are pure metals alloyed? When you take a pure metal, the pure metal's strength, for instance, yield strength and tensile strength from the mechanical properties' perspective, can be enhanced by alloying it.

We can increase the hardness of a pure metal by adding additional components or by alloying it. We can also change or increase the melting point of the solvent by alloying it. In an alloy, there is more than one kind of component. One is something called a solvent and another is the solute. An alloy is basically a solid solution; solvent is the host and solute is the guest.

If you want to increase the melting point of the solvent, you can add some impurity or solute atoms in order to enhance the melting point of this base material. We can also enhance the strength of the solvent at high temperatures, by doing certain kinds of alloying. We will see such few examples.

Another important aspect, corrosion, which is a deteriorative property, can also be enhanced by alloying. Stainless steel is corrosion free; stainless steel is an alloy of iron, steel, chromium and certain other materials. The resistance to corrosion is offered by elements like chromium. It also enhances the manufacturability. Certain materials cannot be manufactured readily; certain pure metals cannot be manufactured readily. Hence, in order to enhance their manufacturability, we usually do some alloying, so that the solvents' manufacturability is enhanced by alloying it with a foreign element.

We can also sometimes reduce the melting point of the base metal by alloying. So, these are all the different advantages that one would get by alloying and hence, we see alloys being more prevalent in our daily life than metals in their pure form.

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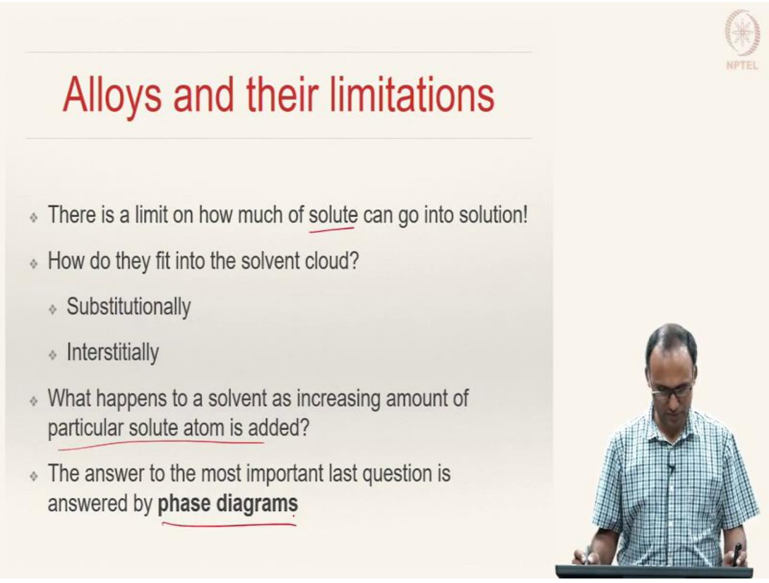

We know that there are several advantages of alloys over pure metals. Having looked at the advantages, we also need to see are there any limitations. The limitation is that there is a limit on how much of solute can go in to solution; that means, you cannot add as much amount of the solute to the solution. There is a limit of solubility of metal A in metal B and vice versa.

It is also important to know that there are different kinds of fitting i.e., if you are adding a solute atom to solvent, how these solute atoms go and fit in the solvent cloud. They can either sit amongst the solvent atoms substitutionally or interstitially. If the solute atoms are going and sitting in the place of a host atom, then such solutions are called substitutional solid solutions.

But, if the guest atoms are going and sitting in the interstitial spaces available amongst the solvent cloud, then such a solid solution is called interstitial solid solution. What happens to a solvent as increasing amount of particular solute atom is added? You cannot keep on adding the solute atom. As we have discussed, there is a limit.

If you keep on adding, what happens to your base metal? That is something that one needs to understand. Coming to the most important last question: what happens when you add solute atoms to solvent, and what happens to this base metal as an alloy? This important last question is answered by phase diagrams; that is why we are spending a significant amount of time in understanding phase diagrams.