Basics of Mechanical Engineering-2

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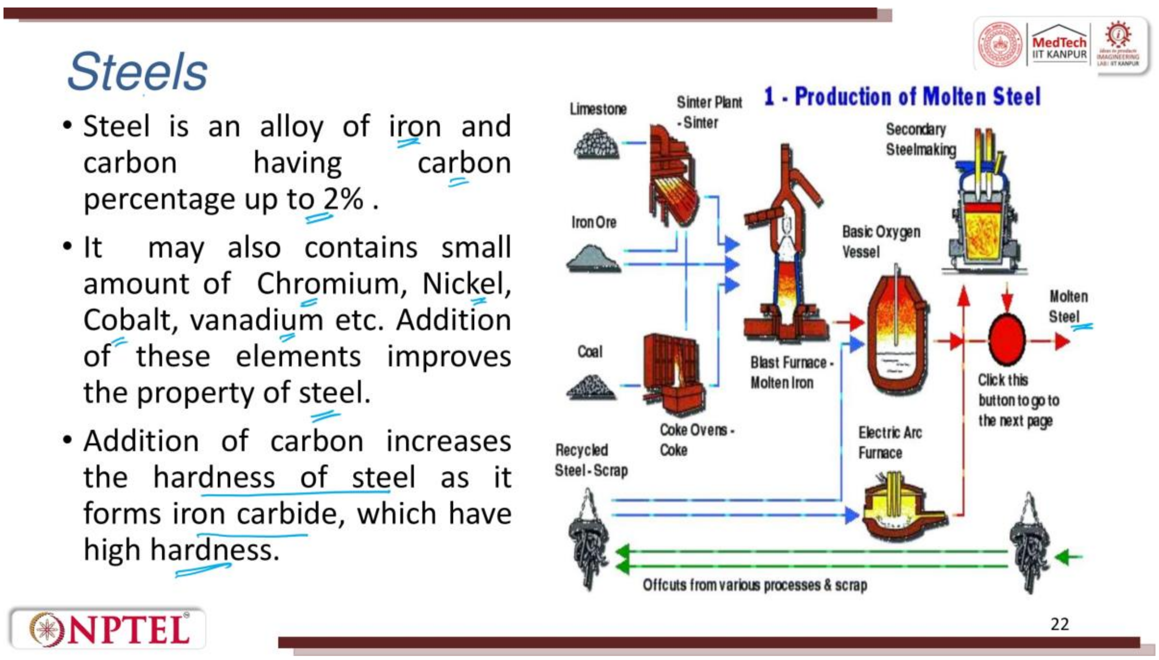
Week 01

Lecture 03

Engineering Materials (Part 2 of 3)

Welcome to the next lecture on Engineering Materials. In this lecture, we will try to cover Steel and its Alloys.

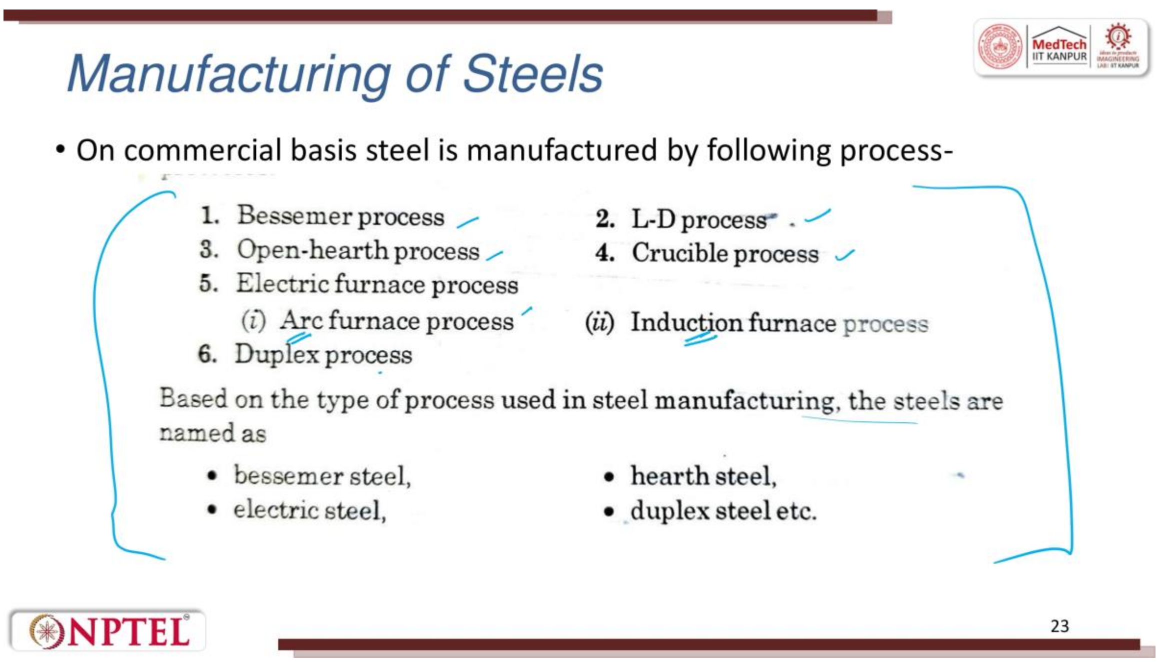


Steel is an alloy of iron and carbon, having a carbon percentage of up to 2%. So, if you see the production of steel, you can see limestone, iron ore, coal, and other scrap items. They are all put into the limestone, which is put into a sinter plant.

Then it gets into a blast furnace. Iron ore is put into the blast furnace, and coal is also added there. So, from here, what they do is they try to put the output into a basic oxygen vessel, from where they try to get the molten steel. The secondary steel-making process is also like this. So, in which the steel scrap is put into an electric furnace, from there it gets into the secondary steel-making, and then you try to make a billet or whatever it is.

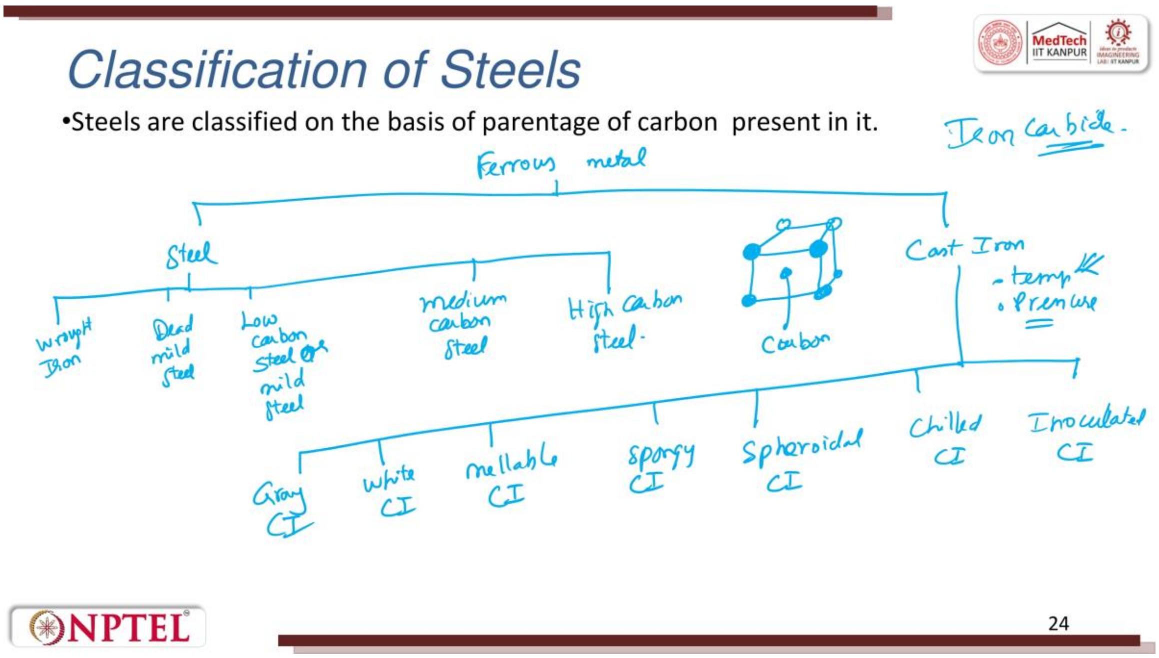
So you get this, and then you try to make steel. So, from scrap also, it gets recirculated, and then you try to make use of it. It may also contain; steel contains iron and carbon. Apart from these two, it can contain a small amount of chromium, nickel, cobalt, and vanadium. The addition of these elements improves the properties of steel.

The addition of carbon increases the strength, that is to say, the hardness of the steel as it forms iron carbide, which has a high hardness. The formation of iron carbide will be dealt with in one lecture when we talk about heat treatment.



The manufacturing of steel has several processes. On a commercial basis, steel is manufactured by these processes. Bessemer process, open hearth process, electric furnace process, duplex process, L-D process, and crucible process.

In electric furnaces, you can have arc furnaces and induction furnaces. So the basic types of processes used in steel manufacturing are named as Bessemer steel, electric steel, hard steel, and duplex steel. So these are all the different types of steel available in the market.



So when we try to classify steel, ferrous metals, steel, and cast iron, the only difference is the carbon content. When we have steel, we have wrought iron.

Then we have dead mild steel, low carbon steel, or mild steel, medium carbon steel, high carbon steel. When we try to look into cast iron, you will have grey cast iron, white cast iron, malleable cast iron, spongy cast iron, and spheroidal cast iron. Then you have chilled cast iron and inoculated cast iron.

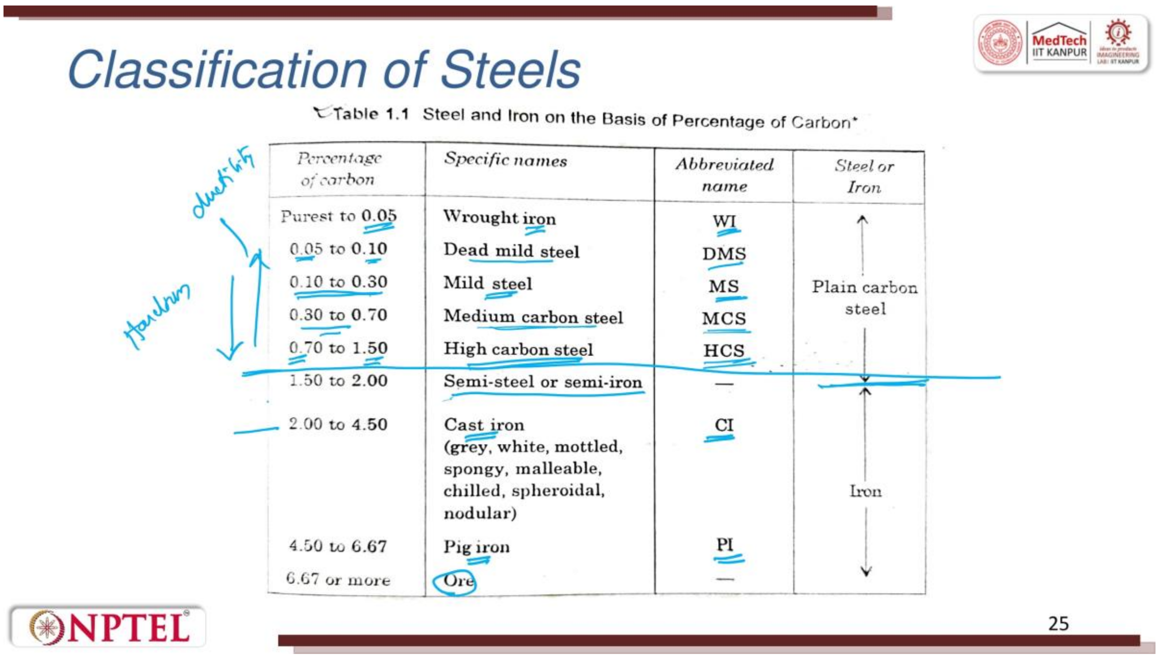
Cast iron is used; it has multiple classifications if you look into it, right. So, steel, a ferrous metal, can be classified into steel and cast iron. The difference between steel and cast iron is the percentage of carbon. So, we follow Hume-Rothery rules. See, what happens is, when you try to have ion atoms in a unit cell, the size of the atom, the radius of the ion atom, is larger than the carbon atom.

So, there is a space in between these atoms. So, the carbon atom easily gets into the iron unit cell and then it occupies a space. So, these are all ion atoms. This is a unit cell. So, you can see how iron diffuses inside and goes and sits there.

So, because of the property of the carbon to diffuse into iron, it easily forms an alloy. So, if there are more numbers of carbon ions, the movement of this cube is restricted. So, the moment it is restricted, then you get cast iron. If it is less, then you try to have some amount of ductility, so you will get steel. So, that is the difference.

So, how is this carbon getting diffused? It can be diffused using temperature or pressure. So, generally, what we do is we try to do heat treatment. We try to take it to a higher temperature. So, the cube slightly expands, and then the carbon diffuses inside.

This is the basic science. How are these alloys getting formed? So, the moment there is carbon formed, it forms Fe or iron carbide because the carbon sitting there, iron is getting formed.



Classification of Steels

Table 1.1 Steel and Iron on the Basis of Percentage of Carbon*

Percentage of carbon	*Specific names*	*Abbreviated name*	*Steel or Iron*
Purest to 0.05	Wrought iron	WI	Plain carbon steel
0.05 to 0.10	Dead mild steel	DMS	
0.10 to 0.30	Mild steel	MS	
0.30 to 0.70	Medium carbon steel	MCS	
0.70 to 1.50	High carbon steel	HCS	
1.50 to 2.00	Semi-steel or semi-iron	—	
2.00 to 4.50	Cast iron (grey, white, mottled, spongy, malleable, chilled, spheroidal, nodular)	CI	Iron
4.50 to 6.67	Pig iron	PI	
6.67 or more	Ore	—	

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So, if you look into the classifications, when the carbon content is less than 0.05, it is called wrought iron, which is Wi. So, you can see here, this is plain carbon steel, and here you see it is iron.

So, from 0.5 to 1, it forms dead mild steel, DMS. 0.1 to 0.3, it forms mild steel, which is MS. This is why, in colloquial terms, we call it MS. MS is nothing but mild steel. In mild steel, you will have a carbon content up to 0.30.

And from 0.30 to 0.7, we make Medium Carbon Steel, which is MCS. And when we have somewhere from 0.7 to 1.5, it is called High Carbon Steel, HCS. From 1.5 to 2, it is called semi-steel or semi-ion. So the transition happens between 1.5 to 2; there is a grey area. And from 2 onwards, it forms cast iron, Ci.

And from 4.5 to 6, it forms pig iron, Pi. So anything more than 6.67 is called ore; it is more than pig iron. So it is very clear that steel comes only up to 1.5. And here, the percentages are directly proportional, so the hardness increases, and the ductility increases as you go from down to top, right? So these are the advantages you get, and carbon is the major culprit. It is not only carbon; you have other additional elements also added to it.

Low Carbon Steels

- These generally contain less than about 0.25 wt.% C and are non-responding to heat treatments intended to form martensite.
- The strengthening is accomplished by cold work. ← metal Forming
- Microstructures consist of ferrite and pearlite constituents.
- These steels are relatively soft and weak, but have outstanding ductility and toughness.
- They are machinable, weldable and least expensive to produce.
- These can be easily rolled and forged to produce rod, bar, plate, etc.

Applications:

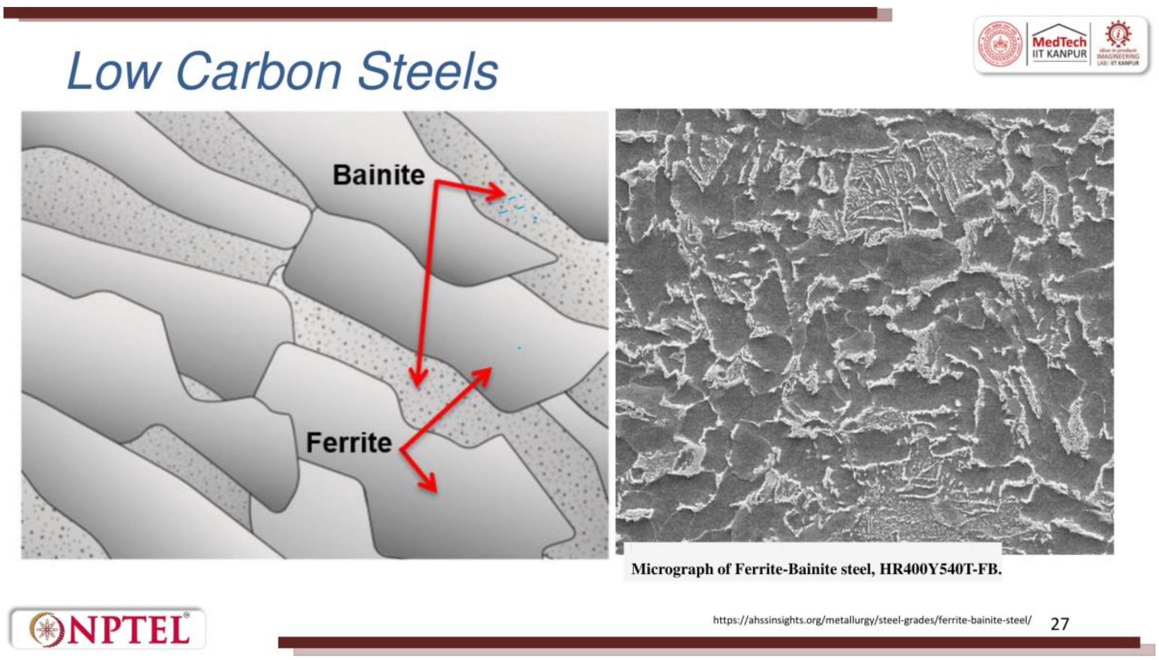
- Pipes
- Automobile part
- Domestic part
- structural application
- tube

https://www.bindingwire.org/binding/low-carbon-steel-wire.html 26

When we look at low carbon steel, it generally contains less than 0.25 weight percentage of C and is non-responsive to the heat treatment intended to form martensite. So, austenite, martensite—these things we will deal with later in our lecture, where we talk about heat treatment and the formation of these structures. The strengthening is accompanied by work hardening. Work hardening is nothing but metal-forming operations, right?

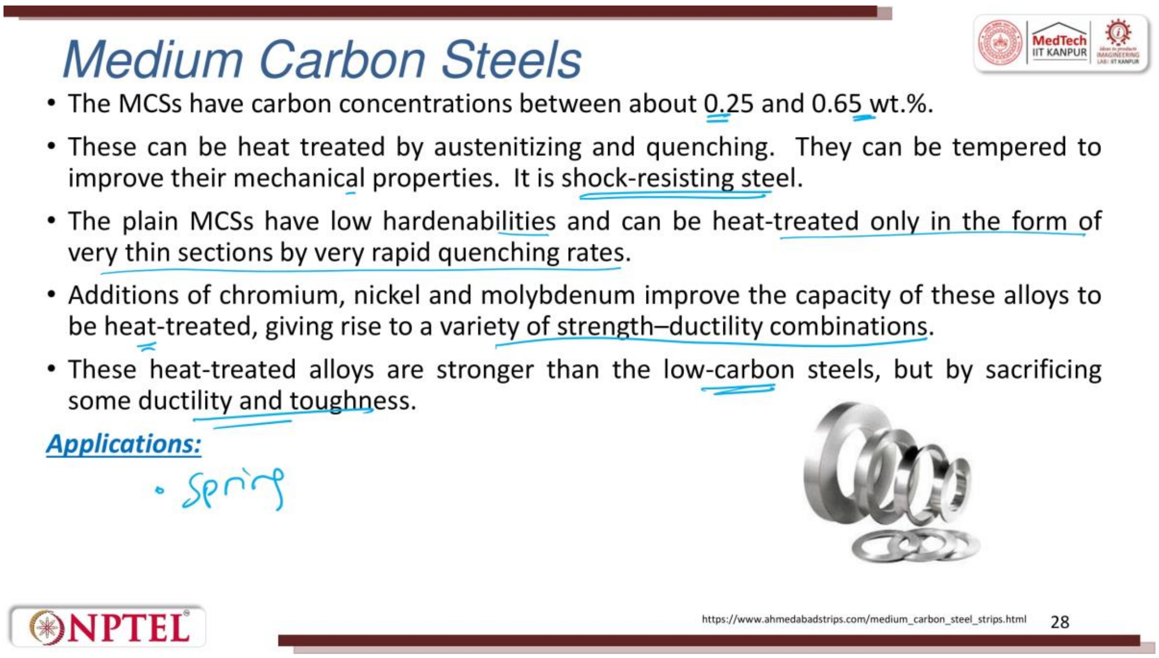
So, the microstructure consists of ferrite and pearlite. These steels are relatively soft and weak but have outstanding ductility and toughness. So, it can be used for applications like steel pipes, automobile parts, and domestic parts. For example, kitchen utensils and other things can be made from it. It can also be used for structural applications, frames, and other structural uses. Tubes can be made from it.

So, they are machinable, weldable, and least expensive to produce. They can be easily rolled or forged to produce rods, bars, plates, etc. Springs and wires can be made from it.



So, this is what the microstructure looks like when you examine low carbon steel. We will have a detailed discussion about it when we explore heat treatment.

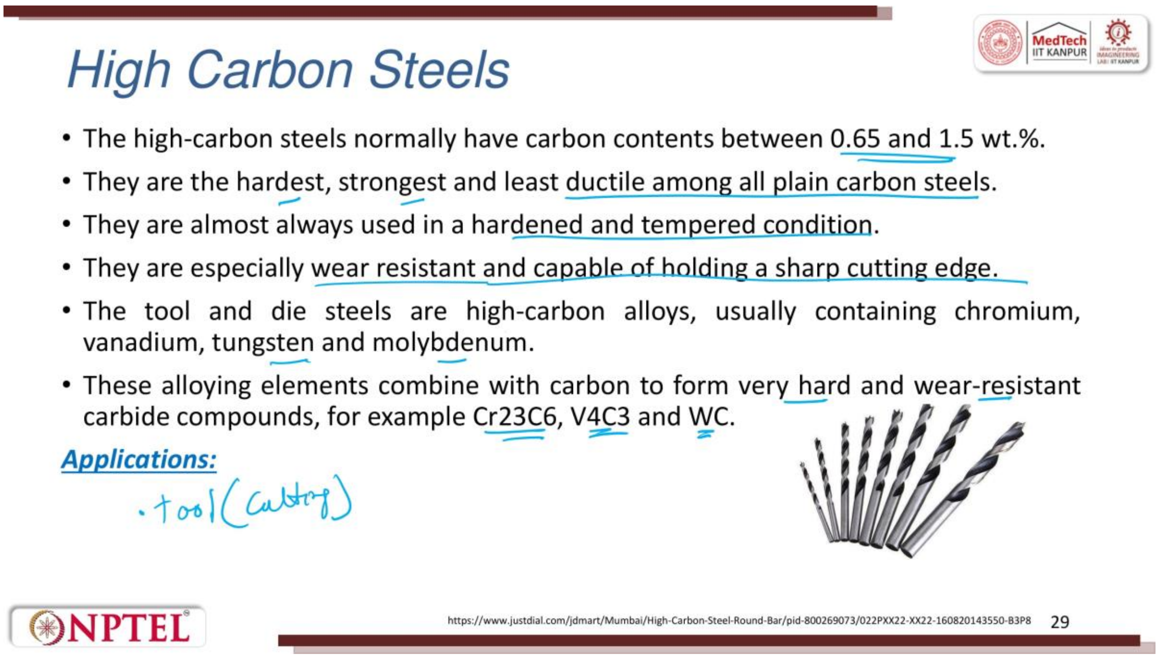
So, you will see ferrite structures here. These are ferrites, and these dot-like structures are bainite, and these are carbon. When you take it to higher or lower temperatures, the carbon diffuses.



When we talk about medium carbon steel, the carbon concentration ranges from 0.25 to 0.65. They can be heat treated by austenitizing and quenching.

They can be tempered to improve their mechanical properties. It has shock resistance. It is a shock-resistant steel. So, for example, springs. Good quality springs, leaf springs which are used in automobiles are made out of it.

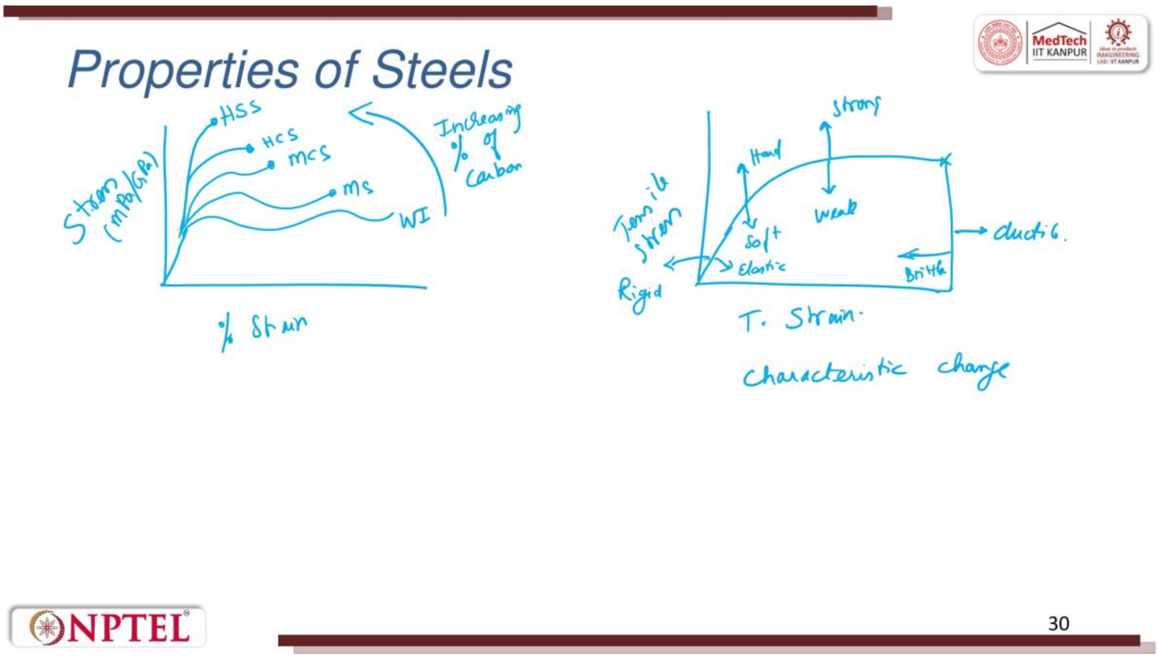
Plain mild carbon steel has low hardenability and can be heat-treated only in the form of very thin structures but by a very rapid quenching rate. So, when we are trying to do a small amount of heat treatment with low temperatures and other things, we always use a low carbon steel material. The addition of chromium, nickel, and molybdenum improves the capacity of these alloys to be heat-treated, giving rise to a varied steel strength-to-ductility combination. These heat-treated alloys are stronger than low carbon steel but sacrifice ductility and toughness. So, the application here can be springs, okay.



So, when we are looking at high carbon steel, high carbon steel normally contains carbon up to 1.5 weight percentage. They are the hardest, strongest, and the least ductile among all plain carbon steels. You see the ductility. When you go back and see my picture here, I have shown it. Ductility and hardness, right?

So, if you want to make it a very high-strength material, a flat plate, So, then we always go for high-carbon steel. Some of the drills are made out of high-carbon steel. They are almost always used in a hardened and tempered condition. They are especially wear-resistant and capable of holding a sharp cutting edge; the drill tools, the chisel edge, all these things are made of it.

For example, the screwdriver tips are all made out of high-carbon steel. The tools and die steel are high-carbon alloys, usually containing chromium, vanadium, tungsten, and molybdenum. These alloy elements combine with carbon to form very hard and wear-resistant properties: chromium, vanadium, and tungsten. So here, cutting tools are made out of high-carbon steel.



So, when we look into the properties of steel, stress versus strain, stress which is in MPa or gigapascals, depending upon your requirements.

Here it is the percentage of strain, right. So, it is a unitless quantity. Then you can see it varying steel properties. So, this is high-speed steel, this is high-carbon steel, this is mild carbon steel, this is mild steel, this is white iron; so, when you increase the percentage of carbon. So, you can see there, the stress increases and the strain reduces. When you try to see a typical tensile stress versus tensile strain.

So, you can try to have this strong, this weak, right, stress I am trying. This is hard and this is soft and this is only relative. This is just for your understanding. This is rigid if it goes like this, and this is elastic when it goes like this. When it goes like this, it is ductile, and when it goes like this, it is brittle. So, this is just a characteristic change of different materials. So, you will try to see that.

So, in properties, you should understand stress versus strain, how does the carbon content influence the stress and strain of the given material, and this is a typical characteristic change which is there.

Alloy Steels

- An alloy is composed of two or more elements of which at least one element is a metal.
- Constitution of an alloy mainly consists of the following:
  1. Base metal
  2. Alloying elements
- The metal constituent present in an alloy with highest proportion is known as the *base metal*.
- Other constituents, metallic or nonmetallic, present in alloy are called *alloying elements*.

When we talk about alloy steel, an alloy is composed of two or more elements for which at least one element is a metal. So, you can have a base metal and an alloying element. The main constituent present in the alloy with the highest portion is called the base metal, and whatever is getting added is called the alloying element.

Purpose

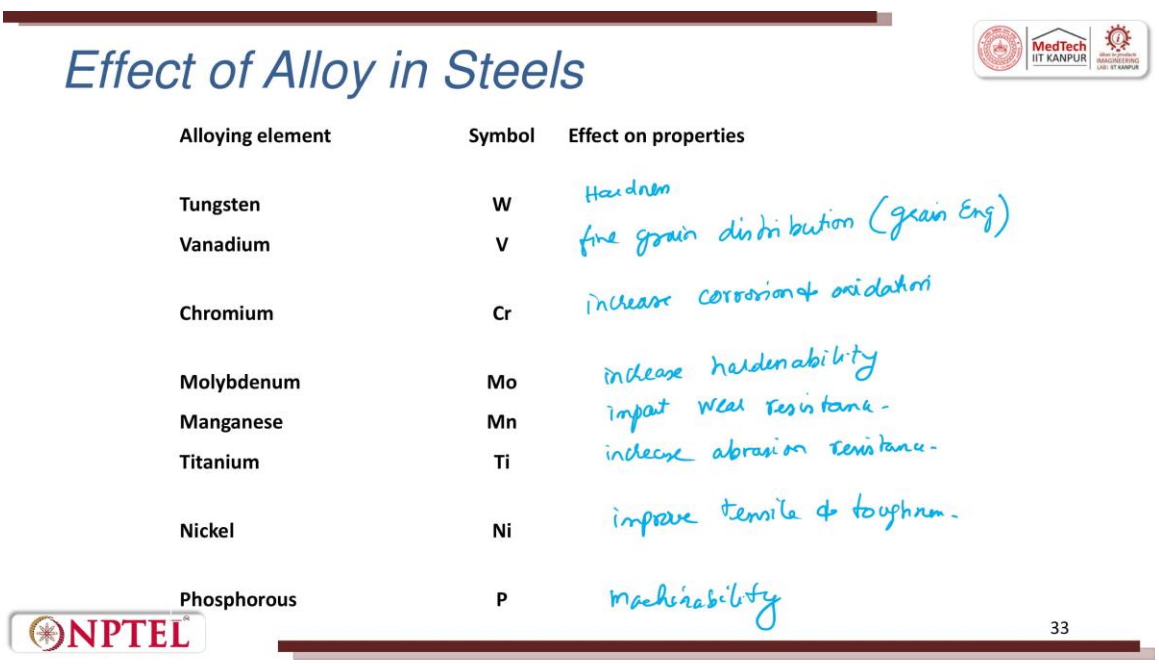
Different purposes of adding alloying elements in steel are as follows:

- To form martensite without cracking of steel.
- To enhance hardenability.
- To increase red hardness (elevated-temperature hardness). hot hardness
- To distribute carbides during tempering.
- To provide wear, corrosion and abrasion resistance.
- To impart toughness.
- To increase ductility.
- To increase machinability and weldability.
- To achieve overall improvement in physical and mechanical properties.

So, there are different purposes for adding alloying elements in steel. To form martensitic without cracking of steel. So, as I told you, martensite, austenite, I will explain to you in the next lecture. To enhance hardenability. To enhance red hardness, red hardness or hot hardness. For example, when we are trying to increase the temperature and check the hardness. When the cutting tool is cutting a workpiece, the temperature goes very high. The cutting tool has a very high temperature.

So, now the hardness of the tool should not be sacrificed. If it is sacrificed, then it gets worn out. So, to increase the hot hardness, to distribute the carbide by tempering, to improve wear, corrosion, and abrasive resistance, to impart toughness, to increase ductility, machinability, and welding, and to achieve the overall improvement in the physical and mechanical properties, we always go for alloying elements. So, the elements can be silicon, chromium, nickel. It can be molybdenum.

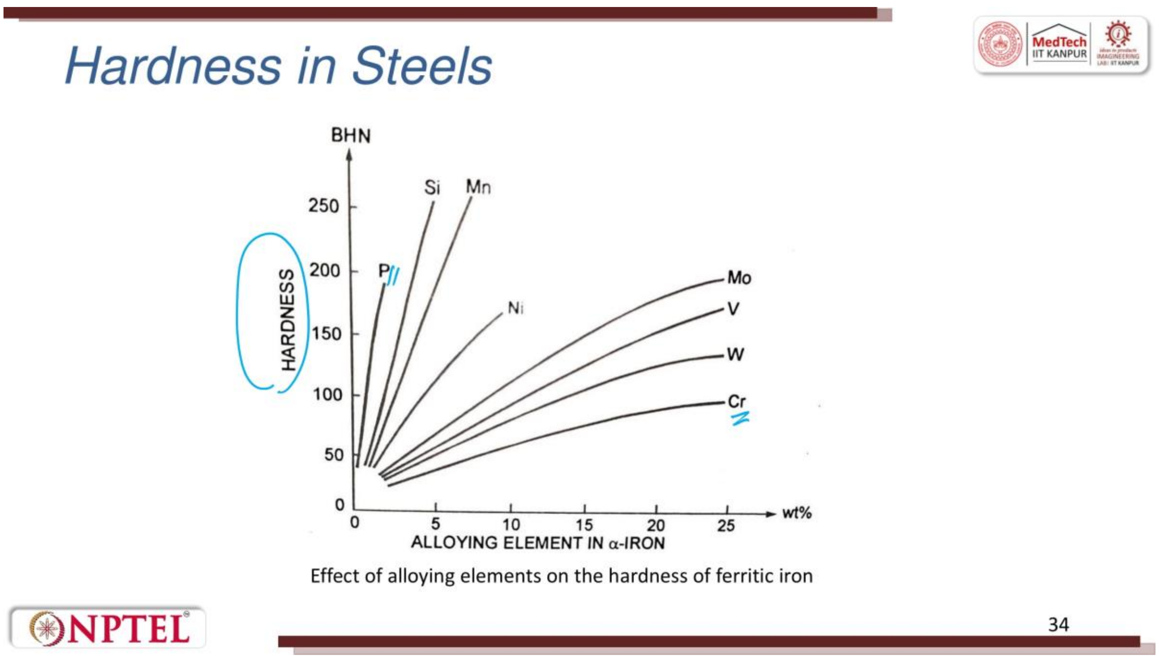
It can be magnesium. It can be manganese. You can add any of these things to meet the requirements.



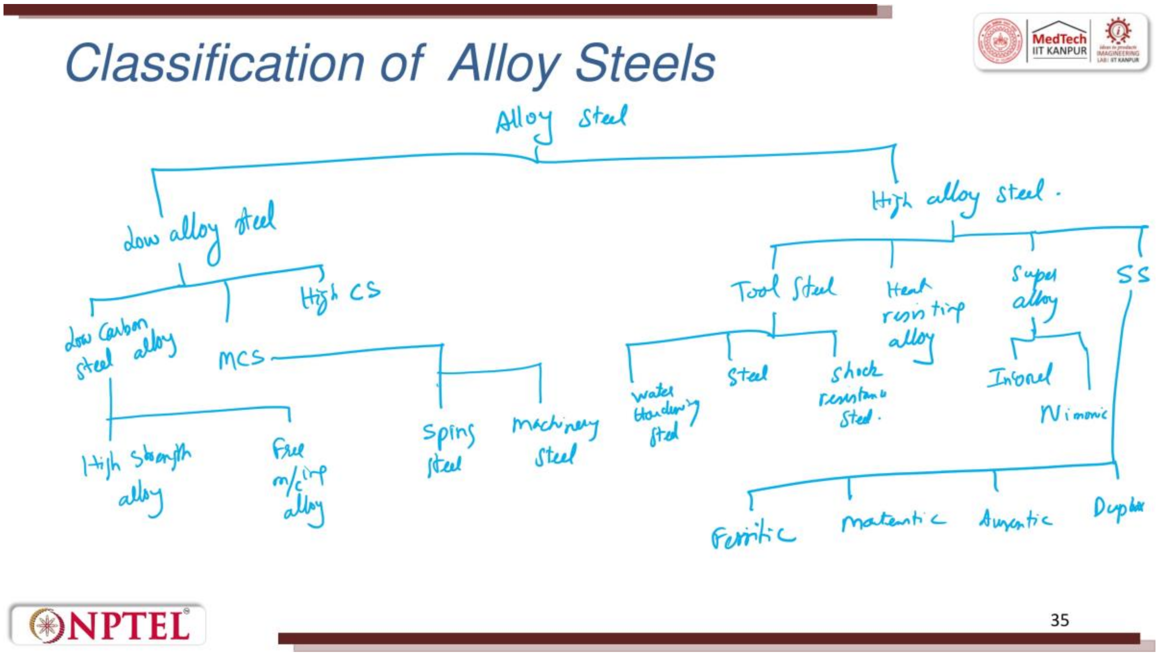
So here are some of the alloying elements. Here are their symbols. So if you want to increase hardness, we add tungsten to increase hardness. To impart fine grain distribution. I told you at the beginning of the lecture itself, when we talk about grain engineering, we try to understand how we make the grain such that we get the property.

Chromium is to increase corrosion and oxidation resistance. Molybdenum is used to increase hardenability, making it harder, hardenability. And then imparting wear resistance is done by manganese, imparting wear resistance.

Titanium is used to increase abrasive resistance and abrasion resistance. Nickel is used to improve tensile strength and toughness. Phosphorus is used to enhance machinability. This means that we can easily machine the component. As you can see, we have added different elements with varying effects on the properties.



When you draw a graph between hardness and alloying elements, you can see here how increasing the chromium percentage affects the hardness, and then what happens by adding phosphorus. So you can see how the hardness is influenced by varying elements.



The classification of alloys. So, when we try to classify alloy steel, it is low alloy steel and high alloy steel. So again here, it is low carbon steel alloy, high carbon steel alloy, and mild carbon steel.

In low carbon, you have high strength alloy and free machining alloy. In mild steel, you have spring steel and machinery steel. Okay, when we talk about high alloy, we have tool steel, heat resisting alloy, and super alloy. And then we have stainless steel, right? Again, in stainless steel, you have ferritic, martensitic, austenitic, and duplex. We will see all these things in detail later.

So, here you can have superalloys, you can have Inconel and Nimonic. And when you try to look at tool steel, again they have three classifications. One is water-hardened steel, then you have ordinary steel, and then you have shock-resistant steel. So, these are the classifications of alloy steel. So, we have used these things as references in this lecture.

In this lecture, you would have seen the steel, alloys of steel, and the classifications of steel in detail. The austenite, martensite, duplex, and ferrite, these things we will try to cover in the heat treatment lecture.

Thank you.