Basic Construction Materials
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Module - 7
Lecture - 34
Metals 1 - Part 2

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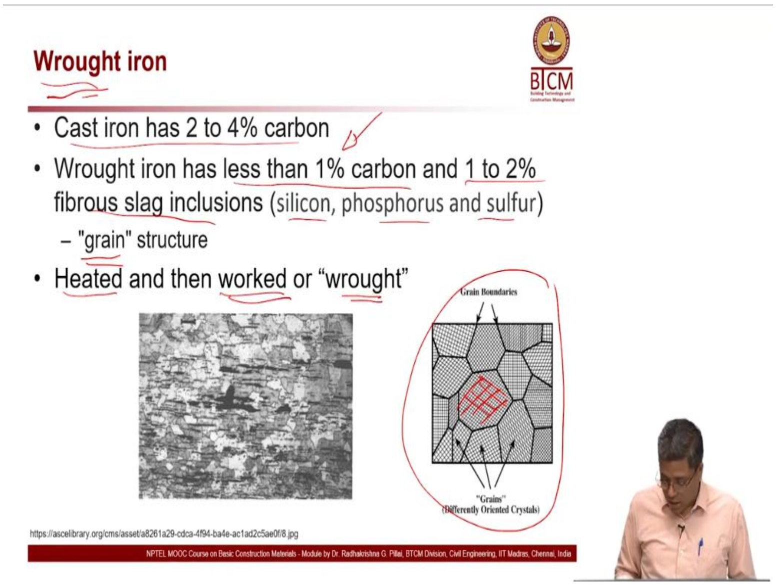

Now, another product is wrought iron. So, as we already talked, cast iron has 2 to 4% carbon. Now, this is wrought iron which we are talking, which is slightly different in microstructure. Let's see what is the difference. It has less than about 1% carbon. Whereas, in cast iron you had 2 to 4% carbon and 1 to 2% slag. That's the key thing, key ingredient there.

Now, you have both carbon and 1 to 2% slag is there. Mainly silicon, phosphorus, sulphur, these are the contents which are present in the slag. Now, because of this, there will be a formation of a grain structure. As we recall this, you might remember this image. In the nature of materials module, we had a detailed discussion on these grains. You can see grains in different directions and all that grain boundaries; all these we discussed. And then, these grain boundaries help in preventing the crack propagation. So, they have a significant role on the mechanical properties.

Now, how is this made? It is heated and then worked. The 'wrought' word is coming from the word 'worked'. So, it is similar to a strain-hardened or that kind of process. So, it is bent;

and during the manufacturing process, it is not just casting like in case of cast iron, here you also have a cold working involved when we talk about the wrought iron.

The main thing with wrought iron is, it has slag also as an ingredient. So, slag, carbon and iron are the 3 main ingredients. And because of which you have a grain formation. And because of the grain formation, the mechanical properties are very different as compared to cast iron and ductile iron.

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And it is lighter and stronger. Because of this lighter and stronger kind of properties, it is used in many engineering applications. One of the first and noticeable application is wrought iron used in Eiffel Tower and also in Statue of Liberty. When you see the Statue of Liberty, the green shell is made of bronze or copper element, but the inside frame is made out of wrought iron, because it has high strength and it is lighter.

When you talk about these large structures, the dead load or the total weight of the structure also has to be minimised. If the total weight is going to be very high, then you will have a huge challenge of creating a good foundation. That also will become very big. So, in-general, there is a need for reducing the total weight of the structure. So, that is why they go for lighter material or less dense material (density is less) with high strength.

So, this is just an image, this one, the inside view of the frame inside the Statue of Liberty. These are all collected from the internet. You can see also these different aesthetically pleasing shapes for various applications in buildings, fences, etc, wrought iron is widely used.

Wrought iron is less harder than the cast iron also, because of the reduction in the carbon content from about 4% to about 1%. The hardness also decreases significantly. So, there are advantages and disadvantages of these various properties. We have to see what is that you need for various engineering applications.

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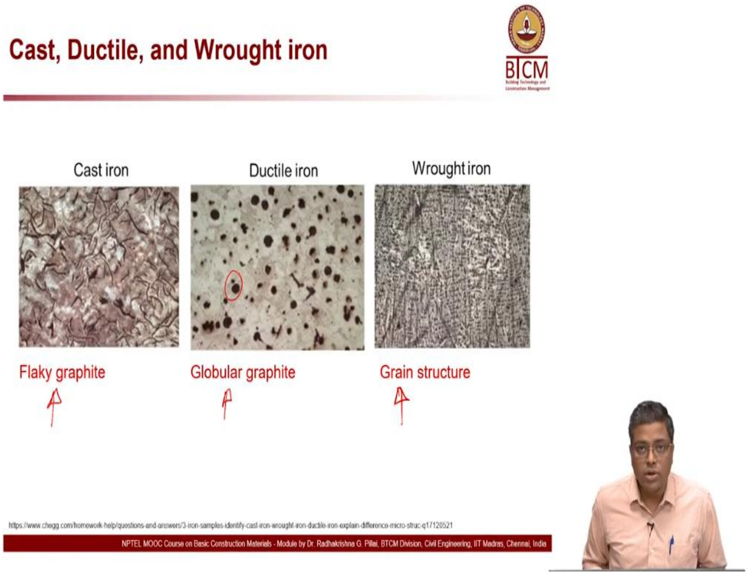

Now, let's look at all these three materials at once, just to kind of summarise. So, you have cast iron on the left side, which is mainly having flaky graphites and because of that, your brittleness of cast iron is very high. Ductile iron is on the middle picture. It has this globular graphite, so, the brittleness decreases, ductility increases, and hence we call it ductile iron. And both these cast iron and ductile iron has high hardness, high strength, corrosion resistance, etc.

Now, another product was wrought iron which is having a grain structure. And it has less carbon than the cast iron or ductile iron, but it also has slag present in it. Because of the presence of slag and lower quantity of carbon, this has a strength which is higher than the cast iron, but at the same time it also relatively light, because of the presence of slag in there. You remember in that blast furnace image, we saw that slag actually floats above the molten iron.

So definitely, the density of slag is less than that of the molten iron. So, when you include some slag inside the material, definitely the density of the material is going to be slightly less. And so, it is stronger because of low carbon. So, it is widely used for engineering applications. Examples: We looked at Eiffel Tower, Statue of Liberty and many other typical applications in buildings.

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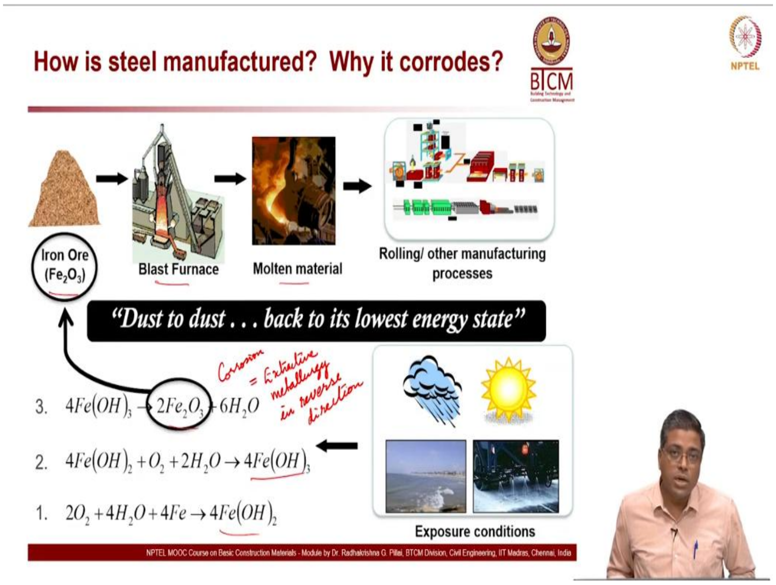

Now, let us look at steel. How steel is manufactured? and we will also talk about why it corrodes. Now, steel is again similar way, you get the iron like from the iron ore to the blast furnace and then you get the molten material and then depending on the raw materials which you put, you get this particular composition of steel, well-controlled. And steel means, there could be a lot of other elements present in that for addressing various properties.

Essentially, when you talk about alloys, a lot of elements come into the picture. I will show that details later on, in the following lectures. And then what you do is, you put the steel through a mill in which you get different shapes; whether it is a steel reinforcing bar, like circular rod or a square shape or an I-section or whatever shape you talk about, you pass it through some mechanical dies and then you get the steel. Then what you do is, when you use the steel in construction, it gets exposed to moisture. That’s why we are talking how it corrodes. It gets exposed to moisture and chlorides, carbon dioxide, oxygen, etc, and which leads to some of the chemical reactions.

Essentially what is happening is, the steel has a higher energy level than the iron ore. As you heat and as you pass it through the mechanical dies, both the heat energy and mechanical energy utilisation is there. And so, this energy, both heat (thermal) and mechanical energy gets stored in the steel. Now, material which has higher energy level will definitely try to react with the environment and tries to go back to its original energy level, which is that of the iron ore. So, if you look carefully in these equations here, these are the corrosion reactions. You will see that you have ferrous hydroxides and Fe_2O_3 forming.

This Fe_2O_3 is essentially the iron ore. The chemical structure or mineral structure is similar to that of the iron ore. So, even there is a definition that the corrosion is nothing but the extractive metallurgy in reverse direction. That is, corrosion is equal to extractive metallurgy in reverse. This is one of the definitions given in one of the NACE books, I remember.

Essentially, during the manufacturing process of steel, the energy level of steel increases because of the heat treatment and the mechanical treatment which is given. And because of that high energy level, when it comes in contact with the environment, it will try to go back.

Now, you can control this rate of corrosion by various means. And that's all advanced level courses. We will not cover those things in this class. But what you need to know is, when you talk about stainless steel, this rate of corrosion is very very small as compared to typical other steels which are used.

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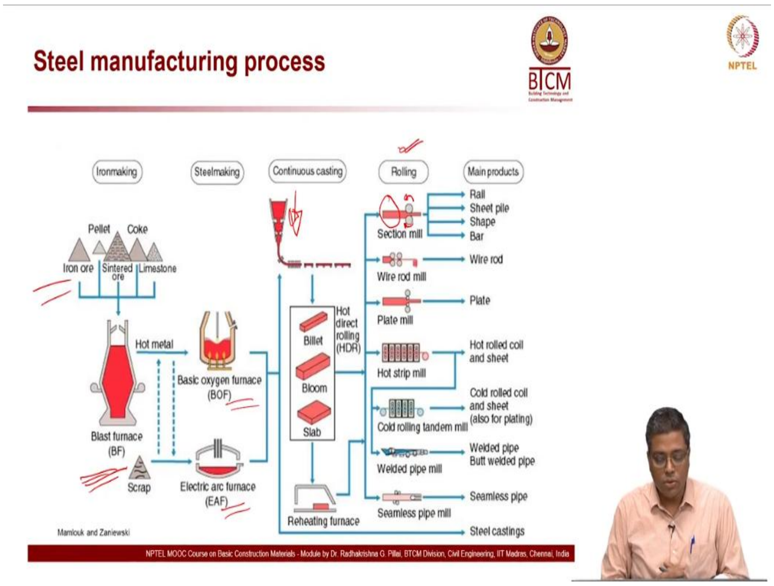

Now, steel manufacturing process is presented in the sketch here. You can see here, you have raw materials and then you have blast furnace. The materials are put in the blast furnace and then either an oxygen furnace or an electric arc furnace is used, depending on the energy and the resources available. Mostly now, people are going for electric arc furnace. And then, the molten material is put through mechanical shape or dies and it gets into these shapes, either a billet or a bloom or a slab.

And then, after that, it is passed through some dies where we call rolling. So, you can see, these are rotating wheels here. You can see here, rotating wheels. There are different manufacturing processes. There are some cases where the wheels are rotating and then, there are some cases where it is extruded. So, different cases, depending on what you are making. But for this simple understanding for this class, we can say that they are passed through some dies, metal dies and which are harder metals, so that the die does not degrade, but rather you get a different shape.

So, you can see here, for one example I am showing; where you can see here on the left side, you have a thicker material. It is passed through a metal die consisting of two wheels as you can see. And as it comes to the other side, this rotates like this and then this rotate like this and then it comes out and you get the desired shape. So, like that, depending on the shape which you want, you have these different processes involved, different shapes you can make.

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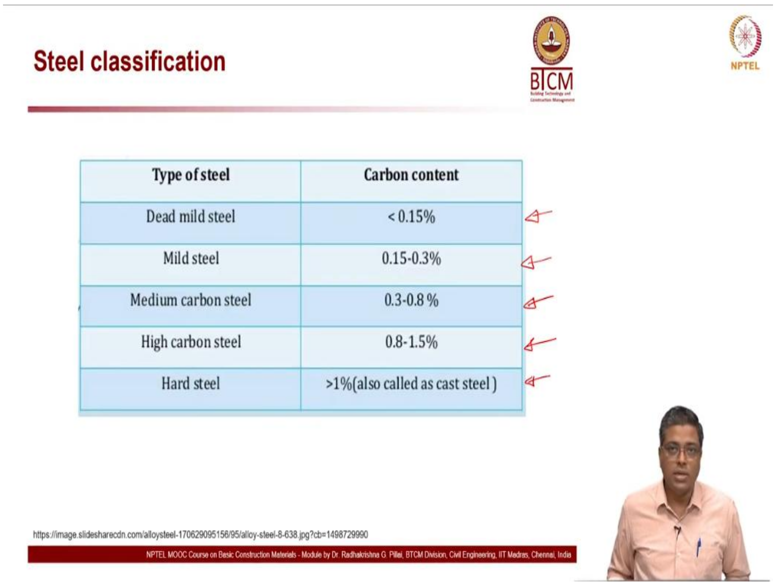

So, let us talk about different type of steels depending mainly on the carbon content; that is how normally they are divided or classified. As you see here, if the carbon content is less than 0.15%, we call it dead mild steel. From 0.15 to 0.3%, we call it mild steel. And then, from 0.3 to 0.8%, we call it medium carbon steel. And then, you have high carbon steel. And then you also have hard steel.

So, you can see the different percentages and how they are different. Cast iron comes like 3 to 4%, which is higher than this, but that is cast iron and we are not mixing that into here.

Here we are talking about steel, where the percentage of carbon is more or less <1%. This is what we typically talk about.

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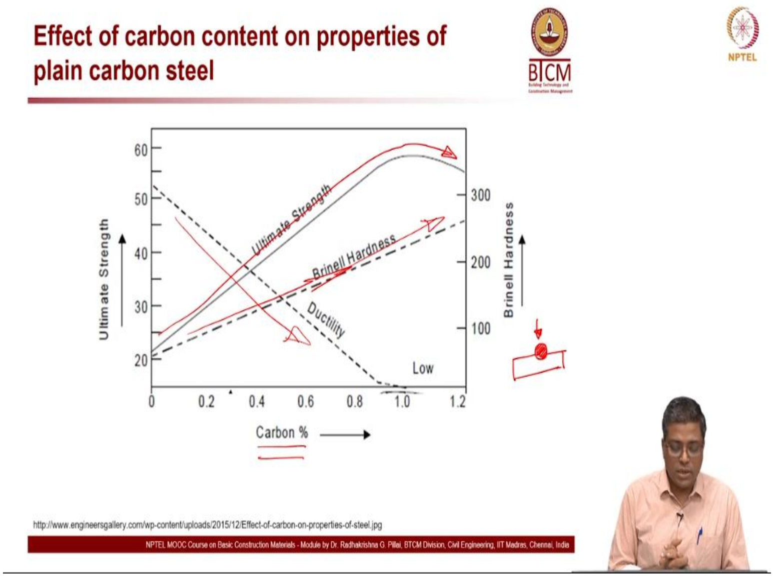

Now, how this carbon content variation influences the tensile strength and hardness of the materials? So, let us look at this solid curve here, this one. So, that's a ultimate strength or tensile strength of the material. You can see, as the carbon content increases, initially the tensile strength increases and then at about 1%, it peaks and then, if you keep on increasing, then the strength decreases.

Now, if you talk about hardness, Brinell hardness is discussed here. How it is done is, you have a spherical ball inundation and then if you have a plate something where you kind of apply a force; and then you look at what is the inundation and diameter of that and etc. So, like this you can measure the hardness. You can read more about that in textbooks. But what you notice here is, as the carbon content increases, the hardness also keep on increasing.

Now, what about ductility? Ductility actually decreases. As the carbon content is increasing, ductility decreases and after about 0.8%, it does not have much of an influence, but you can see that ductility decreases. So, there is always this danger of brittleness. Don't keep on increasing the carbon content, because that will definitely increase the brittleness of the material or decreases the ductility of the material.

So, for engineering applications, considering the safety and all that aspects, we want the material or whatever material we use, we want them to be ductile in nature. If it is not ductile, there will be a catastrophic failure, because you don’t realise that it is about to fail. So, that’s the main idea. So, to avoid such catastrophic failure or to keep the structures flexible in nature, before it collapses; or it should deform significantly, so that people can see that it is deforming and escape from the building or whatever facility you talk about.

So, you need the structures to be ductile in nature. So, we need ductile material to be used. Ductility is very important aspect in addition to the strength of the materials.

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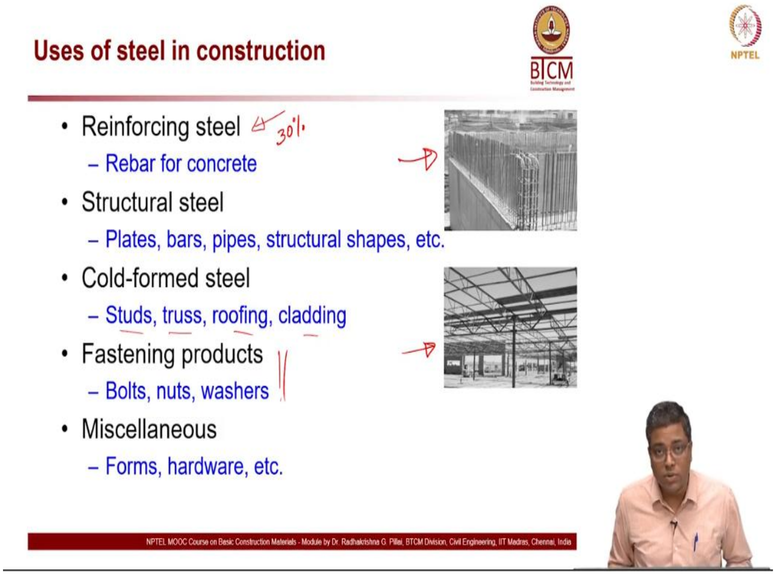

Now, where do we use steel in construction? One of the major application is reinforcing steel. About 30% of the steel made in this country is used as reinforcement, that is, it’s for reinforcement; or these round rebars which you see, which is used in concrete construction. About 30% of all the steel which is made in the country is rebars.

Then we have structural steel. So, this is a example of reinforcing steel, you can see rebars. And when we talk about structural steel, we are talking about this trusses, plates, bars (square shape or something, which is not circular rebars) pipes, structural shapes means I-section, angle section, channel section, so many sections are there. There will be another lecture on that coming up.

And then, cold-formed steel. We already discussed earlier what cold-form is. And studs, truss members, roofing, cladding and of course the fasteners; all these elements, they need to be connected together by using either bolts, nuts, washers, etc. There also, these kind of different steel products are heavily used. And nowadays, when we talk about form works, we have steel form works nowadays.

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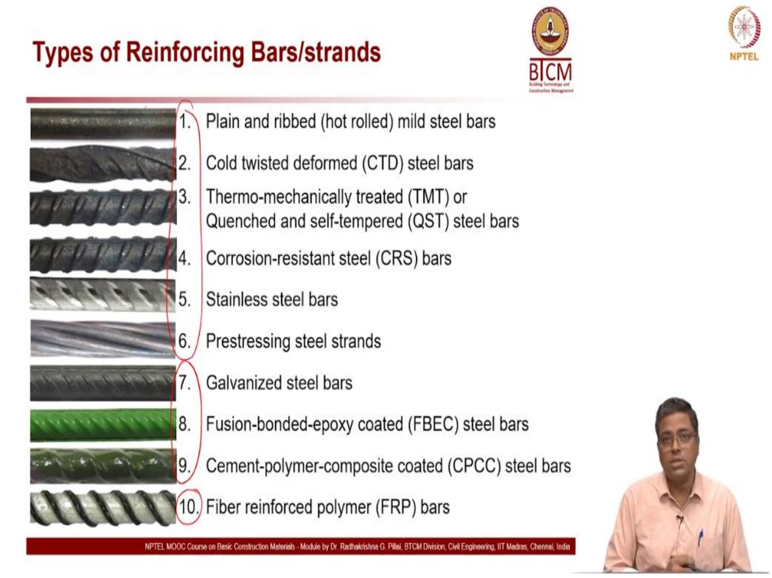

And this is just a quick look at different type of rebars. We will have a detailed discussion in the next lecture. Just want to give you a feeling of this, that there are different type of rebars in the market, as you can see on different pictures. Of course, there are coated rebars also. This 7, 8 and 9 are coated rebars. These are coated rebars. Then this is fiber reinforced polymer rebars. So, that’s just coming separate, but anyway, focus is that steel is used for making steel reinforcement. So, first 6 of them, you can see that they are all completely steel products.

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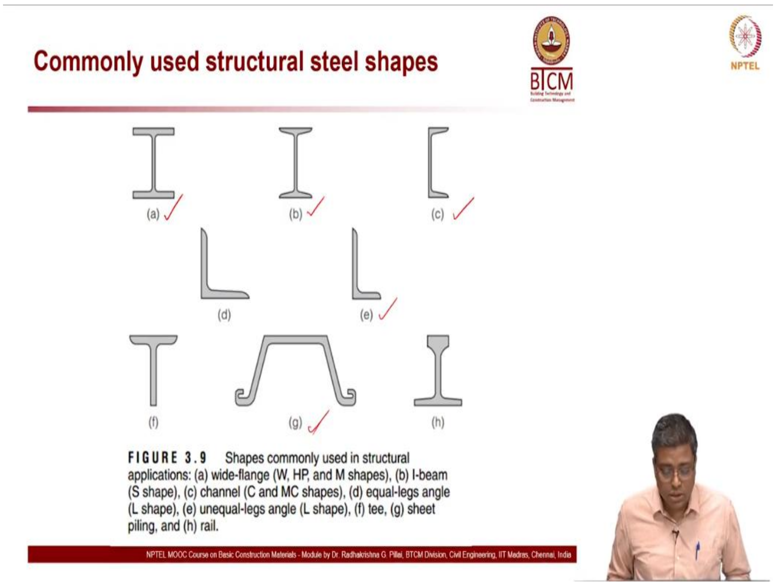

Now, these are the different channel or a different structural steel shapes. I-section and then here also you have looks like I; and then channel, angle and then you have sheet piling, different shapes are there. This is just a quick summary on how different type of steel sections look like. Again, we will have a detail lecture on this coming up. So, this is just to give you a flavour of what you can expect in the coming lectures.

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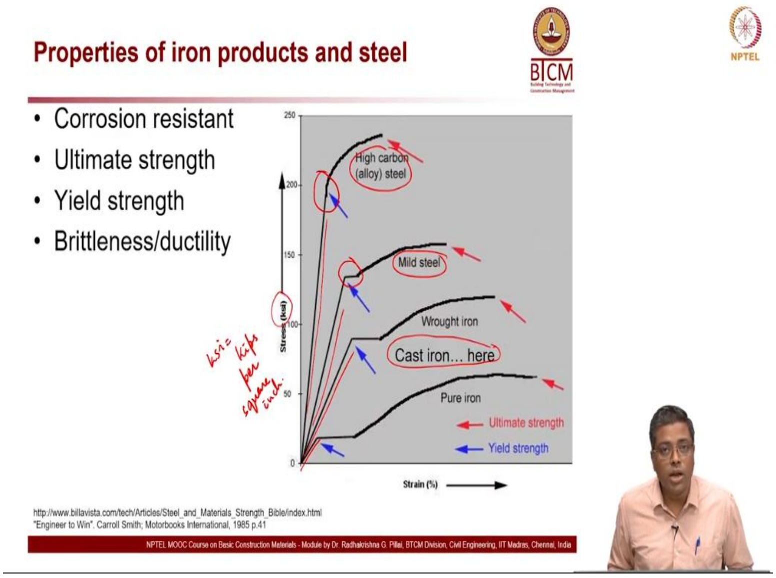

Now, we talk about properties of these different iron and iron products and steel. Let us look at corrosion resistance. Of course, cast iron, wrought iron, etc has higher corrosion resistance than the steel, just because of the energy consumption. I already discussed that.

And then, ultimate strength: Of course, steel will have much higher strength as compared to other products. But let's look at this graph here.

Pure iron: It is very very less; pure iron ultimate strength is somewhere about 60-70 ksi. That ksi stands for kips per square inch. It is similar to the megapascal. Now, cast iron is somewhat in between the wrought iron and the pure iron. And then, as you go for steel, you see that the strength keep on increasing. You look at this red arrows over there, the strength keep on increasing. You have high carbon steel, where strength is much higher than the mild steel.

And not only strength, you also see that elastic properties here. The slope of these curves also keep changing. That means, modulus of elasticity also is increasing. If you have a stress-strain behavior or a stress-strain graph, you can actually learn a lot about various products.

And now also, if you see mild steel, you have a plateau region here. You have plateau region which is missing in this high carbon state, because of a lot of elements present leading to the alloying action, you have a gradual transition, rather than a well-defined yield point.

So, these are all the different features; the blue arrows indicate kind of the yield strength. And you can see that there is a plateau up to mild yield, but in the high carbon alloy steel, there is no plate, yield plate.

And brittleness and ductility:

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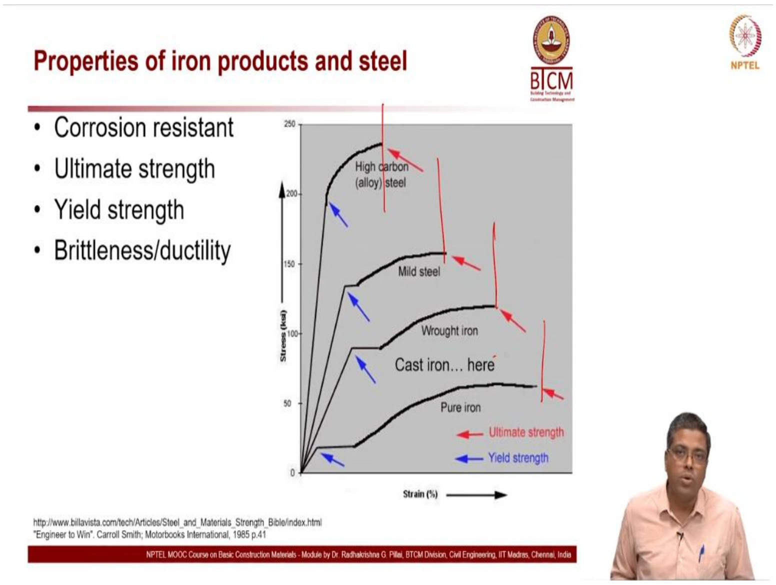

As you can see here, the brittleness and ductility. So, here you can see that ductility keep on decreasing. If I look at this; so, ductility for the pure iron is much higher; ductility is higher or the percent elongation is going to be higher, but as compared to the high carbon steel. So, as this strength is keep on increasing, there is a general trend that ductility decreases. But nowadays, we have products where, within a particular range of products, you can still change the chemical composition and still get the ductility even with higher strength.

So, that’s all possible, but this is just a general discussion on how pure iron, cast iron, wrought iron, mild steel and high carbon steel behaves.

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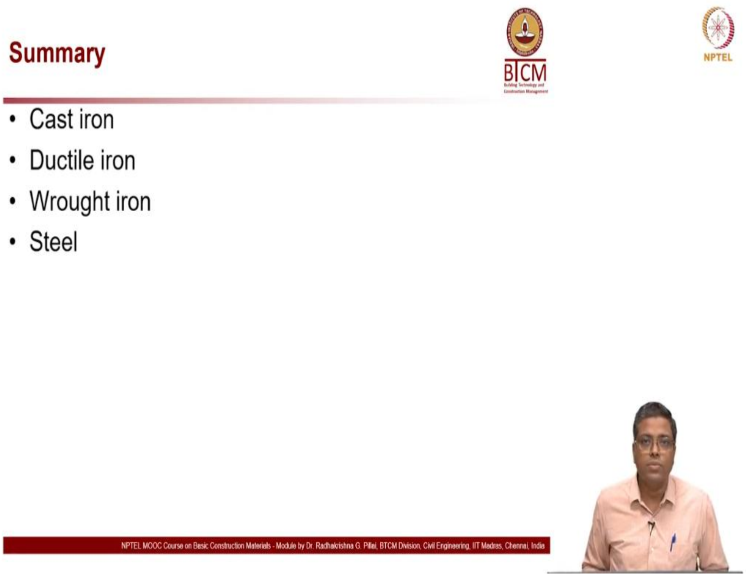

So, to summarise, we looked at how these 4 materials, cast iron, ductile iron, wrought iron and steel are produced in general; and what are the major properties of this; and how the carbon content actually influences the ductility, the strength, the hardness, etc. So, with that, we will just close this lecture. Thank you.