Basic Construction Materials
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Module - 7
Lecture - 33
Metals 1 - Part 1

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Hi, welcome to this module on Metals, as part of this course on Basic Construction Materials. In the first part of this module, in today's lecture, we will look at iron, iron products and steel.

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Essentially, we will be talking about how they are manufactured and some basic properties of these materials. And in the future lectures, we will look at steel reinforcing bars and structural steel also.

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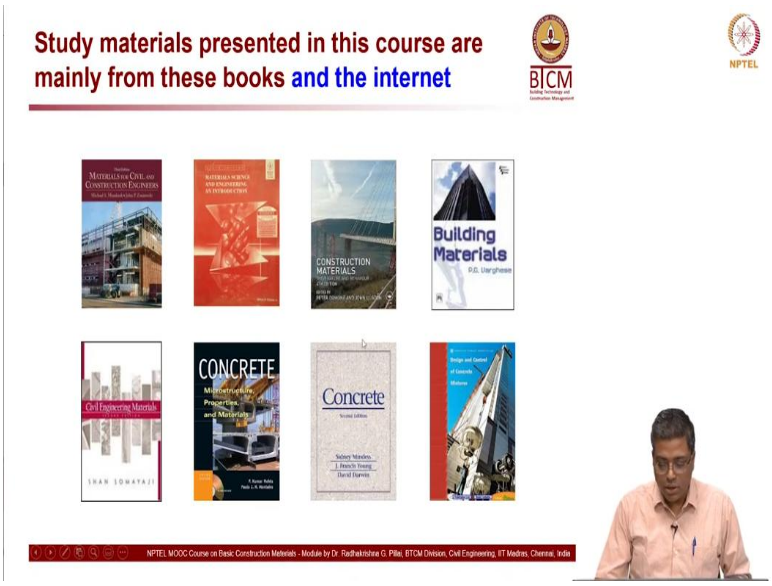

These are some of the books and all that I have been using. And essentially, a lot of material from the internet have been used for this particular lecture.

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Now, what are the various iron products? They include pig iron; then cast, ductile and wrought iron. These two, we will be covering today. And steel reinforcement and structural steel will be covered in the subsequent lectures. But these are the major iron and steel products or iron products. Steel is essentially made of iron with some other materials.

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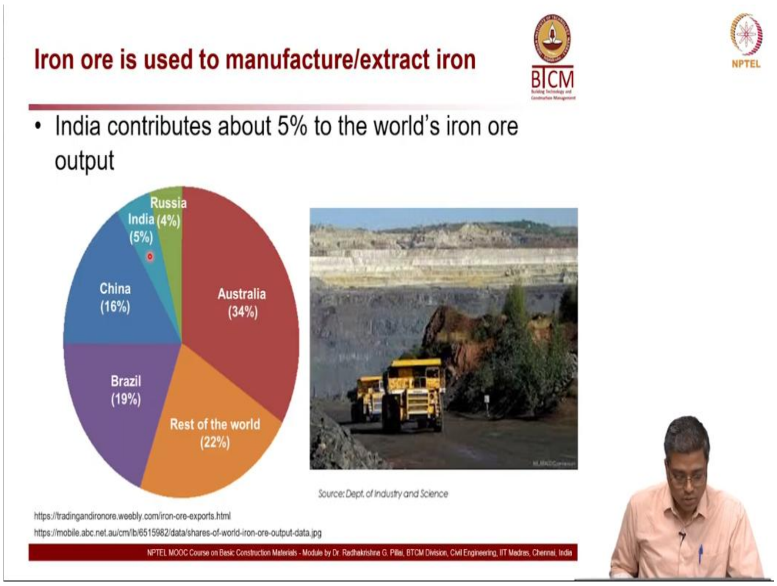

So, iron ore is used to manufacture the product, iron which we call. What does it use? Iron ore hematite. And India contributes about 5% to the world's iron ore output. This is a photograph of a mine in Australia. And you can see here, this pie chart on the left side, which kind of shows how much is the production or contribution by various countries towards the iron ore extraction.

You can see that Australia plays a major role, about 35 percent. And India is about 5% of the total iron ore which is produced or supplied in the world is from India. So, we are not a small player, definitely we have significant stake on this.

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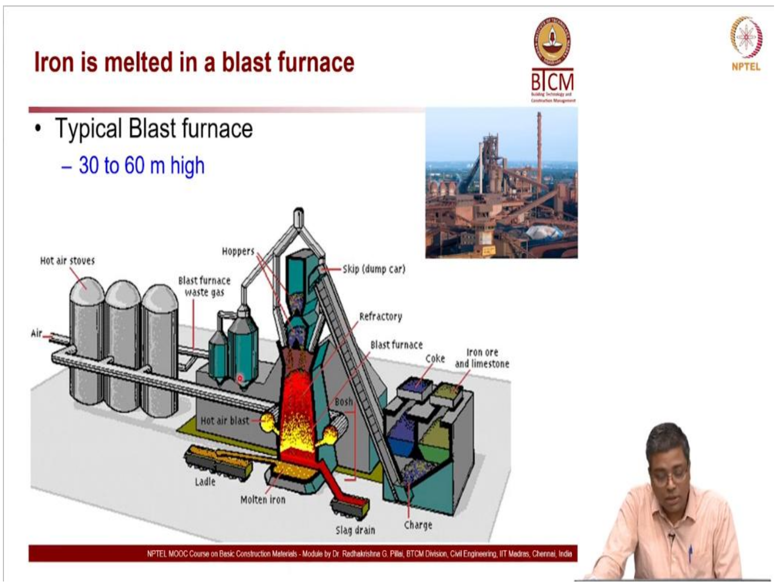

Now, let us look at how iron is actually made. First, the iron ore is put into the blast furnace. So, you can see the picture here on the top right. This is how a typical blast furnace would look like. It is a huge structure, which will be typically about anywhere from 30 to 60 metre high, depending on the capacity, etc.

So, you can see here, the raw materials are piled here. And then, there is this conveyor belt which takes the raw material to the top. And here also, another conveyor belt which comes to the top, you can see. And then, at the top, it’s dumped into the hopper. And actually here, they are stacked inside this furnace. Like I said, this is about 30 to 50 metre height or 60 metre height and you have lot of material volume you can occupy here. So, these materials are stacked inside this furnace. And then you have this hot air blast. That’s why it is called blast furnace.

So, hot air is blasted from the bottom. And the material as; I will show you in the next slide, but you can see here, the material inside here, inside the furnace get heated up; and then it reacts and then starts melting and you get the molten iron at the bottom and also some slag is formed or floating on the molten iron.

That slag is also used for other purposes. You can see here, all additional part of the furnace which helps in completing the process. You can spend some time on reading each of these items and try to understand what each of these are for.

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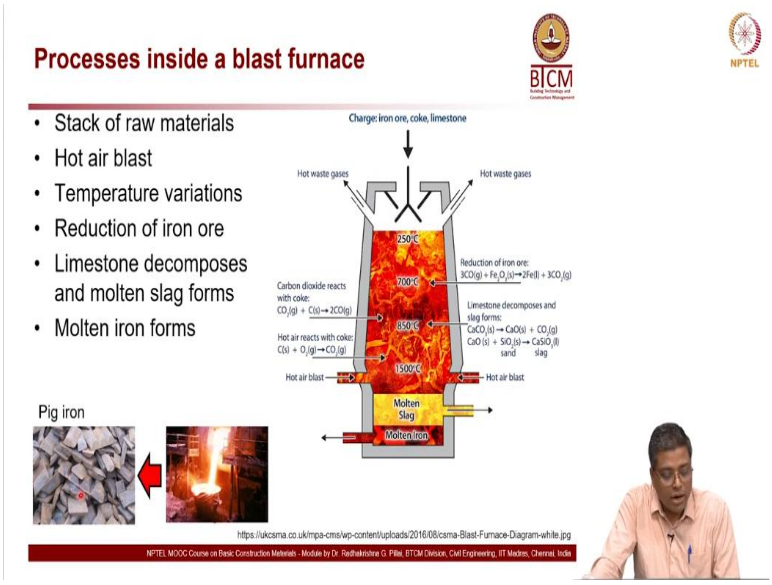

Now, the process inside the blast furnace, that is, I am showing another photograph here. Again, all these are from the internet. You can look at these addresses which I have provided at the bottom of the page to get more details and to read more about these images which are explained here.

Here, first you have a stack of raw materials, like this is the image of that hopper which I showed in the previous slide. So, you are putting the iron ore, typically hematite; then coke and limestone. So, all these are dumped through or placed through this hopper and stacked here inside the furnace. And then, what you do is, you have this hot air blast, which is here, almost at the bottom of the furnace. And then, because of this hot air, there is temperature variation. As you can see here at the bottom, it is 1500°C and as you move up, 850, 700 and up to about 250°C at the top of the furnace.

Now, what these temperature differences does is, look at here at about 700°C range, the iron ore gets reduced to Fe in the liquid state and the carbon dioxide. And then what happens is, as the temperature increases, you also have carbon dioxide reaction and reduction of iron ore and limestone also decomposes at this temperature. At about 700°C, you have reduction of iron ore.

As the temperature increases, as you move down into the furnace, you also see that limestone starts decomposing and what is formed? Slag is formed. Now, as the temperature keep on increasing as it goes down, this slag and everything starts really melting and then you can see the molten slag falls down and then settle here; or rather float on top of the molten iron.

So, molten iron being heavier, it will settle down. And molten slag being lighter than the molten iron, it will float on top. So, what is in the slag? You can see the formula here, calcium silicate oxide. And this slag is taken out to produce or I mean it’s used even for cement manufacturing now a days. And then you have molten slag over here. And that’s used for making pig iron.

You can see here, this picture over here is indicating this point here. Molten slag is taken out and then ladle and then it is poured into forms to make pig iron like this. I will show you more detail about that.

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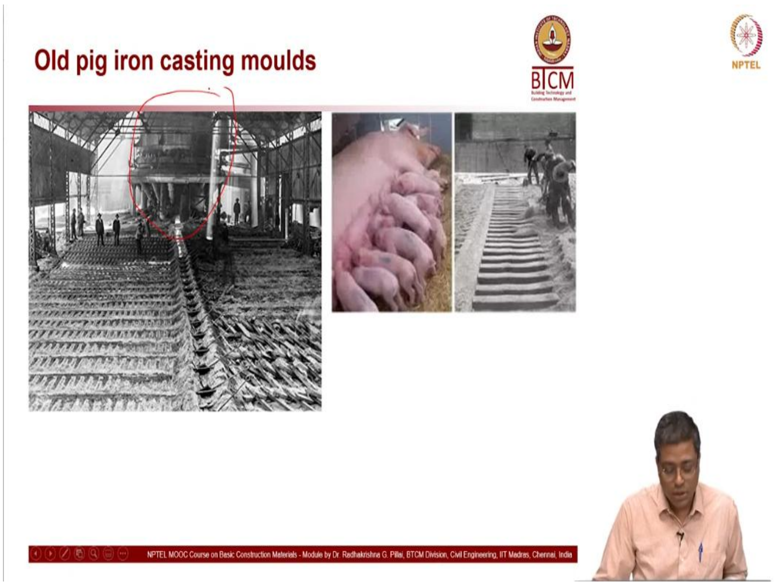

Now, this is the picture of an old pig iron casting mould. You can see on the left side. And first, let's see why it is called pig iron. It is because the shape of these pig iron pieces or this mould area, they kind of look like baby piglets being breastfed. You can see the picture here. So you can see, one main channel here, through which the molten material is poured and it flows down and then flows to the left or right, as you can see in this black and white picture on the left side.

You can see that the hot material or the molten iron is flowing down and then flowing into these small moulds in that area. So, similar, this kind of picture, if you take a photograph of these piglets being breastfed, it will somewhat resembles that. And that is how the people started calling it pig iron.

There is also another story by which they say that the face of the very old pig iron moulds, they look like the face of a pig. I don't have that photograph here. But that is also another thing which if you read in the internet, you will find that these are the stories behind the name pig iron.

Now, you can also see how big the furnace looks like here. You can see the large size. And you can compare that with the size of the human beings or people standing there.

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Now, this is a modern pig iron casting mould, where again, you can see molten material on the left. You can see here, molten material being poured and then it flows down and then it flows. Now here, this is actually a conveyor belt. It's not that this molten material is flowing all the way till here, but it is rather taking its position in one of the moulds and then it's transported using kind of a conveyor belt.

You can see on the right side picture also, the molten material is poured into this and then it settles and then it is taken out using a conveyor belt. So, the technology has changed a little bit. In the first one which I showed in the previous slide, it was more of the material flow, all the way to the mould. Here, the material flows, but then it is taken using a conveyor belt. So, there is a little difference in that.

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Let us look at what is the composition and key properties of pig iron. It has about 90-95% of iron and then 3-4% of carbon and traces of various other materials or other elements such as silicon, manganese, phosphorus, etc. So, this is a typical photo of how this pig iron would look like. Of course, it depends on the shape of the moulds. And you can see this tapered shape, which makes it easy to be lifted out of the mould.

It is not well-controlled manufacturing. As you are seeing, this is not really a well-controlled manufacturing process because this hot molten material is poured into the moulds or pigs and then it is taken out. It is harder than 100% pure iron. So, hardness is very high because of the presence of high concentration of carbon, about 3-4%.. That is why this is harder in nature. And also lower strength, because it is very porous in nature. Because as I said, the manufacturing process itself is not very well-controlled.

So, because it's porous, low strength, high hardness; mainly, low strength, the products which are coming out of this are not really of high quality. So, you will see some times, all these type of fasteners or low cost products which are good enough for those particular applications, but not necessarily for all the applications where you really need higher strength material.

So, this pig iron products are not very high quality, but you have to see whether for that particular application, whether this is sufficient or not. If not, you have to go for other products.

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Now, another more refined product is cast iron. Cast iron is used for pipelines; water pipeline, sewage line and many products are there. You can see here, pipeline and then these are some of the connections for the pipes. Wherever there is a complex shape, that shape can be achieved by making a mould, that is where cast iron comes into the picture and then pipelines, because it used to be very comparatively high strength than the iron, so people started using cast iron.

But there were some problems, I will come to that later. And these are other examples of cast iron. Of course, corrosion is an issue, but it is not as big issue as steel because it corrodes relatively less than the steel. But still, there are other mechanical related problems like brittleness. So, I will come to that later. And then, also when you have very complex shapes, there cast iron is very widely used, because it is very easy to make those.

So, you can see here, this also. Once you have a mould of that particular shape, then you can make this product. So, here also, other examples where you have complex shapes, cast iron can definitely be used, including cooking ware.

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Now, why is it better as compared to pig iron? Because of its better manufacturing process, as I said already. Now, here you can see a photograph on the left side where the molten iron plus carbon is being poured into the cast or into the mould. You can see here. This is the mould. You can see a lot of moulds like an assembly line.

Now, on the right side, it is more clear on how these moulds look like. These moulds are made out of foundry sand. This is the foundry sand which you see on the top right image. The foundry sand is clean, that means there are no clay particles in it; and it is uniformly sized or has uniform gradation and consists of silica sand typically. Also many other important property of this foundry sand is, it should be cohesive in nature. In other words, it should hold together and then form that complex shape whatever is required, once it is moulded into that shape. It should not just fall off. So, you need very high cohesiveness also. Mechanical interlock plus cohesiveness plays a role and then it just helds things in place.

This is how the typical foundry sand look like. You can see here, there are some cast or shapes of foundry sand and then the molten material is poured into this place here; and it flows and then makes the shape.

On the bottom, you have an example of something which looks like a wheel shape or a gear, whatever machinery parts. These kind of complex shapes, whenever you see, you can think that most often it is made out of cast iron, because you have high strength. Main problem with using cast iron is brittleness, but still it’s widely used in many applications because of the easiness to make it, that is, to get the complex shapes.

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So, these are again some of the applications. You can see pipelines, drainage pipes, sewer lines and then also machine parts.

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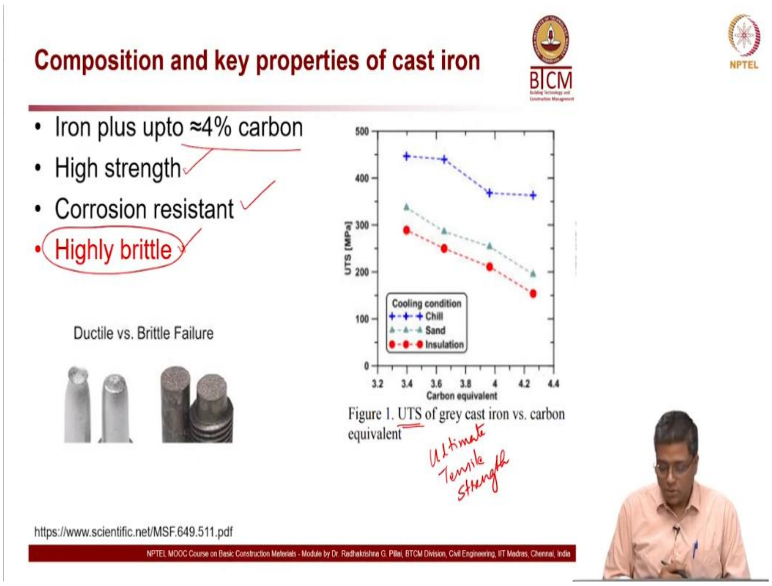

Now, let us look at the composition and key properties of cast iron. Cast iron consists of Iron plus up to about 4% of carbon, that is the key ingredient which gives it its properties. And because of this, you get high strength, high corrosion resistance and high brittleness. So, this (high brittleness) is the problem. High strength and high corrosion resistance are very good. But highly brittle means, it has a lot of implications; and catastrophic failure, etc, because you will not get any warning that the material is about to fail. So, that's a major problem with this cast iron.

Now, if you look at the graph on the right side, you will see UTS, which stands for Ultimate Tensile Strength. And you can see here, this is carbon equivalent on the x-axis or abscissa and the Ultimate Tensile Strength on the y-axis or ordinate. What you see here is that we are talking about only this range in this graph, that is about 3.4 to 4.3% of carbon. It is not like from 0 to 4.2%. When you look at 0 to 4.2%, the properties are going to be very different.

Here we are talking about just this small range from about 3.4 to 4.2%. And in this range of carbon content, how the variation in the range will change the properties. Let us look at only one case here, I am going to take this triangle case. At 3.4% carbon, the strength is about 350. And when carbon content reaches about 4.2, the strength decreases to about 200. You can say this is about 200. So, about 150 megapascal reduction in strength, when you change the carbon content or when you increase the carbon content from 3.4 to 4.2%. Very small, 0.8% is the difference. Although it is very small variation, it has huge impact on the strength property.

So, that is where metallurgists will have to be very careful while making or in controlling the composition. I just got this image from the internet, but I am not going to cover all these different cases. And here, the idea of showing you this graph is only to show that there is a significant reduction in the strength as a function of increase in carbon content in this particular range. So, this graph is just to show you the importance of the percentage of carbon on the strength of the material.

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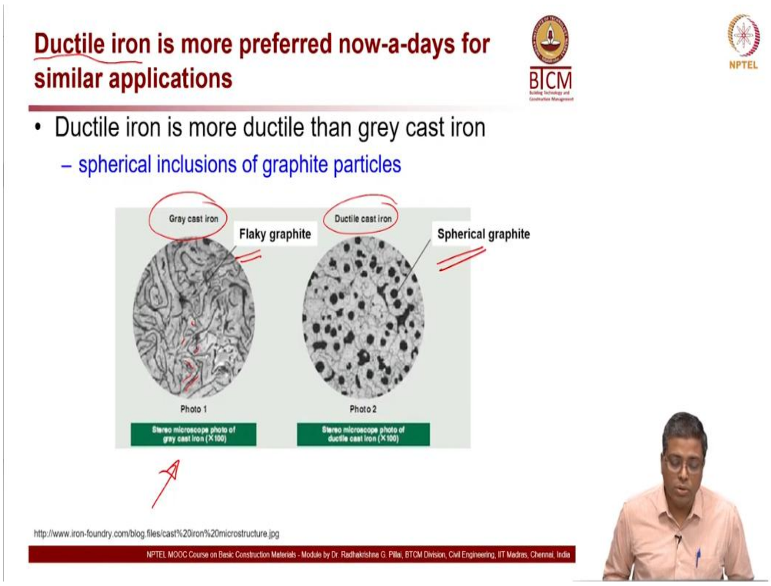

In the cast iron, we talked about that brittleness is the very big problem or negative or unfavourable property. So, engineers actually worked on how to change or increase the ductility or rather decrease the brittleness. They came up with new product which is called ductile iron. It is more ductile or less brittle than the grey cast iron. Now, why this is becoming more ductile is because it has a different type of carbon or the microstructure is different.

Let us look at only the first picture here, this one. This is about grey cast iron. You can see these flaky like black lines on that and the flaky graphites. This we covered earlier in the module on nature of materials, but let us look at it again. These are flaky; you can see all these black lines here. So, imagine when there is a crack formation or something along those flaky black graphite, what will happen is, the crack will propagate very fast. Stress concentration will happen. And then, crack will propagate very fast. That is why it has very high brittleness.

Whereas, in the ductile cast iron on the right side, you will see that they have this spherical graphite or globular graphite. So, in such a microstructure, crack propagation is not as easy as in the case of a cast iron where it has flaky graphite. So, spherical graphite in the case of ductile cast iron and in the case of cast iron, it is flaky graphite.

Because of this spherical nature, it helps in preventing the progression of the cracks or crack propagation is more difficult when you have spherical graphite as compared to flaky graphite. So, that is why it has ductile behaviour as compared to a cast iron. So, we call it ductile iron. This is the major difference between these two and it is achieved by changing the manufacturing process.

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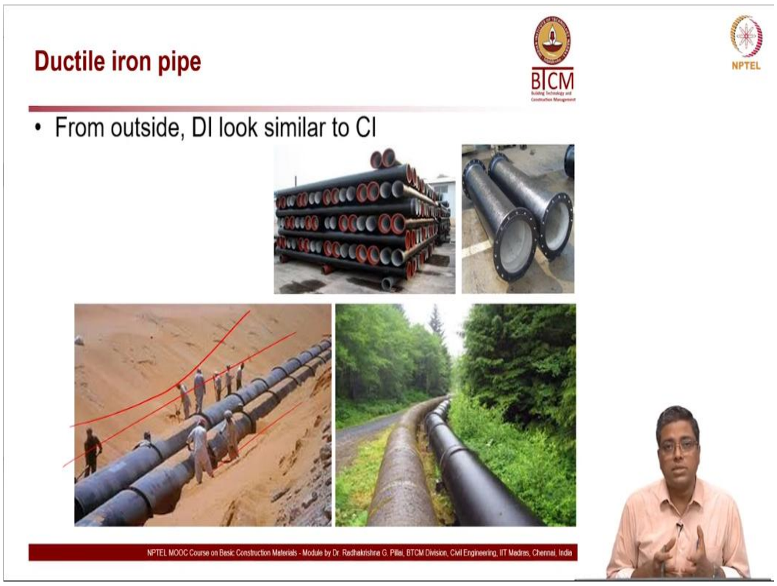

From outside, it still looks more or like similar. You cannot really make out whether a pipe is a ductile iron or a cast iron. It is quite difficult to make out, unless you look into the microstructure of that. Now, think about these pipelines, long pipelines. Let us say there is some cavitation or something happening to the base of these pipelines and it starts sinking.

What will happen is, the pipe might deform, say, local sinking or something. If it happens, locally the pipe might deform. If the pipe is not ductile enough, it will actually crack. So, you really need a ductile system or a flexible system rather if you want to call it that way; it is more easy for you to understand. So, the ductile are relatively more flexible as compared to the cast iron.

Nowadays, you will see that ductile iron is more preferred than cast iron products, especially when you talk about possibilities of deformations. You want structural systems, like even this pipes to deform but not crack. So, that is the idea. Deformation is okay, but it should not crack. If it is cracked, the liquid which is flowing through will leak. We do not want that to happen. We want ductile structures and we don’t want structures to be of very brittle in nature.