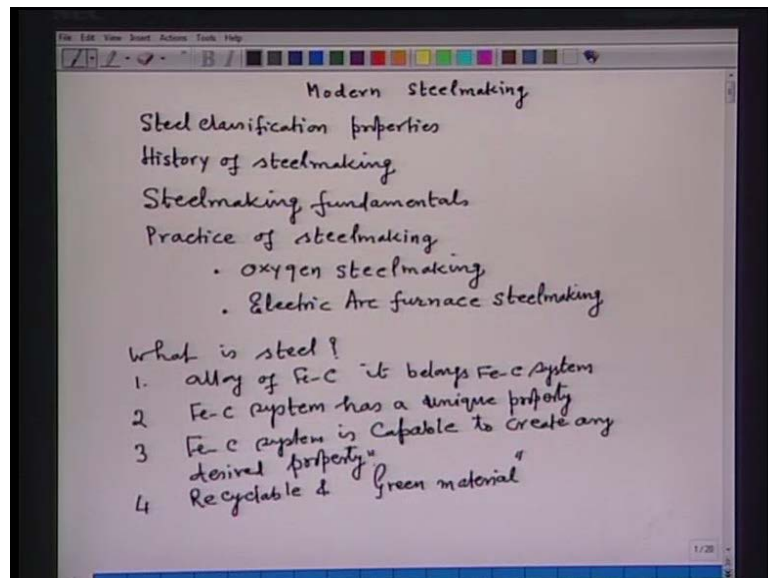


Steel Making
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Model No. # 01
Lecture No. # 08
Modern Steelmaking I, Oxygen Steelmaking

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I will be lecturing on modern steel making. The lecture will essentially comprise of, say: steel classification properties, history of steel making which will be followed by steel making fundamentals, and after covering steel making fundamentals, I will be covering practice of steel making. In practice of steelmaking, I will be covering: one - oxygen steel making and subsequently electric arc furnace steel making.

So, this will be the organization of various lectures that I will be delivering to you. As such, I will be starting, first of all, to tell you - what is steel? The whole idea is that you can appreciate the importance of steel in the modern economy.

Now, the first point is that steel is an alloy of iron and carbon and it belongs to, rather steel belongs to, iron-carbon system. This iron-carbon system has a unique property of

alloying with several elements of the periodic table, with that I mean, that they are elements like: cobalt, nickel, chromium, vanadium, tungsten, molybdenum and name any other element; this iron-carbon system has the capability to have some solubility of that element and it imparts an altogether different property in the steel, or you can call altogether a different material.

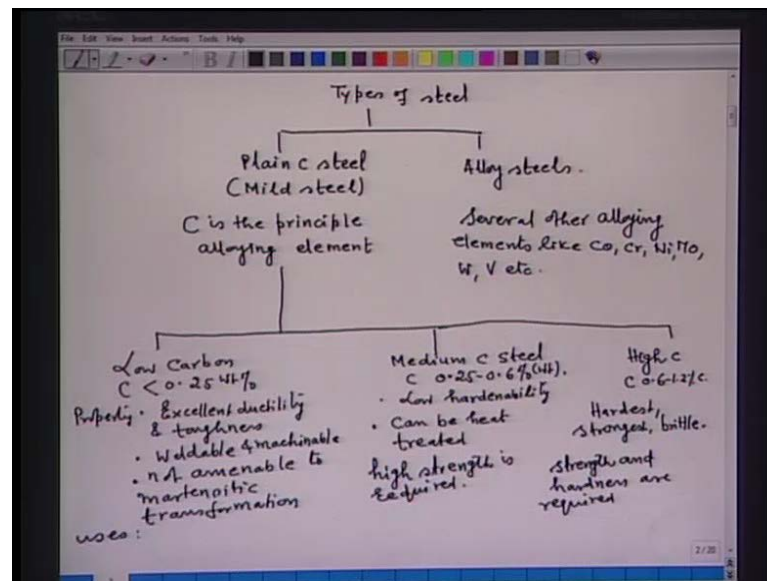
Third, this iron-carbon system is also capable to create different properties by altering microstructure through heat treatment and deformation processing; so, this is somewhat a very unique property that this iron-carbon system has. I repeat once again, iron-carbon system is capable to create any desired service property by altering microstructure through heat treatment and deformation processing; so, this is somewhat a very unique property that this system has.

Fourth, which is very important, that is, steel is recyclable and hence you can call it to be a green material, and hence, steel can be considered or can be called as a green material and that is a very important thing.

Now, these above features which I have told you, they have the most important engineering applications, that is, the above features of steel makes steel as the most important engineering material.

You will wonder that around two and a half thousand different grades of steel are produced for different applications, starting from constructional steel to automobile industry and to aircraft industry which is a very high-tech industry.

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So, what I mean is, steel is a very important material and it has very diversified applications in all areas of industry. So, let us now see what the different types of steel are there.

Essentially, we can classify in two broad categories: first is plain carbon steel; plain carbon steel is also called with the name mild steel or sometimes it is also called simply, carbon steel; another is alloy steels.

In plain carbon steel, carbon is the principal alloying element; in case of alloy steels, they also contain carbon, but besides carbon the alloy steels have several other alloying elements like cobalt, chromium, nickel, molybdenum, tungsten, vanadium, etcetera.

I mean, all these alloying elements, they are added in order to get a special property for a particular application. Now, let us further classify the plain carbon steel, we can classify based on the carbon content.

So, we have first of all low carbon steel; in low carbon steel, carbon content is less than 0.25 weight percent. Now, the property that these steels have, they possess excellent ductility and toughness, they are also weldable and machinable, but little bit disadvantage is that they are not amenable to martensitic transformation.

Now, as regards uses, this low carbon steels are commonly used, say, in industrial products like bolts, nuts, sheets, plates and the product derived from there.

Another important type of plain carbon steel is the medium carbon steel. In the medium carbon steel, carbon is in between 0.25 to 0.6 percent; I will say it is a weight percent.

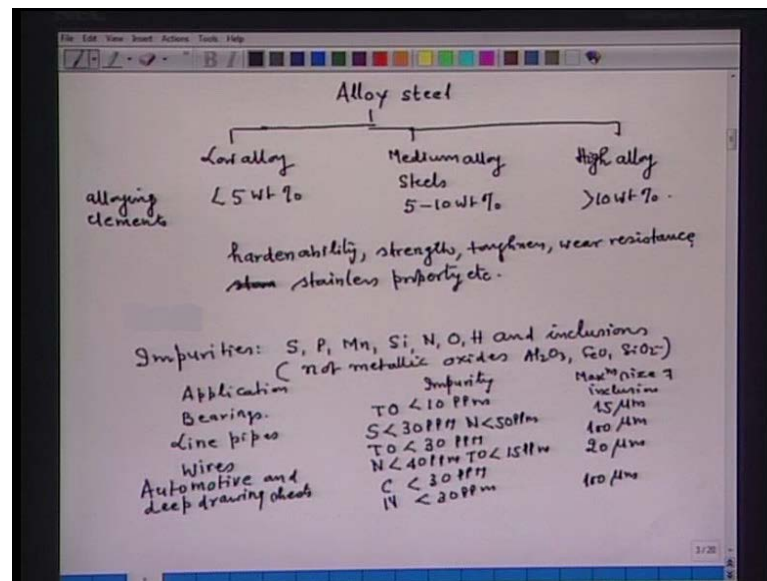
Now, among the properties, these steels have low hardenability and a very important property that these medium steel possess is that they can be heat-treated; what does it mean?

As I said in the beginning, showing the importance of steel, I said that iron-carbon system is capable to create unique property by altering microstructure to heat treatment and deformation processing, **so it is in this connection, medium carbon steel**. If they can be heat treated, then you can get from one type of steel several different steels by heat treating them; that is, simply heating and cooling at different rates. That is what the important advantage of medium carbon steel is, that they can be heat-treated and as a result of heat treatment several important mechanical or service properties can be induced in the material.

These steels, their uses are wherever high strength is required, such as machinery, automobile and agricultural parts: gears, axles, connecting rods - all these have medium carbon steel.

Now, the third important category in this is high carbon steel and in the high carbon steel the carbon varies between 0.6 to 1.2 percent carbon. As such, these steels are hardest; I will just put it, these steels are hardest, strongest, but at the same time brittle. So, these steels are used where strength and hardness are simultaneously required, for example, razor blades, cutting tools, music wire, and so on.

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Now, let us see the classification of alloy steels. Among alloy steels, say, we have low alloy steel; in the low alloy steel the alloying elements are less than 5 weight percent; this is the alloying elements, they are less than 5 weight percent.

Then, we have medium alloy steels and here the alloying elements vary from 5 to 10 weight percent; then, we have high alloy steels and here the alloying elements are greater than 10 weight percent.

Now, these alloying elements are added to improve, for example, the properties like hardenability, strength, toughness, wear resistance, and to provide stainless property, for example, addition of chromium - you get stainless steel, etcetera.

So, now remember all these alloy steel which I have put over here, they have carbon content also; the carbon content may vary, low alloy steel may be 0.2 to 0.3 percent and accordingly carbon content is also there in all alloy steels.

Now, whether we have plain carbon steel or alloy steels, all steels contain the impurities like sulphur, phosphorous, manganese, silicon, then nitrogen, oxygen, hydrogen and inclusions. These impurities, in fact, they originate during the steel making stage because when you produce steel from hot metal or from pig iron, then these impurities are carried over to the steel. Partially we can remove these from converting hot metal to steel, but still these impurities, they enter through the steel making stage. So, what is required is

that, their content must be controlled for a given application because these impurities cannot be tolerated in a very large quantity.

So, certain applications, they require strict control over the presence of these impurities. Now, I give some examples; say, if I put here application, then I put here impurity level - that is tolerable impurity level, and here I put the maximum size of inclusion. (Refer Slide Time: 16:48)

I am giving you a very few examples, rest of these things you can see from the books and create your knowledge, say for example, bearings. Steels for bearings can tolerate, say, total oxygen, **TO** - I am writing - should be less than 10 PPM, then inclusion size should not be greater than 15 micron meter which is very small.

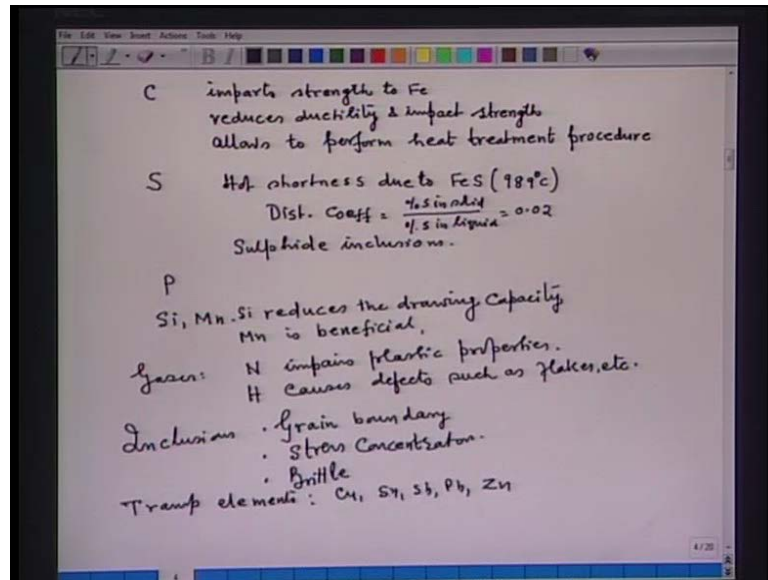
Similarly, for application like line pipes - on line pipe sulphur should be less than 30 PPM, nitrogen should be less than 50 PPM, and total oxygen should be less than 30 PPM and tolerable inclusion size, maximum is 100 micron meter.

Now, similarly, if I say a wire - that is a special wire - here you require nitrogen less than 40 PPM, total oxygen less than 15 PPM and tolerable inclusion size is 20 micron meter; then automotive and deep drawing sheets - they have carbon less than 30 PPM, and nitrogen also less than 30 PPM and maximum tolerable inclusion size is 100 micron meter.

So, what I mean, these are just a few examples, there are many examples that require very stringent impurity level control as well as inclusion control.

Just for the illustration purpose, I have given few here, many you can see from the books and see that you know these things.

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Now, in general if we want to explore the effect of impurities on mechanical properties, because ultimately this steel will be put in application; so, in general, carbon imparts strength to iron; remember pure iron is very ductile and is not useful for any application.

At the same time, carbon reduces ductility and impact strength; very important property that carbon has - it allows to perform heat treatment procedure. Now, with this I mean and probably you are also clear, that heat treatment is one of the main technology to alter the microstructure of the steel, and hence, to create a different material.

Now, regarding another impurity sulphur, sulphur essentially causes hot shortness due to presence of FeS at the grain boundary; the FeS has a melting point of 989 degree Celsius. So, when sulphur containing steel is subjected to deformation processing, then we have to heat it and most of the deforming processing operation require steel to heat above 1000 degree Celsius. In that case, the FeS, if present in the grain boundary, will melt and will create lot of problems - and that is in fact, called hot shortness.

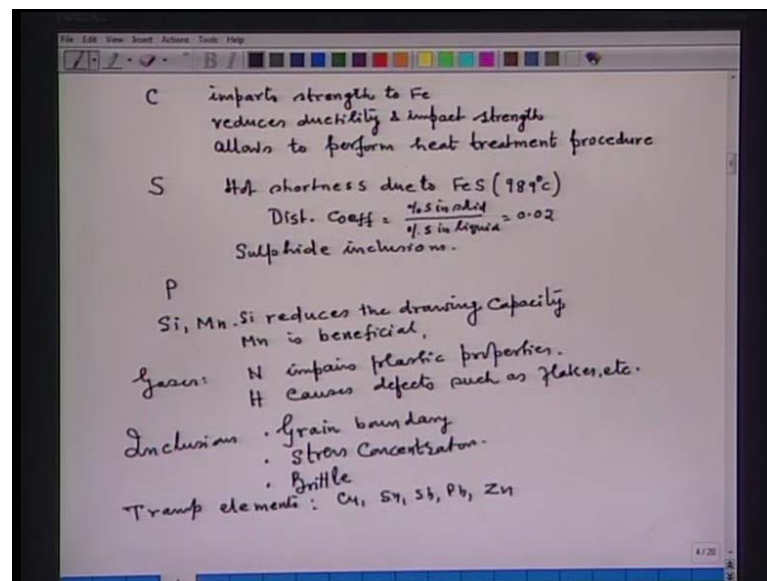
The formation of this FeS can be understood by considering the coefficient of distribution of sulphur between solid and liquid. That is, when steel solidifies, the sulphur segregates because the distribution coefficient - if I put it distribution coefficient, which is also called segregation coefficient - that is equal to percent sulphur in solid upon percent sulphur in liquid and this value is around 0.02.

So, you can imagine if steel is solidifying from its melting point, any excess amount of sulphur will be rejected because solubility of sulphur in steel is very low; so the last liquid which will solidify has a very high amount of sulphur and on account of it FeS will form, and it will precipitate at the grain boundary.

So, that is one of the important effects of sulphur. When such steels are heat treated, may get tears and cracks are developed, and another important thing that sulphur forms - they form sulphide inclusions, they have lower weldability and also corrosion resistance. Now, as regards sulphur, it can be said that except free machining steel that requires little high amount of sulphur, none of the grades of steel can tolerate the amount of sulphur.

Similarly, about the phosphorous; phosphorous also segregates during solidification, its distribution coefficient is also around 0.02 - with the meaning that during solidification, if excess amount of phosphorous is present, it will also be rejected in the liquid.

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As a result, the last liquid will solidify, it has a tendency to form Fe₃P and by virtue of that, it will impair many plastic properties of steel. So, phosphorous in fact, it impairs the plastic property, and hence, all efforts are done or should be done to remove phosphorous from metal.

Other further important things are silicon and manganese. Silicon reduces the drawing capacity of steel, manganese is beneficial, why it is beneficial? Because in presence of

sulphur, manganese reacts with sulphur and forms manganese sulphide which has a higher melting point.

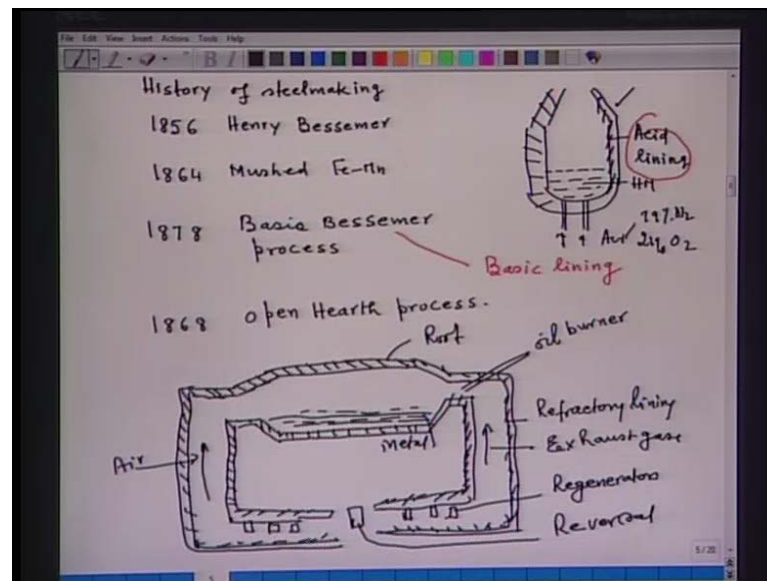
So, this manganese reduces hot shortness - that is the important thing. The presence of gases, for example, nitrogen - it impairs plastic properties, then hydrogen - it causes defects such as flakes and etcetera, presence of oxygen - it forms oxide inclusions.

The next important thing is the inclusions, they are present at the grain boundary; inclusions if present at the grain boundary, then they weaken the intra granular bonds. Second, inclusions also act as stress concentrators and also some type of inclusions are brittle. So, what will happen if you roll them? Brittle inclusions will crack and accordingly you weld the crack; so these are some of the deleterious effects of impurity on the properties of steel.

Several other effects on mechanical properties will be there, I request you to go through the books and make yourself up-to-date.

Now, in some steels which are produced from scrap, sometime tramp elements are also present and these tramp elements are very harmful because they have very low melting point. For example: copper, tin, antimony, lead, zinc - they are all called tramp elements, but their source in steel is from the scrap. So, having known in overall blick of steel, classification, impurities, now let us pursue history of steel making, that is unsaid, now we have to produce it.

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The history of steel making, now I will say, history of modern steel making. In 1856, Henry Bessemer could develop a process for bulk steel production; no heat was supplied from outside because he knew that most of the refining reactions are exothermic in nature.

What he did, he just constructed a pear shaped vessel and lined it with acid refractory material, and through the bottom of the vessel, he blew air; so, this is the metal, through the bottom he blew air.

Air contains 79 percent nitrogen by volume and 21 percent oxygen by volume. As a result of this, the reaction between iron, carbon, silicon, manganese, it goes and he was able to produce steel from hot metal. What was the problem that he envisaged? He could not reduce the phosphorous content of hot metal; because one, the lining which he had put here was acid lining; this is the acid lining and this is the hot metal.

So, by virtue of the acid lining, it was not possible for him to remove phosphorous; so, the problem that he faced was, sulphur and phosphorous could not be removed and the oxygen content of steel was also very high.

In around 1864, Mushed had developed iron-manganese alloy, with this development, it did become possible to reduce the oxygen content of steel.

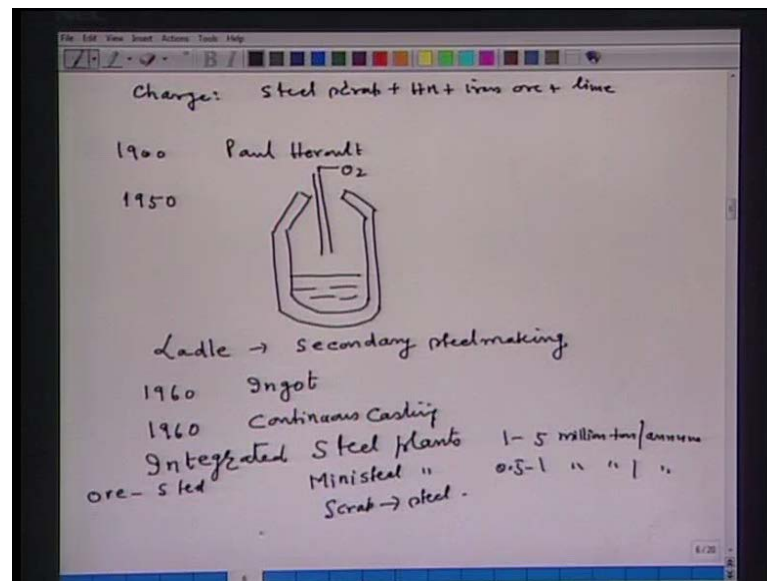
In around 1878, a basic Bessemer process was developed. The essential difference between the two is - the shape of the vessel is same, as I have shown over here; all that he has done, instead of acid lining what basic Bessemer process did, he employed basic lining, that was the only difference; as a result of the basic lining, he was able to remove phosphorous from the hot metal. So, with the advent of basic Bessemer process of steel making, it became possible to reduce phosphorous also.

In around 1868, open **hearth** process was developed; open hearth process has a very shallow, refractory lined tray. I will try to draw, let me see. So, this is shallow tray, this is the refractory lining, all the refractory lining here, acid lining or basic lining, both open hearth **(())** developed. (Refer Slide Time: 31:05)

So, this I will put as a refractory lining, this is the roof, and from here as the provision of injecting fuel, that is, oil burner; somewhere here we have the metal, and then here is the slag - this I will call as a hot metal, and then these are the so called regenerators - that regenerators were used to preheat the air; and here was an air wall, this is the wall for reversal; that is, in one cycle here it goes air - preheated air, then here goes exhaust gases out.

So, one regenerator on the heating side, another on the cooling side; when on heating side, then preheated air pass through this and exhaust gases go through the another outlet; that is what the whole idea of employing these two regenerators.

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The essential feature of this open hearth process is that it was a shallow, refractory lined tray with a roof about it, and the charge for this - since heat was being supplied from outside as you see in the oil burner - so, the charge consisted of a steel scrap, plus hot metal, plus iron ore, plus lime; it was introduced through the doors; source of heat was combustion of gaseous and liquid fuels, since it was possible to use outside source of energy.

Any amount of scrap would be melted, so the process was highly flexible; the time was around 6 to 8 hours. So, this open hearth steel making has dominated the steel production for a very long time because the basic Bessemer process, though solved the problem of phosphorous content of steel, but still the nitrogen content of steel was very high; because of this, people though used basic Bessemer in those period, but still open hearth process was predominantly used.

Now, in around 1900, Paul Heroult has showed the use of electricity for steel production, source of heat was electric energy; bath was shallow, but the quality of steel was better than the open hearth. The only problem with this electric furnace is that it uses electrical energy which is very expensive; so, as a result, the electric arc furnace was used for the use of alloy and especially steels.

In 1950, at Linz and Donawitz, a process was tried in a pear shaped vessel; this is the refractory line, this is hot metal, pure oxygen was blown from the top and he was able to convert hot metal to steel. This particular technology has revolutionized the steel industry because it was highly flexible; there was no problem with the plugging up the bottom as it was there in basic Bessemer (Refer Slide Time: 35:45)

The only problem is, that in the beginning they have used the mild steel as a material of Linz which was melting, but later on, the development took place and this process has become the modern steel making.

Now, parallel to these developments, the ladle was also explored to use as a reactor and as a result, several secondary steelmaking processes also came into existence; so, a large number of secondary steelmaking were developed around the 60s; in 60s, also this top blown oxygen steelmaking was converted to top and bottom blowing steel making; that is how, the modern steel making through top and bottom blowing has come into existence.

Now, say, for more than 150 years till 1960, ingot casting was the predominant route for casting of liquid steel; in 1960 and around that, continuous casting has come into existence; a continuous casting of steel was developed and this continuous casting has also revolutionized the steel industry.

Now, the present status of steel industry comprises of, for example, we have integrated steel plants and in integrated steel plant, the capacity may vary from 1 to 5 million ton per annum; then we have mini steel plants and their capacity may go from 0.5 to 1 million ton per annum.

The essential different between integrated steel plant and mini steel plant - integrated steel plant, it starts from ore and produces the steel; whereas, mini steel plant mostly, they have scrap and then to steel.

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The image shows a digital screen with handwritten notes in black ink. The notes are organized into two main sections: 'Long products + flat products' and 'World steel production'. Below these, there is a table of 'Top steel producers' for the year 2007, listing companies, their production in million tons, and their global ranking.

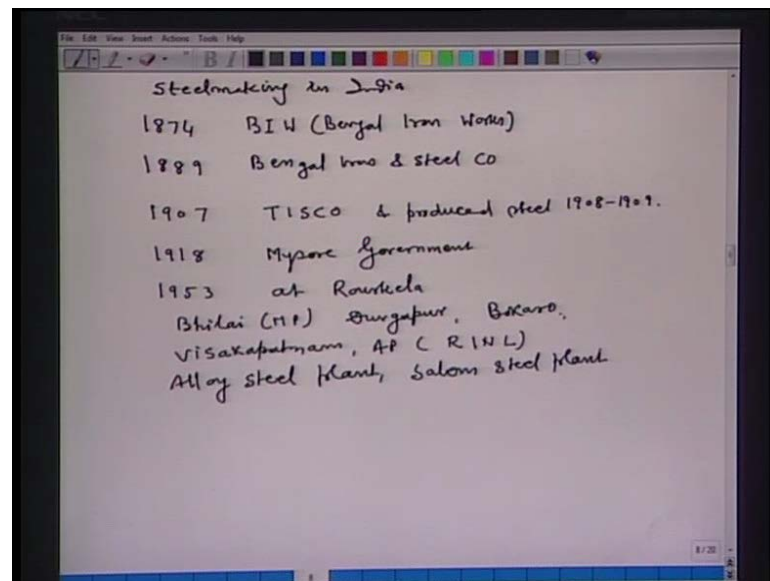
Long products + flat products	
World steel production	
2007	2008
1.3 billion tons	1.42 billion tons
2011	
1.6 billion tons	

Top steel producers		
	2007	
Arcelor Mittal	116.4 million tons	(1)
Nippon steel	35.7 "	(2)
Posco	30.1 "	(4)
Tata Steel	26.1 "	(8)
SAIL	13.9 "	21
Voest Alpine	6.9 "	43

We have long products and flat products, both products are being produced. World steel production, just there off idea, world steel production in 2007, 2008; in 2007 we have 1.3 billion tons, in 2008 it grows to 1.42 billion tons; expected production in the year 2011 is around 1.6 billion tons.

Some of the top steel producers, Arcelor Mittal, this data I am giving you for 2007, has produced 116.4 million tons and its rank is number 1, then second was Nippon steel - produced 35.7 million tons and ranks number 2, then Posco which is in Korea - it has produced 30.1 and rank is number 4, then Tata steel has produced 26.1 million tons and its rank is number 8, then SAIL Steel Authority of India Limited - it has produced 13.9 and it is ranked as number 21, then Voest Alpine which is in Austria - it produced around 6.9 million tons and ranked around 43, is the ranking number.

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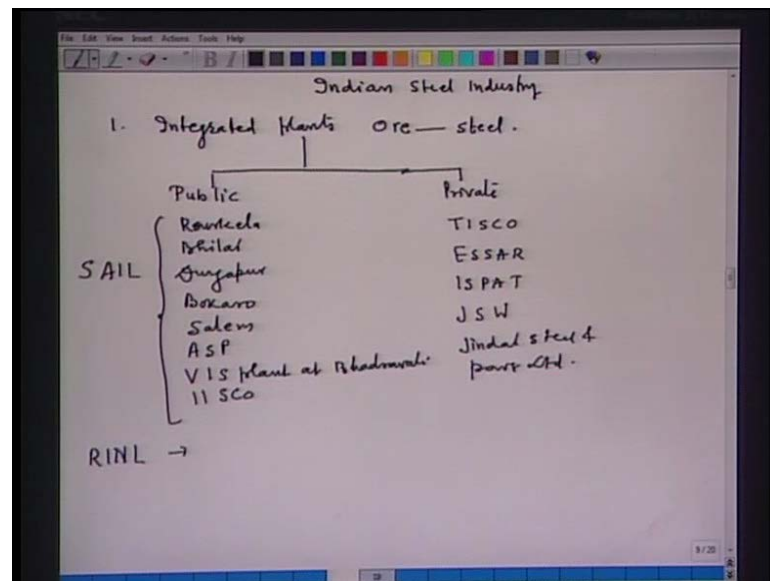
Now, just following in short, steel making in India - a brief historical background. Steelmaking in India, the first attempt to produce steel in India was made in 1874, when Bengal Iron Works came into existence.

In 1889, Bengal iron and steel company had acquired BIW and continued to produce steel, until it was taken over by TISCO in 1936. In 1907, Tata Iron and Steel Company was found by Jamshedji Tata and produced steel in 1908 in 1909.

In 1918, Mysore government decided a steel plant at Badravathi. In 1953, to the reason of our late Pandit Jawaharlal Nehru, an integrated steel plant in public sector at Rourkela with the German collaboration had come into existence.

Since then, Bhilai was added, say, Bhilai in Madhya Pradesh; then came Durgapur, then came Bocaro, and then came another steel plant in Vishakhapatnam in Andhra Pradesh under Rashtriya Ispat Nigam Limited, RINL; then came alloy steel plant at Durgapur and Salem steel plant were also added.

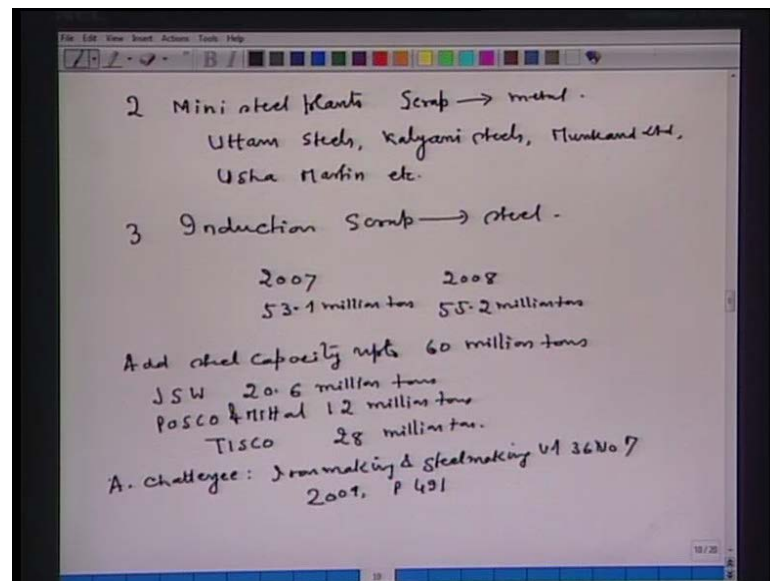
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Indian steel industry is organized in three sectors - first, you have integrated plants. The integrated plants, they use ore and produce steel; these integrated steel plants, we have in public sector and we have in private sector. In public sector, as I have said already, you have at Rourkela, then Bhilai, Durgapur, Bokaro, Salem, alloy steel plant at Durgapur, then you have Visvesvaraya steel plant - Visvesvaraya iron and steel plant at Badravathi, and Iron and Steel company at Burnpur, these all come under a limited company which is called SAIL, which is, Steel Authority of India limited; another organization which is RINL, Rashtriya Ispat Nigam limited, under which comes Vishakhapatnam Iron and Steel Works.

Then, in private sector we have, for example, TISCO, as all of us know, Tata Iron and Steel Company; then we have ESSAR steel plant, then we have ISPAT industries, then Jindal Steel plant, then Jindal Steel and Power limited and so on.

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So, this is the one type of plant sector that is integrated sector. Another sector is the mini steel plant; second is the mini steel plant, mini steel plants - they use scrap and produce metal. There are several mini steel plants, I just put down a few - Uttam steels is one, Kalyani steels, Mukand limited, Usha Martin, etcetera; you can add few more so that to update yourself; this is the second type of sector.

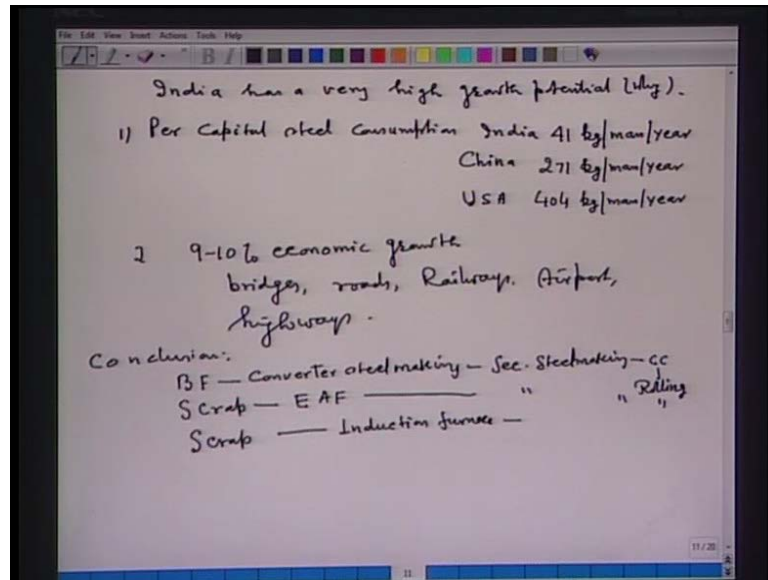
Third sector which is grown in the last 10-15 years very fast is the induction furnace sector. This sector uses scrap, same thing scrap, and produces steel; this particular sector is dispersed all over the country.

India, say, in 2007, India has produced 53.1 million tons of steel in 2007. In 2008, it produced 55.2 million tons of steel. Now, India is rather planning to add steel capacity up to 60 million tons in the future by inviting several steel players; among them, Jindal steel works will be adding 20.6 million tons additional capacity, then Posco and Mittal, each will add 12 million tons capacity - additional, TISCO will add around 28 million tons additional capacity.

If you want further detail you can see the article by A Chatterjee, it gives various other details on iron making and steelmaking.

Steelmaking, volume 36, number 7, 2009 page 491, there you can find out several other details.

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India has a very high growth potential for steel, why? The first, per capital consumption of steel which is considered to be a sign of prosperity, India - 41 kg per man per year, China - 271 kg per man per year, USA has 404 kg per man per year, the one reason.

Second reason is, that it is expected a very high economic growth - we expect around 9 to 10 percent economic growth in the near future; this calls a tremendous infrastructure growth like building of bridges, roads, railways, airports, highways and what not.

So, as such, India has a very high growth potential of steel because of these two reasons; if you also have other reasons, please add it and see that India has a very vast scope for growth of steel industry.

There is going to be a huge demand of steel in the years to come. As for some estimate, by 2030, India will be needing 300 million tons of steel, however it is an estimate.

Now, to conclude this lecture, technology of steel production has made rapid strides in the last few decades. As a result, what happened, open hearth furnace and basic Bessemer - they remain only of historical importance.

Today, to my knowledge, none of the plant or very few plants in the world, they are producing steel either by open hearth or by basic Bessemer in its original version. As such, the modern steelmaking comprises of blast furnace, followed by converter steel

making, secondary steel making, continuous casting and rolling; this is a route that is followed by integrated steel plants all around the world including India.

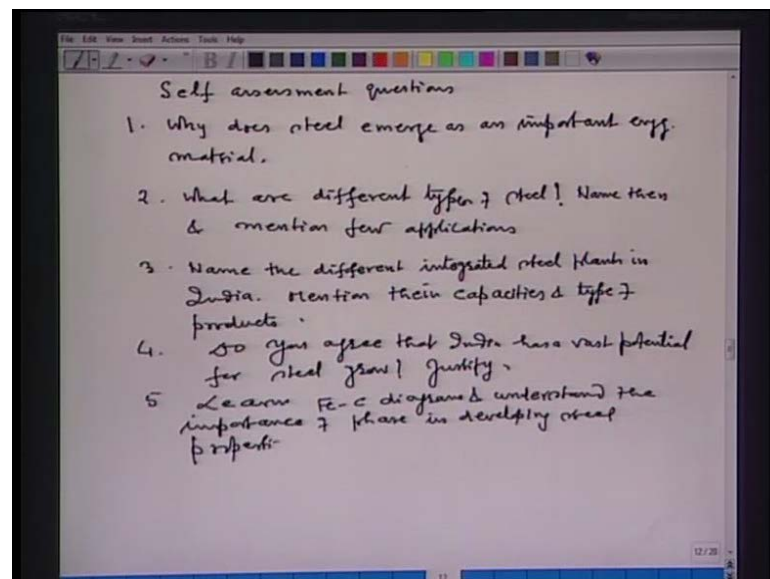
Another route is, that you have the scrap, goes in electric arc furnace, then secondary steel making, continuous casting and rolling, hereafter, the route is same; this is the route followed by the mini steel plants of the world including India.

Another route is also followed by scrap used in the induction furnace; then the manufacturing may sell ingot as such, or it may go to secondary steelmaking, or continuous casting and rolling, so it depends.

So, in conclusion, I have to say that the modern steelmaking comprises of blast furnace, converter steelmaking, secondary steelmaking, continuous casting and rolling, or scrap, electric arc furnace, and so on.

So, as such, we will be concentrating on the converter steelmaking and electric arc furnace. Now, before I finish my lecture, I will like to give you certain questions for your self-assessment.

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I will be writing certain questions, the self-assessment questions.

First question is - why does steel emerge as an important engineering material?

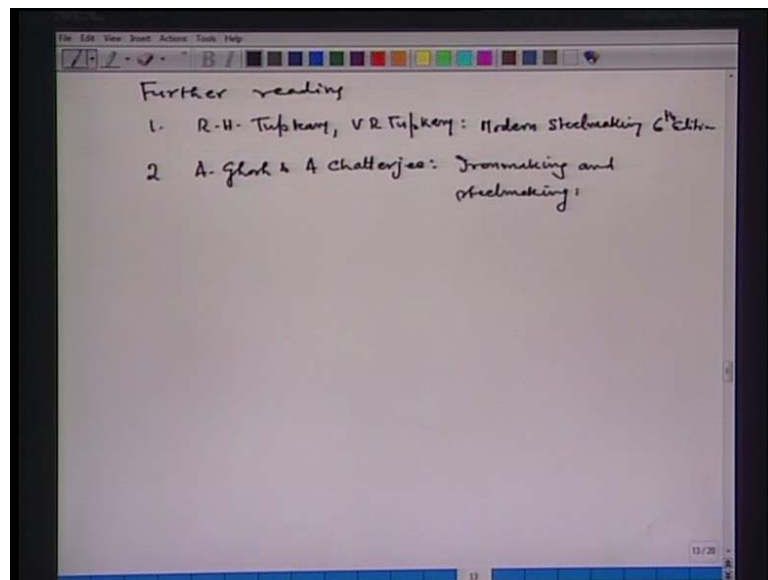
Second question is - what are the different types of steel? Name them and mention few applications.

Third, name the different integrated steel plants in India. Mention their capacities and type of products.

Fourth, do you agree that India has a vast potential for steel growth, justify?

Fifth, learn iron-carbon diagram and understand the importance of phases in developing steel properties.

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Now, the last thing, I will like to give you few references for further reading; you can consult one book by R H Tupkary and V R Tupkary, Modern steelmaking, sixth edition or any edition; because I followed the sixth edition.

Second, you can also consider A Ghosh and A Chatterjee, Iron making and Steelmaking. That is the end of the lecture.