Nature and Properties of Materials
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Lecture 1
History and Evolution of Materials

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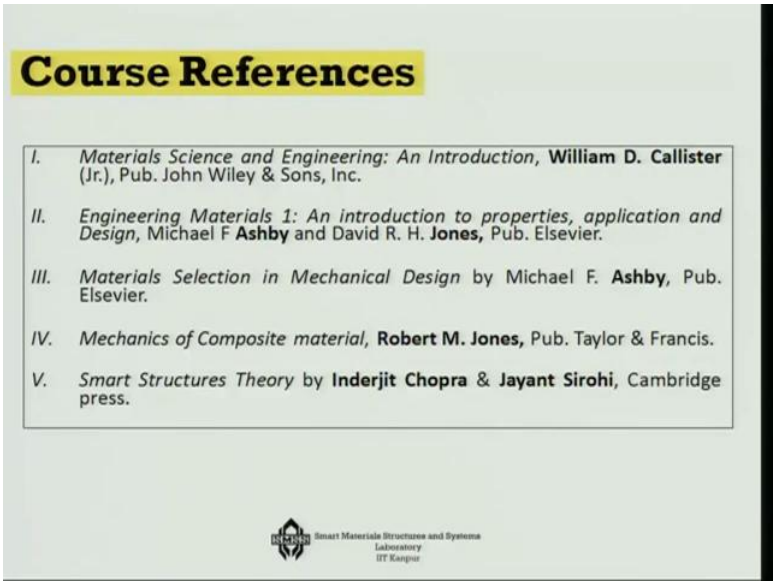

I am Bishak Bhattacharya from IIT Kanpur. Now in this course, although we will be using heavily various references and sources, but there are some broad textbooks for your reference. The 1st one is actually "Materials science and Engineering: An introduction" by Callister. This is a John Wiley and Sons book, this book is very helpful for this entire course.

In fact, this course I offer it in IIT Kanpur. This is used as a textbook for this particular course.

And similarly, there is another book by Ashby and Jones, which is "Engineering Materials: An Introduction to properties, application and design". So when the 1st book more talks about the properties of the materials. The 2nd book talks about application and design, so from that point of view the 2nd book will be very helpful for us.

The 3rd book is specifically designed towards the case studies, so that is "Material Selection in Mechanical Design" that is by Ashby and that is also very widely we will be using it towards the 4th series or 4th week onwards we will be using the 3rd book.

And then the "Mechanics of Composite Material" because I told you that once we explore all the engineering materials, we will think of how to mix and match such engineering with real to make more advanced materials to tailor them towards certain applications, so then the composite materials will come into picture. And towards that, the Jones book could be a good introductory book.

Finally when I will talk about the Smart Structures or the Smart Materials and the Smart Structures, the Chopra and Sirohi's book will be very useful for us. So thus in this entire course, there will be these 5 books which we will be using and it could be a very good reference if you want to get more in depth knowledge in this subject, okay.

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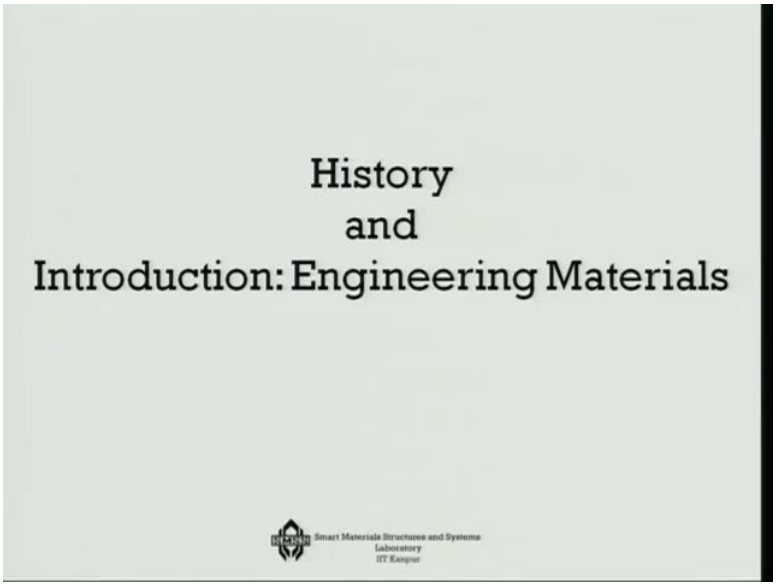

So in today's lecture, we will talk about history and introduction of engineering materials, okay. So basically, we will start with the materials as the evil civilization you know actually progress how we had actually gone for the use of various materials.

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As you know that materials are actually the drivers of our society and various applications. You think of transportation, without material you cannot build an automobile, a car, a cycle, an aircraft, so the entire transportation needs some material.

You think of housing, without material you cannot develop any home, so there are also certain groups of materials are needed. For clothing you need materials, for communication like an antenna, there also you need materials, which will be capable of receiving the signals or transmitting the signals and then recreations, lasers, etcetera.

For each and every purpose you will need basically materials all around yourself in order to give you the life that we have today. But the world was not so easy and comfortable if you look back into the evolution of human beings. If you look back towards the history you would see that we have started with things like Stone Age and then from Stone Age we came to the Bronze Age, then from Bronze Age to the Iron Age.

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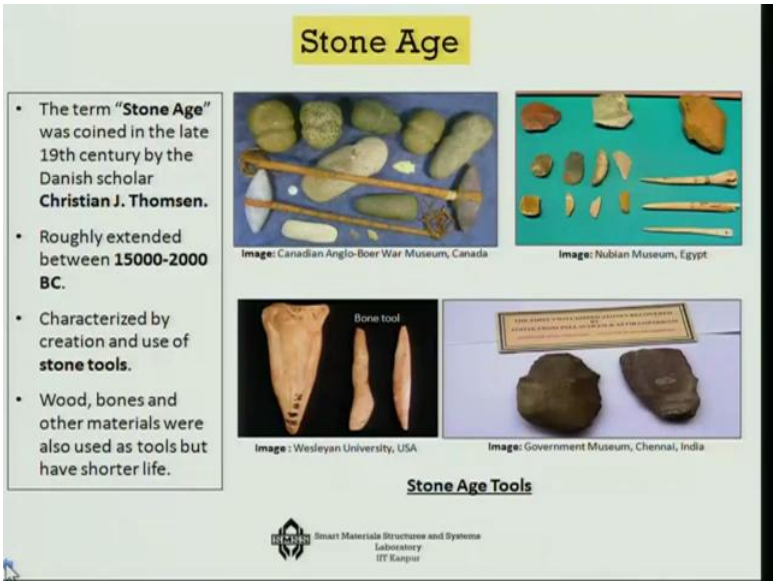

So phase by phase, we have actually developed our materials and thus you know we have reached today. So if you look back actually to the Stone Age, so that is the beginning of we would say the usage of materials. Now the Stone Age essentially was actually continued from 15,000 before Christ, which means when just the Homo sapiens was evolving till about 2000 to 3000 before Christ depending on the area that we are talking about.

And the major implement by which the Stone Age is named is actually related to stones for various types of hunting purposes, okay. So that is why you would see that various shapes of stones, mostly these stones are actually made from what you call igneous rocks, okay. So and some of them are from metamorphic rocks, so mostly igneous rocks why because they give you very high strength.

I will later on tell you that how today we are reinventing the history; we are developing new materials which are actually derived from these Stone Age materials, okay. So these materials that are used in the Stone Ages, they are basically explored from various volcanoes, etcetera and various rocks on mountainous areas.

And the limited extent other than the stones are of course bones and woods are also used, but since Stone was predominant element which is mostly used for hunting purposes hence this era is named as the Stone Age era, okay. And there is a whole lot of technology that evolved around it.

Some of it have survived today, some of it has gone lost for example, you know how to make a stone in so sharp so that you can actually do activities like sewing using the Stone or you

can actually make very fine wholes on beads using the tone, so all these things as you can see are in the Lubian Museum of Egypt. There is a good collection of these types of you know Stone tools.

In fact, you could say that these are the beginning very beginning of the lathe machines you know where which is mostly based on metals, but the principle that is used for that is roughly the same. So that is the Stone Age era I would say which continued for a long time until the human beings have actually reached a stage when they had a situation of the basic needs which were covered by the Stone in for the use of the Stone.

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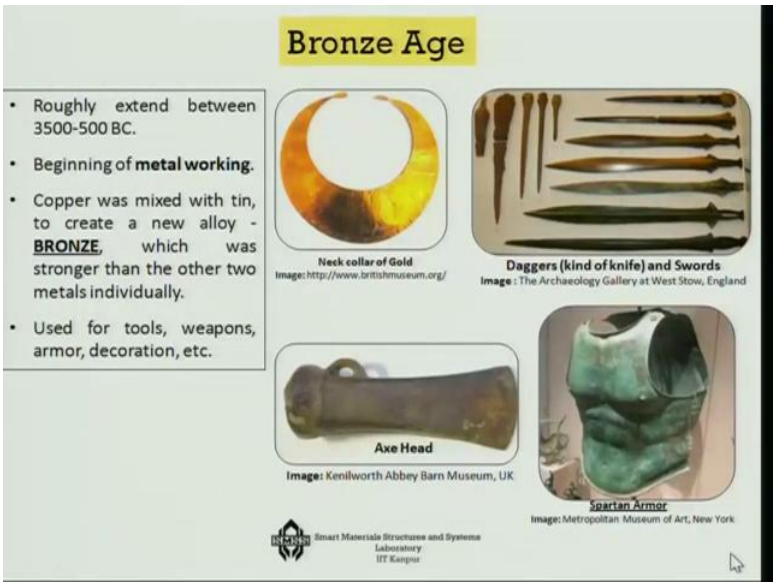

And the civilisation has to progress further. Now as it happen that because of some chance I would say you know kind of discovery the Bronze Age (())(7:23) from the Stone Age. So during the Bronze Age what happened, these you know instead of the use of stone, now it is the metals which have come into the picture? Metals like the copper mixed with tin.

In fact, initially copper is used in some places for some very small amount of time, but it was found that coppers are very much malleable and they are not that strong, so you that you can make useful implements or tools out of them. And hence when they found this new alloy again a chance discovery that from certain you know ores that you mix actually copper with tin, you get something called Bronze which is much stronger.

Then suddenly the Bronze Age has started where the people have developed swords, daggers made of bronze okay, as you can see here various types of bronze related things. There are

also some examples of gold and other things, but that is mostly for the ornamental purposes. So the eventually the metals I would say started with actually bronze itself.

If you actually think of the history of India, there are enormous evidences of Bronze Age in India. It actually you know people say started at around 3000 before Christ or so of course, the exact timing there is still lot of debate on it and the use of such Bronze Age culture was found in Mohanjo daro Harappa areas in mostly around this part and the north-west part of India.

And here for example, one of the very beautiful evidence of the Bronze Age civilization is the Dancing girl, National Museum Delhi you will find this small piece of bronze, product which is made using something called a lost rocks method okay. So and it is very nicely described in many of our scriptures.

For example If you read Vishnu Puram and similar such old pictures, you would see that it is very nicely depicted there that how you can make an initial model out of rocks and then this rocks model you know you actually pour the molten metal into it and in that process of course the rocks is lost that is why it is called lost rocks method and you get the exact replica of the you know product that you are making.

So this kind of lost rock technique with bronze is used for making various types of not only sculptures or dolls, but also you know various types of pots or items of ornamentation, it is very heavily used. So thus Bronze Age is actually is widely found in Indian civilisation and particularly in the context of the Indus Valley civilisation and Harappa civilisation.

Now I would say it is not only the bronze, but also there are certain things like this you know this ceramic okay. Later on I will actually tell you that the ceramic you know also came into existence side-by-side in fact, ceramics played a very important role in the Indus Valley civilisation. And we actually claimed that India is possibly the 1st place where the ceramics and to some extent the ceramic composites were actually discovered.

And they are hugely applied for potteries, for making bricks, for beautiful you know building constructions, so ceramic played a very important role in all these things. So during the Bronze Age of course the predominant material is bronze it, but I would say that this you know ceramic also side by side came into the picture. Now after that next came the Iron Age.

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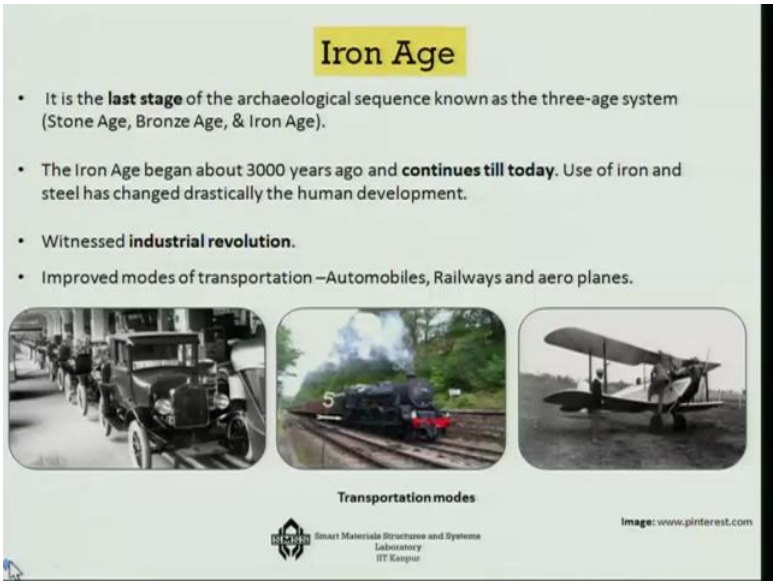

And people say in fact that one of the reasons why the Indus Valley civilisation was actually defeated by the aliens is because the aliens had better arms which were made of iron and hence you know they worked much better than the bronze counterpart and they won the battle. However, the point is that the Iron Age had actually been very widely distributed all over the world and in India also.

I will talk about it later on that southern part of India had very good culture of an iron age. So this started roughly about 3000 years ago and it was found very soon that Iron is a much better material in terms of hardness, strength okay and also you can make composites out of it and you can make various types of variations of iron to the extent of steel which of course came from the Industrial Revolution.

Now, ones the iron came and slowly where not the iron has embedded us. For example, you think of the automobiles, the early automobiles were made of wood, but the Ford T generations were actually made of you know steel, so the steel dominated automobiles, of course the entire railway transportation system got dominated by iron.

People tried to replace the railway coaches by making aluminium material and aluminium based coaches, but they really did not get a success so far and then of course other things like aircrafts, et cetera. But in aircraft, iron is more in the form of alloys partly know because of its heavyweight. So that is the iron age has really advanced from that 3000 years ago till today it is continued.

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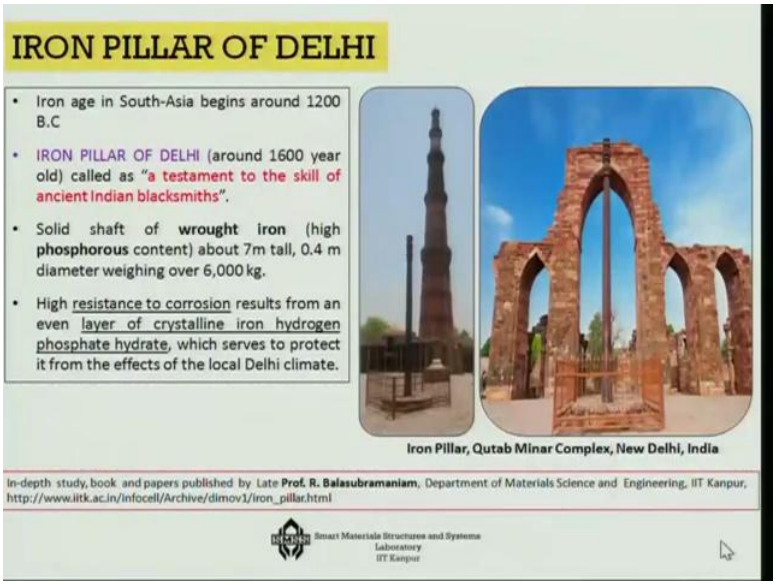

Now, iron of course we have a very reach heritage. Not just I talked about the Bronze Age, iron age also we have a very rich heritage. If you know have ever visited Delhi, you must have seen the famous iron pillar of Delhi. And if you want to know more about these, you can actually read a book by our own ex late colleague Professor Balasubramanyam of Material Science Department who has written a beautiful book on iron pillars.

The mystery of this iron pillar, why it has not been corroded from thousands of years. In fact, he is the person who actually found out that the mystery lies in terms of how this iron was actually you know obtained and the rich phosphorus contained in some of the sources of iron is what actually gave that beautiful property of anti corrosiveness in these iron pillars.

So this high resistance to corrosion because of the iron hydrate you know hydrogen phosphate hydrate actually, if you check this particular type of a system you know in this particular reference you will see that there is a layer of crystalline iron hydrogen phosphate hydrate which serves to protect it from the effects of the Delhi climate.

So that was like a very interesting part of early improvement or early applications of iron for making various types of products. Now also please keep in mind that a column is predominately a compressive force carrying system. This is important; I will later on tell you that from iron to steel that is what has actually changed the world.

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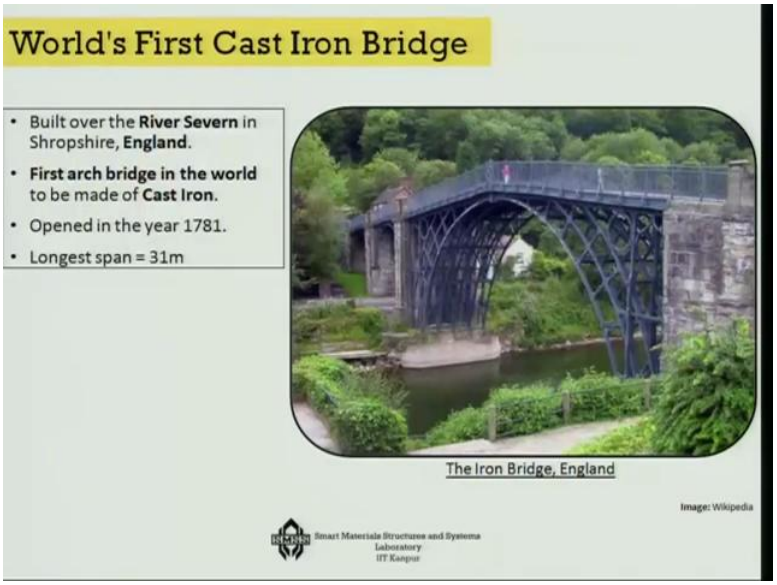

So Iron now not only you know later on limited only for these kinds of you know columns, et cetera, but also for making bridge like World's first cast iron bridge is in England, it is on the river Severn and this is the 1st arch bridge. Now this arch bridge configuration that is very interesting actually if you look at this arch part of the bridge, okay.

So it is this particular part if you look at it that it is developed in such a manner that there will be only compressive load in each of the members of the arches, okay. So you have to keep in mind that this form of iron we are talking about cast iron, they are very weak in tension and since they are very weak in tension hence, you know you cannot really make a bridge where there will be tensile force that will be working on the system.

So this is made you know design is done in such a manner that it will be predominately compressive in nature and that is the beauty of the arch bridge system and in 1781 it was 1st developed and that you may say as the 1st use of iron from general say applications like columns or chariots, etcetera to something like a large infrastructure system for example for the bridge system.

Of course, at a later stage this is also used for the development of the Eiffel Tower that actually showed the mighty power of the Industrial Revolution. So that is the early stage of iron development, so from there let us come to the steel part of it because iron becomes much stronger in the form of steel.

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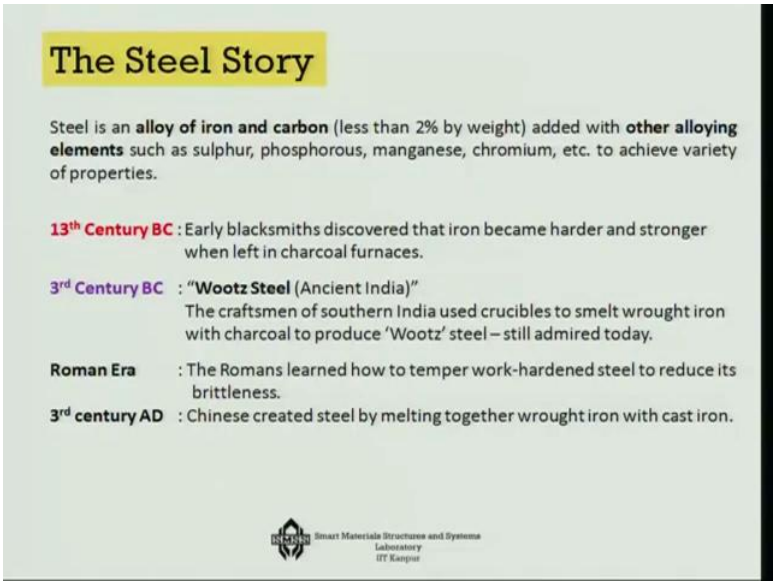

Now it was kind of known to early people that when you are making iron physically from the raw iron you know from the ores when you are actually melting it and if you leave it in the furnace for some time, they found it to be harder and stronger. Then did not know the reason that the reason is because some amount of charcoal is generally used to heat it up actually makes it stronger.

This was very well understood by the southern part of ancient India. In fact, the steel that they used to prepare is known as Wootz steel. Even today you know when we talk about steel; we always try to find out in the Indian context that whether it is from the southern part of India or not because people believe that southern part has a much better you know kind of knowledge of steel production.

So where that myth is come is actually because of this Wootz steel you know that had dominated entire medieval period in India. Now there are other evidences of making steel in Roman eras and in the 3rd century AD in Chinese making steel, but Wootz steel is really very famous in terms of the early advancement of steel.

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Of course with respect to the Industrial Revolution you get the modern of steelmaking, the 1st one being the Bessemer, the famous Bessemer process. So in the Bessemer process as you know might have studied in your basic courses that it always start with a Bessemer converter, okay. And when you are actually blasting air, air blast injected into the molten pig iron and the objective is that.

Now you know that you have to mix iron with limited amount of carbon. If the carbon content is too high it will be harder, but it will be very brittle. So you have to have an optimal content of carbon, something like 3.5 to 4.5%. And that you do through air blasting, hot air blasting which actually converts some of the carbon to carbon dioxide. And it is good but the material, the ore has to be free from phosphorus, okay.

It is interesting that the same phosphorus was used for the anti corrosion point of view in Delhi iron pillars, but in the Bessemer process it works very well provided the ore is free from phosphorus. Now there are some improvements to tackle the phosphorus because if we are talking about in the background of Europe and there the phosphorus is removed with the use of actually lime stones in the Gilchrist Thomas process.

So that is one improvement on the Bessemer process, which happened around 1860. To give you a kind of a timeframe, we are talking about 1857; you know the famous Indian mutiny that is the time when already they have caught hold of how to make the very good quality of steel, which means how to make very good quality of armaments. So 1860, already the steelmaking process has advanced further from the Bessemer process.

In 1865, came the famous Open hearth process, so that is also known as Siemens Martin or Open hearth process. And in this process what they do is that they actually mix the steel scrap here okay with the you know pig iron, so that actually helps in terms of reducing the carbon content by dilutions or oxidation, so that is in 1865.

Of course at a later stage people have understood that how to use oxidant blast because if you use air, what happens is that with oxygen you get nitrogen and other impurities, but you do not need the impurities, you need the pure oxygen in order to convert some part of carbon to carbon dioxide. So that you know with the oxygen blast technique in 1953 or so you get actually a very good kind of you know steelmaking.

However, further you know with the advent of the Electric arc furnace, you do not have to really generate heat with the help of fossil fuels anymore, so the chance of carbon getting included beyond a certain degree is totally avoided in the induction furnace. Of course it is more expensive, but it is a much more green processed. So thus there are lots of developments of steel that has taken place predominately based on the iron.

And you can say in some extent, we are continuing with the Iron Age even today. So one of the most important things is that you know the iron products or the steel products, you can actually recycle them even if it is older than 150 years. So that means you know you think of it that how green it is for the environment that you can recycle it again and again and again that is a good part of iron, okay.

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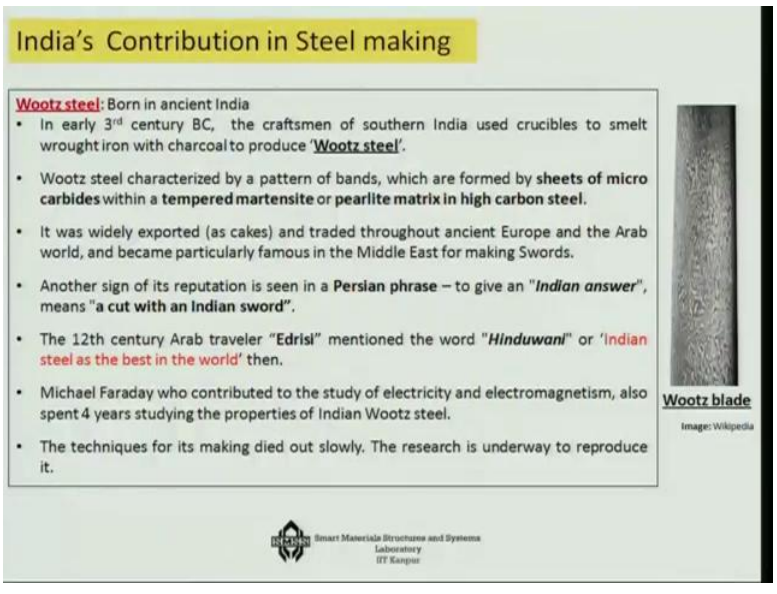

So that is you know kind of very brief about the steelmaking process. Now India's contribution if I just highlight a little more in terms of the Wootz steel because it is still a mystery that how the Wootz steel became so famous. It is like it is kind of what you can say iron it is a composite in which you have the tempered Martin site or Pearlite matrix of iron.

And that actually is having enhanced strength because of the shapes of this micro carbides and the source of this micro carbides are actually the Wootz that are used in that process of generating the heat. So actually keep some kind of a banded pattern of bands that was the tilted sign of actually Wootz steel.

And it became so popular that in the entire Middle East, you know there are these Persian phrases like "a cut with an Indian sword" okay or it is "Hinduwani" that is "Indian steel as the best in the world". So that was the kind of the Marvel that the Wootz steel had generated. In fact, Faraday actually spent about 4 years studying the properties of the Indian Wootz steel.

So Indian Wootz steel is really something which was I would say one of the first you know ventures towards making a good product out of iron, so that is why we should really take pride in this particular thing. Now if you consider in the today's context, steel plays a very important role in our civilisation. See particularly for example the railway tracks, we have the 4th longest railway network something like 65,000 km next to USA, China and Russia.

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And this railway network is possible because of the Rail steel, which has a content of carbon of about 0.6 to 0.8% with some other alloys like manganese, silicon, sulphur, phosphorus,

Molybdenum, chromium and vanadium. But you know it is very at extensive and a robust network of say application of steel.

And can see there are various such things like this diamond crossing in Nagpur for example, where you have the north and south you know crossing okay. So imagine the amount of wear and tear that these things will be facing and the steel plays a very important role there. Similarly you think of the Pamban rail bridge okay, so that is once again a marvel out of steel.

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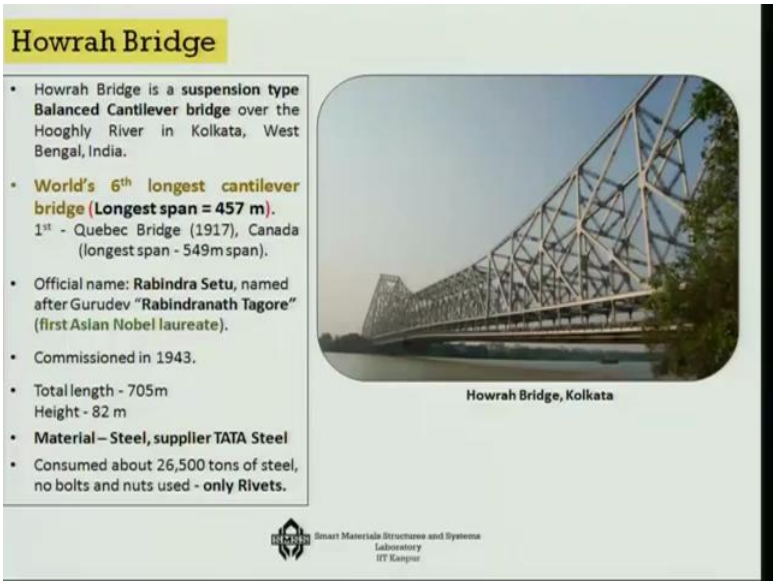

In fact, I will tell you about other very early applications of steel that is the Howrah Bridge in Kolkata. If you look at it, it is basically a suspension bridge, just like we have talked about the cast iron bridge, where it actually predominately takes a compressive load. This is an example where it is like 2 cantilevers, it is (())(26:32) cantilever bridge it is called and this 2 cantilevers come from 2 sides.

So because it is like you know 2 cantilevers from the 2 sides, so there is one cantilever from this side and there is another cantilever from this side. So basically, due to the load, application of load in both the cases, there is a bending that you would not see in that cast iron bridge over river Severn.

And this bending actually what it means, is that if you take any member, you would see that the stress profile on the member is having tension as well as compression in it, okay. And this tension carrying capacity of steel iron, cast iron from it does not have that.

But once you mix it with a very new know kind of a controlled amount of carbon and some of the other materials, you get this beautiful property of steel that is equally good in tension and compression and that is how these you know one of the longest, 6th longest cantilever bridge in the World was made possible because of the advancement of steel. So you know that kind of glorifies the metal, the role of the metals and the advancement in the metals.

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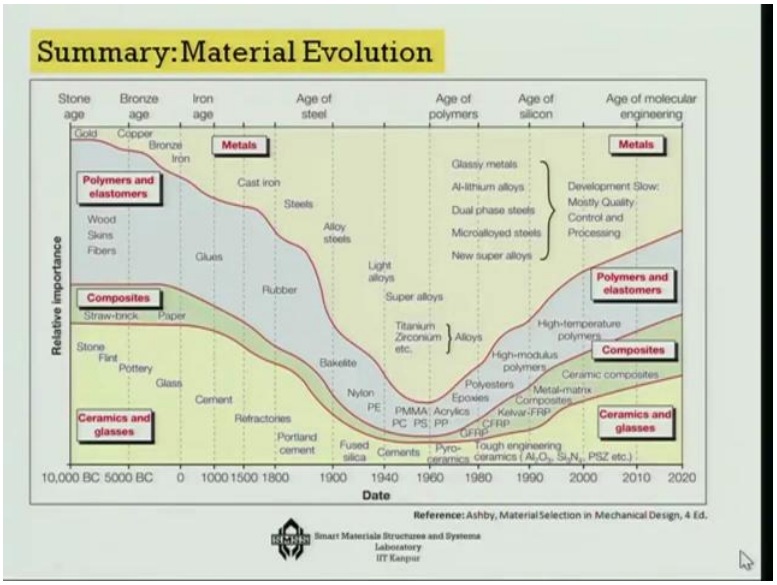

Now let us try to summarise this evolution of the materials. So if you try to summarise this evolution of the materials, what you would see is that suppose 10,000 BC when we are talking about, at that time if you look at it then you know you would see that there is a predominant use of stone, flint, etc as I told you that is the beginning of stone age.

If you talk of other materials, straw brick I told you the Indus Valley civilisation, you know that is the beginning of ceramics. This is the initial part of material used, so these straw brick I told you that is from the Indus Valley civilisation. Then there is some use of wood, skin and fibres and that you may say that other than you know like stones, et cetera, some of the organic elements like skins, etc they used for dressmaking.

After that the pottery, glasses are coming into picture, the discovery of Papyrus that is creating the paper and of course as you can see that the Red Line is expanding here, that is the metallic line. So from the Stone Age, now there comes 1st the copper, then the bronze and then the iron and this gulf is expanding more and more, okay.

So if you look at you know the mediaeval period for example, you would see that by the time there are some refractory materials, there are some you know glues, but the cast iron takes a

very predominant role. And once we are beyond industrial revolution, you will see that the still comes into picture, then the alloy steel come into picture.

And then possibly beyond 1900 or so, I would rather say with the First World War and the Second World War or around, we start to get a new material. Earlier, in terms of polymers and elastomers, we had only organic materials like wood, skins and fibres, glues or rubber which is from the natural rubber. But it is around the Second World War also that we have this nylon polyethylene, etc that got discovered, okay.

So that started to play a very important role. We will see that after that onwards once again their use is expanding, okay. Today their use is continuously expanding. What else we are getting in the metals after the alloy steels, then you know the light alloys came into picture particularly because of the development of the aircraft sector.

And then of course one of the jet aircraft you know had initiated the development of super alloys which is like you know a mixing of various types of metals like titanium, vanadium, chromium, etc. It is like to 33 metals together you know develops a super alloy, so it is quite a feat of achievement in terms of you know advancement of metals.

Then there are various types of formations of metals like glassy metals like aluminium, lithium alloys, Dual phase steel, Micro alloyed steel and some new super alloys. So here you know it is like the development is slowed down, but mostly there is a quality you know that is actually increasing, not in terms of rapid increase in terms of quantity. If you talk of in terms of quantity, then you would see that the metal is shrinking now.

So post 1960 metal, again the use of metal is shrinking. What is expanding? Polymers and elastomers that is expanding, we now are having very high-quality polymers that is coming up and composites that is expanding as I told you that composites are basically mixing of various types of materials. For example, we have the carbon fibre reinforced plastic CFRP, glass fibre reinforced plastic, we have Kevlar which is used for bullet-proof jackets.

We have metal matrix, we have ceramic composites, so there are various types of composites that is coming up and one very interesting thing is that you may say that the Stone Age is actually coming back here in a different format. The ceramic and glasses, they are actually, their use is expanding continuously, the advance ceramic, so ceramics are taking the place of metals back again that is very interesting.

In fact, in this course we will see the power of ceramics you know that is happening in today's context. So that is the summary in terms of the material you know evolution that actually we have seen in today's context. Thank you.