Nature and Properties of Materials
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Lecture 12
Metals 2

In the last lecture, we have talked about metals and metallic alloys which are ferrous having ferrous connections, but now we are going to talk about nonferrous alloys. This also has very interesting applications. Before starting that, I would like to ask you a question that what is the material composition of this Beverage Can?

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Let us say this is a Coke Can, what is the material composition of the Can okay. So you can guess it actually that what are the various materials that is possible. One thing you will notice once you finish up a Beverage Can is that it becomes quite light when you finish it up okay. So it is metallic, but it is very light material that you may guess so that is the clue.

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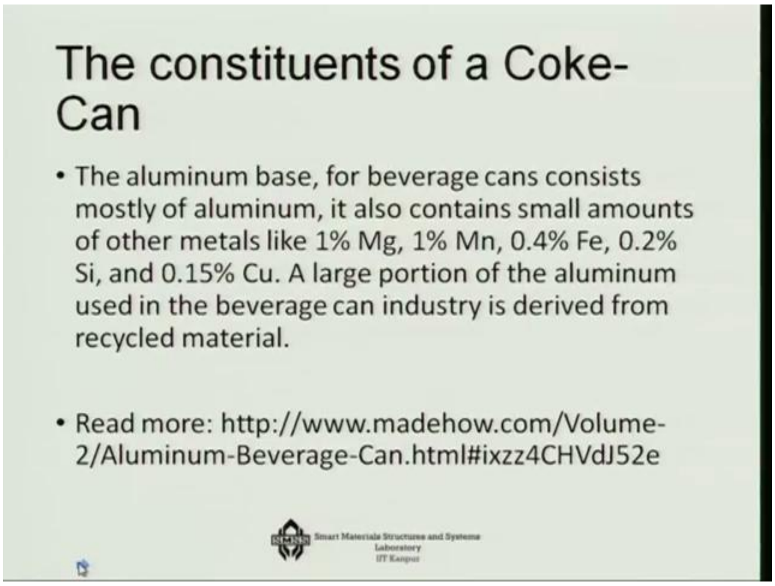

If you actually really find it out, you will see that that lightness is attributed because of its aluminum base, most of the Beverage Can consist mostly of Aluminium, but also it is an alloy, this is a nonferrous alloy, it has 1% of Magnesium, 1% of Manganese, 0.4 percent of Iron and 0.2 % of Silicon and a very small percentage of Copper. So that is very interesting that when we talk about a nonferrous alloy, this is one of the very interesting examples of a nonferrous alloy.

And one of the good things is that this is made of an Aluminium alloy and this Aluminium alloy can be actually mostly derived from a recycled material. So which means it is actually a very green way of using a material. I have given a site which you can actually visit in order to know more of this type of Coke Can how it is made, et cetera.

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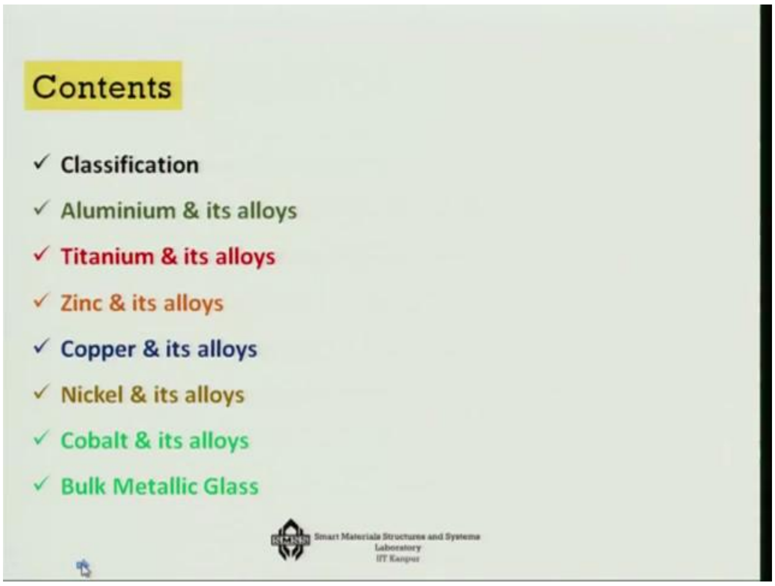

So in today's lecture, we are going to talk about the 1st of all the various classifications of metallic alloys. And then we are going to specifically focus on Aluminium and its alloys, Titanium and its alloys, Zinc and its alloys, Copper and its alloys, Nickel and its alloys, Cobalt and its alloys and finally something which is totally non crystalline form of metal that is bulk metallic glass. So quite a bit of thing you would like to cover in this particular lecture.

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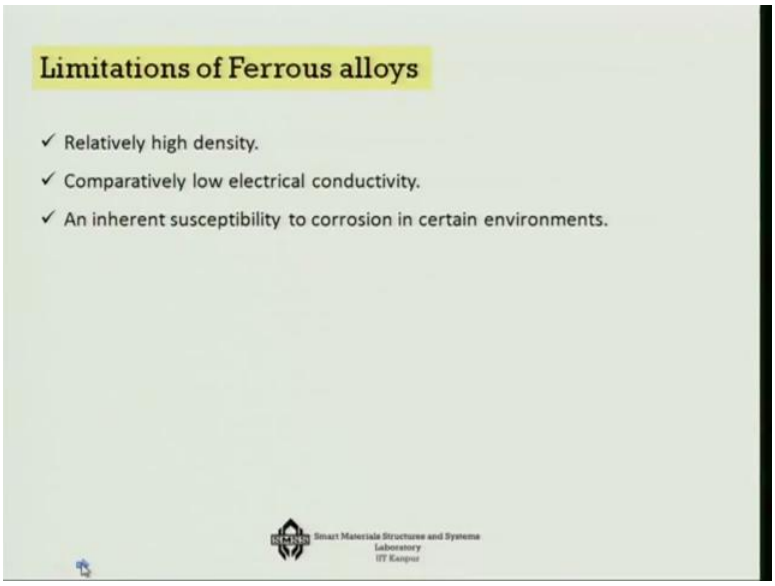

Now, what are the limitations of ferrous alloys? Ferrous alloys no doubts they are very extensively used, but particularly for transport applications for white good they are not good why, because they have relatively high density there you can feel that they are very heavy.

They have also low electrical conductivity and also they have an inherent susceptibility to corrosion and in certain environments, let us say under saline water.

Let us say this Coke Can example for example, Coke is highly acidic, so if you put the Coke on ferrous material, you would see that how it is getting corroded with respect to time. But this particular Aluminium alloy composition, it has a very good corrosion resistance. So the density, the electrical conductivity and the corrosion resistance are some of the important points why one has to go for nonferrous alloys.

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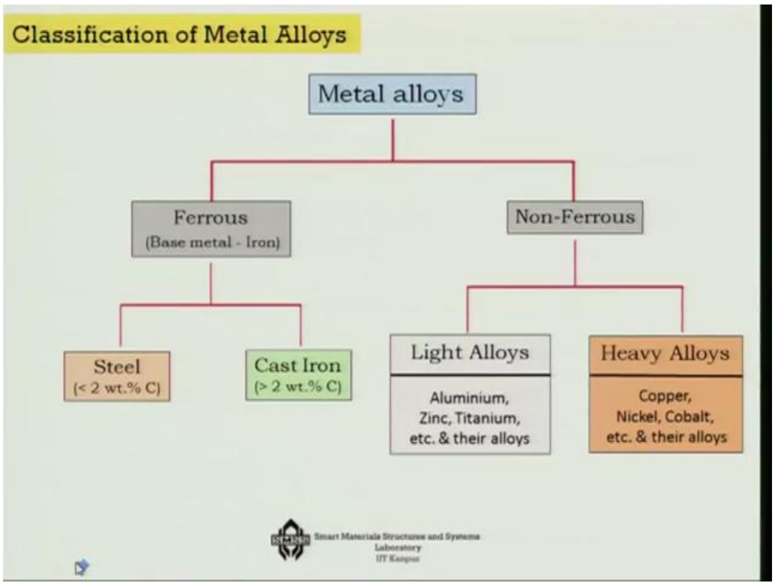

Now, the classification of metallic alloys if you see then there is a branch, the ferrous alloys with the base metal as Iron, then you have Steel, cast Iron, et cetera and I have covered this in the last lecture. In today's lecture, we are going to talk about nonferrous alloys, where we are going to talk about various light alloys like from Aluminium, Zinc, Titanium and their alloys and also heavier alloys for example, alloys which has Copper origin, Copper, Nickel, Cobalt, et cetera and their alloys, so a light group and a heavy group.

So let us first start to talk about the light group, then we will go to the heavy group, so light nonferrous alloys let us talk about it.

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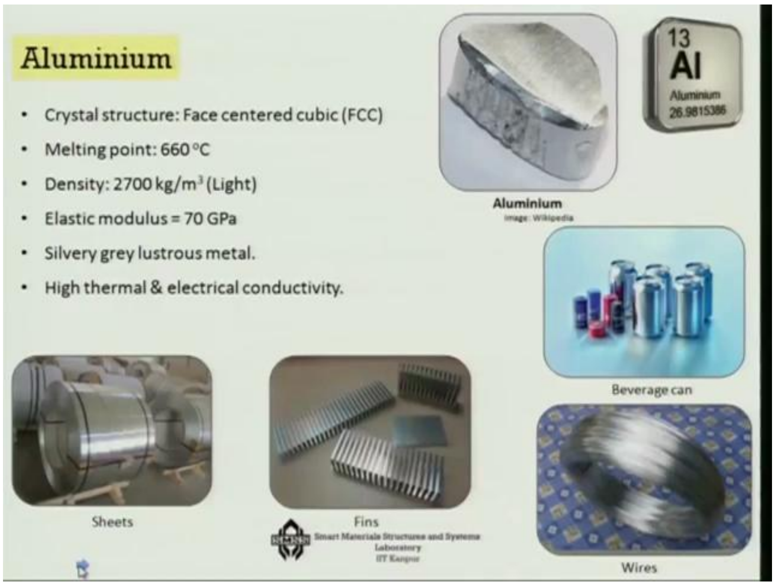

The 1st material that we will consider in this is Aluminium why Aluminium, I already told you that Aluminium is very abundant in earth crust. In fact, it is so abundant that it is usually makes no sense that why do not we make each and everything out of Aluminium. But we have not made it historically for a very long time mainly because extracting Aluminium from earth crust is a very energy intensive procedure and it was not very well known till about the end part of 19th century that people started to realize.

And Aluminium at that point of time becomes a highly fashionable material. In fact, during the Napoleon's regimen in France, Aluminium is used as ornaments, so that is how the journey of Aluminium started. But people very soon understood the importance of Aluminium in terms of transport materials okay, so making the sheets, making the radiation films, making wires, Beverage Cans, there are many applications.

And any many has a Face centered cubic FCC crystal structure with a melting point of about 600 degree, density is very light 2700 kg per meter cube. Compare it with Steel; Steel is something like 7400 kg per meter cube, so it is one third the density of Steel. Elastic modulus of course is lower; 70GPa Steel has much higher elastic modulus. In Callide has a silver grey lustre and it has high thermal and electrical conductivity.

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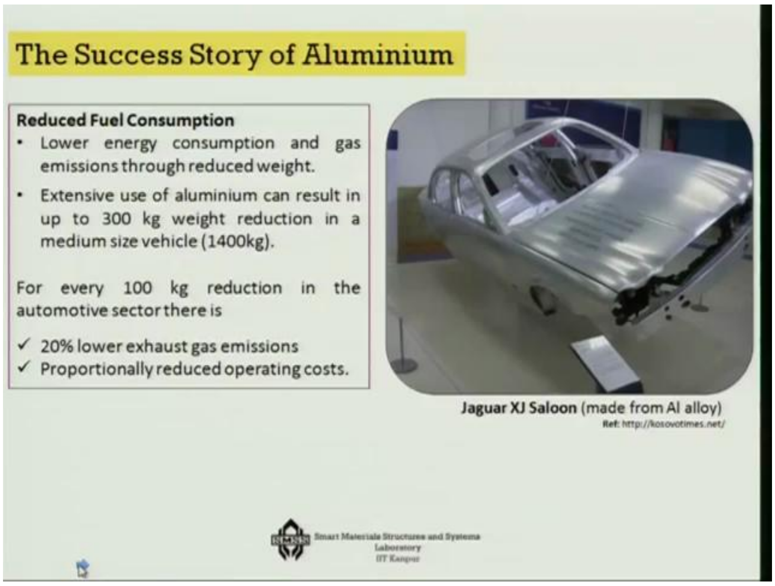

Now Aluminium one of the very important reasons why it became very popular is that the fuel consumption, the fuel became there was a fuel crisis at one point of time and also huge pollution. In order to reduce that in Europe they have to come up with a transport solution, which is based on lighter materials. And there what is found as that if you can replace the car body by Aluminium, you can save something like 300 KG weight reduction in a medium sized vehicle of about 1400 KG.

So that is very good because for every 100 KG of reduction in the automotive sector there is 20% lower exhaust gas emission, and also proportionally reduces the operating cost. So as you reduce, you are going to gain more and more reduction in terms of exhaust gas and also in terms of fuel economy. That is how Aluminium started to be used in many cars to know the bodies actually substituted from ferrous alloys to Aluminium and its alloys.

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Now not only in the automobile transportation sector, but today if you look at the aircraft transportation sector let us see this A 340, the wing part of the A 340 if you look at it, that is actually made of a Aluminium alloy based plate. And here this Aluminium alloy based plate as you can see this is a rim box here, this is preferred because it has improved toughness, and of course lower weight and it has increased resistance to both fatigue as well as corrosion. So that is the point where even the aircraft industry has got interest in Aluminium base system.

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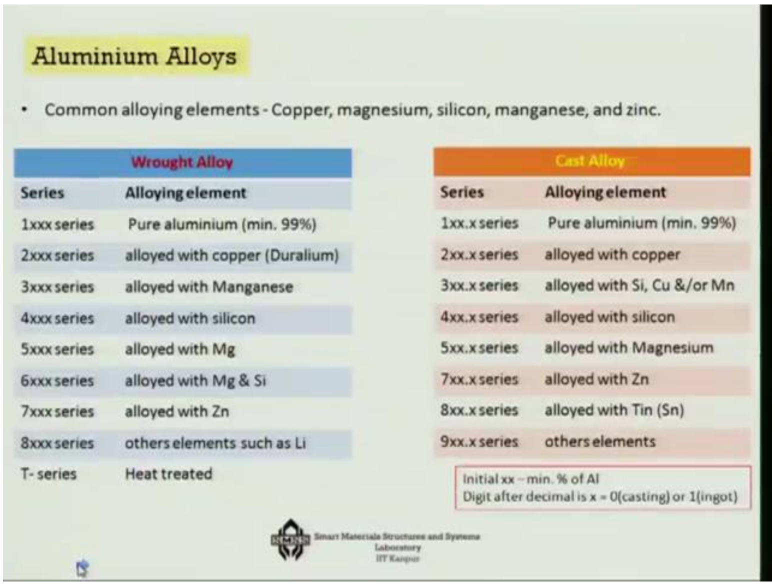

Now there are many alloys, Aluminium is one thing which has been explored with various materials for example, Copper, Magnesium, Silicon, Manganese and Zinc. And depending on what kind of alloying is happening, there are different grades of Aluminium. For example, the gaide one is having pure Aluminium about 99% pure. And there is this XXX here; the initial XX means actually the percentage of Aluminium.

And sometimes you will see XX point X series okay when you try to buy it from the market, the digit after decimal is 0 if you see in this X that means for casting. And if you see 1 here, that means this is ingot, so that is the kind of way of depicting various grades of Aluminium. So grade one is for pure Aluminium as I said, grade 2 is actually alloyed with Copper, that is known as Duralium.

It is the 1st material that is used for aircraft application. Grade 3 is with Manganese; grade 4 is with Silicon, 5 with Magnesium, 6 with Magnesium and Silicon, 7 with Zinc and 8 with other elements such as Lithium. And if you get a T, that T means it is also heat treated along with that. So that is how we actually kind of define various types of grades of Aluminium.

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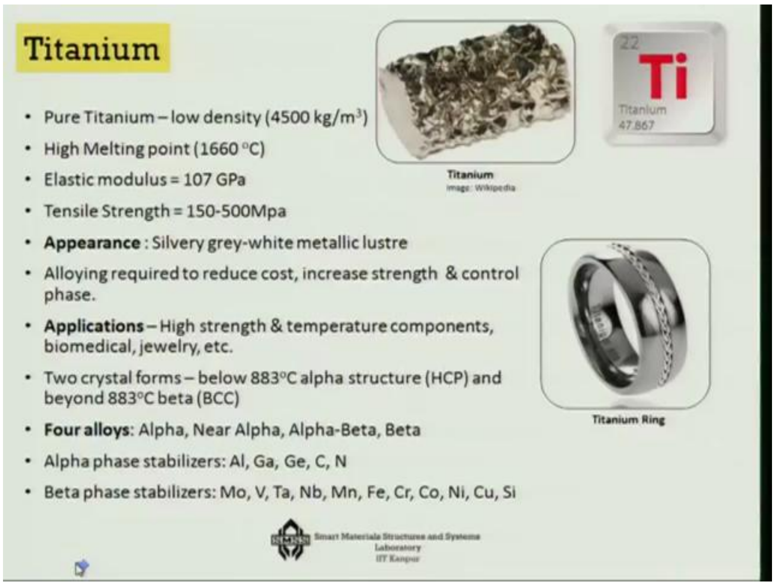

Now, the next thing that became important in terms of transport applications is actually Titanium. Its density is actually higher than Aluminium but lower than Steel, so we always say in a density scale density of Aluminium is actually less than the density of Titanium and density of Titanium is less than the density of Iron based alloys. So it is about 4500 KG per meter cube, its melting point is quite high 1660.

Elastic modulus in pure form is also higher than Aluminium, but is lower than Steel. Tensile strength is about 150 to 500MPa. It has a silvery grey white metallic lustre and its alloying is having certain typicality in it, it has a basically 3 kinds of structures. Below 883 degree it has a Alpha structure which is hexagon closed packed HCP.

Beyond 883 it has a Beta structure, now you may find out in alloys that it has either an Alpha or a Beta or near Alpha or Alpha-Beta, these 2 are actually based on presence of some amount of Beta configuration in it. Because of this excellent lightweight high-temperature and good strength, it is having applications in high strength and temperature components, biomedical applications and also in jewellery because it has good lustre as I told you.

In fact there are many aircraft applications where this is used. The Alpha phase, there are some of the materials that are generally used for stabilization Aluminium, Gallium, and Germanium or Carbon or Nitrogen, even Oxygen is used for Alpha phase stabilization. Beta phase, there is Molybdenum, Vanadium, Tantalum, Niobium, Manganese, Iron, Chromium, Cobalt, Nickel, Copper and Silicon they are used for Beta phase stabilization, so that is titanium as such.

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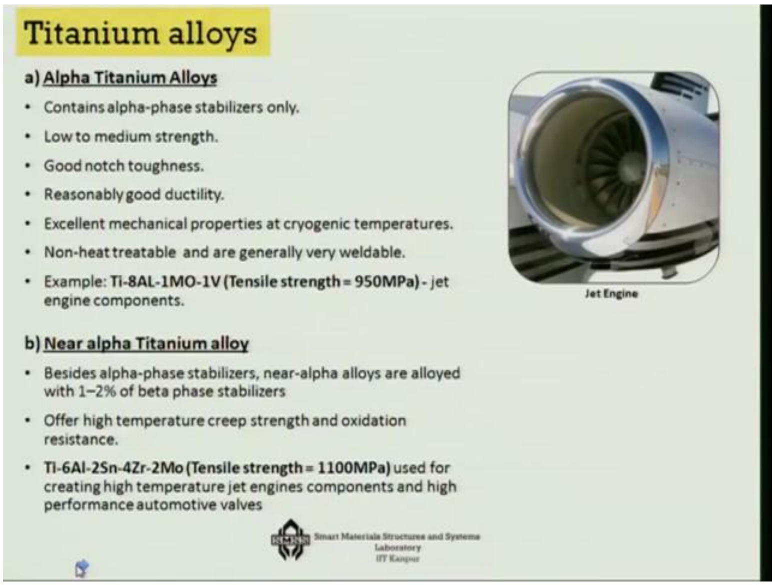

Now titanium alloys, let us talk about a little bit of them Alpha Titanium alloy to begin with that is the low-temperature phase. It contains the Alpha phase stabilizers, low to medium strength; it has good notch toughness, reasonably good ductility, and excellent mechanical properties at cryogenic temperature, but it is non-heat treatable that is the problem with Alpha series and is generally very much weldable.

So example, one of them is Ti-8AL and 1 Molybdenum, 1 Vanadium wt %, so 8% Aluminium, 1% molybdenum, 1% Vanadium and rest is Titanium, through which you can get a tensile strength of about 950MPa and that is used in jet engine components because of particularly the cryogenic temperature it has to undergo very low-temperature regions and perform, so there titanium alloy is very much useful.

The 2nd group is Near Alpha Titanium, which has not only Alpha phase stabilizer but also some amount of Beta phase stabilizer very low, 1 to 2%. They offer high temperature creep strength and oxidation resistance. One example is that about 6% Aluminium, 2% Stannum tin, 4% Zirconium, 2% Molybdenum, you get a much higher tensile strength 1100 megapascal and that is used for high-temperature jet engine components and high-performance automotive valves because it gives you a very high-temperature kind of performance.

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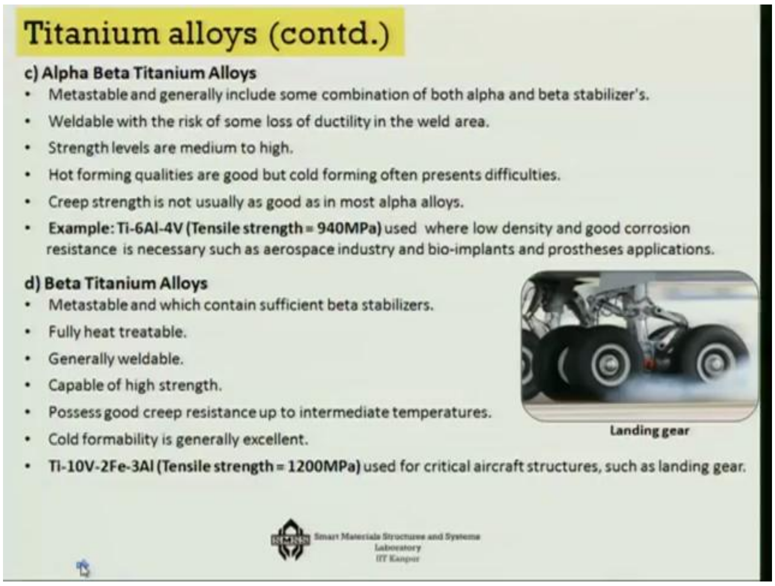

Then you have the Alpha-Beta, this one is metastable that means it is not very much stable configuration, generally includes some combination of both Alpha and Beta stabilizers. It is weldable, but if you weld there is risk of loss of some amount of ductility, Strength levels are medium to high, hot forming qualities are good but cold forming often represents difficulties. Creep strength is not usually as good as in most Alpha alloys.

One example is Titanium with 6% Aluminium, 4% vanadium, is used where low-density and good corrosion resistance is necessary such as in aerospace industry, Bio implants, prosthetic applications. Finally, the important one is the Beta Titanium alloys okay. And this one is fully heat treatable, generally weldable, it is actually capable of high strength and also it possess very good creep resistance okay up to quite a high-temperature and cold formability is generally excellent.

One of the examples is with 10% Vanadium, Iron 2% and Aluminium; you get a tensile strength of 1200MPa. This is used for many critical aircraft structures such as landing gear applications as you can see that the landing gear part many a times is made of Titanium alloys, which is a Beta Titanium alloy, so that is about the titanium alloy.

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The next is Zinc, now Zinc shares one commonality with Titanium is that this is also Hexagonally close packed HCP, but its density is very high. We are suddenly now jumping from a low-density to a reasonably high density very close to Iron, 7140. Melting point is also not very high, 420 degrees centigrade; it has a silvery grey lustrous appearance and easy castability.

Application of Zinc is mostly in terms of corrosion resistance like Galvanic coating, corrosion protection of structures and also in batteries. And you must be knowing that in our body on so you need up to very small percentage trace almost, but it is needed so that to prevent to have good immunity, brain growth, to prevent diarrhea, pneumonia and all sorts of such problems. So that is why zinc to a very small trace amount is generally needed in our body also.

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So that is the basic Zinc of course, now Zinc has many alloys which we will talk about particularly when we will discuss our other heavy nonferrous alloys. So when we will talk about nonferrous alloys, one of the best materials is actually copper. Now Copper has a Face Centered cubic structure FCC. Melting point quite high, 1085 degrees centigrade, density wise it is heavier than Steel 8920, it has a distinctive orange colour as you can see the colour okay.

It is used for all the traditional utensils and it is used because one very important thing is that it has a good corrosion resistance, so it does not get corroded very easily. The other good thing of it is that it is soft, malleable, ductile and very tough. So that means you can give it various shapes, it has a very good machinability and it has also one of the reasons why it is used for cooking systems is that it has good electrical and thermal conductivity.

In fact, in terms of thermal conductivity, the 3 materials that are generally used Silver has the highest, next is Copper, and next is Aluminium. And if it is in a very pure form like 99.99%, then it is used for electrical wires otherwise, we use it in terms of alloys. So it has about 97% conductivity of silver, but the cost of it is 1 8^{th} of Silver. So you may say that this is the poor man’s silver and that is the good part of actually copper.

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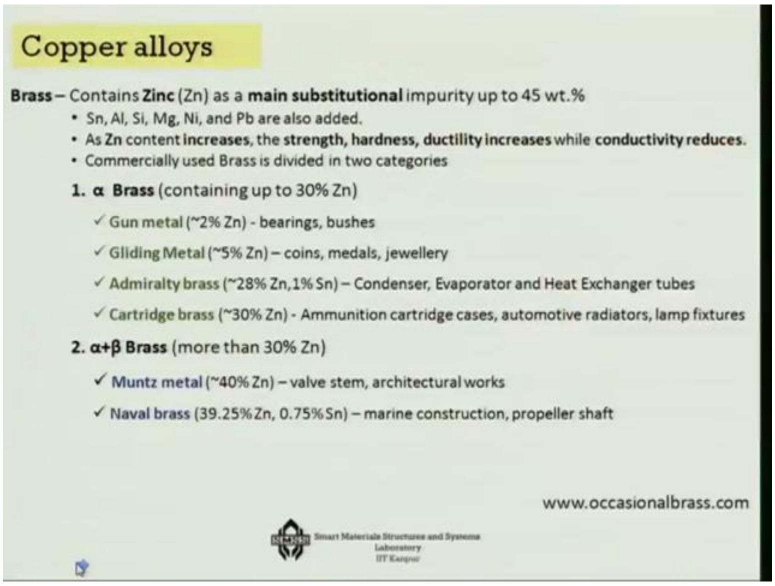

Now, what are the alloys that Copper is generally used to make, the most important one is Brass which contains Zinc earlier we talked about Zinc. And Zinc actually goes as a substitutional impurity, which means that Copper atom and Zinc atoms are of considerable size, means one can be substituted inside the lattice of the other. Also, Tin, Aluminium, Silicon, Magnesium and Nickel and Lead are also added.

And important thing about Zinc addition is that if Zinc increases, its strength increases, its hardness increases, and ductility also increases, but the conductivity reduces, it comes down. Now commercially, when we get Brass, there are 2 types of Brass one is called Alpha Brass which has about 30% of Zinc. This has many variations which for example, Gun metal which has 2% Zinc used in bearings or bushes or say Gliding metal 5% of Zinc, used in coins, medals and jewellery.

Or say Admiralty Brass, which has about 28% of Zinc, 1% of Tin which is used in condensers, evaporators, heat exchangers. Then the Cartridge Brass, which has about 30% of Zinc, it is also used in ammunition cartridge cases, automotive radiators, lamp fixtures, so the degree of Zinc in much higher in it. And if you get even higher percentage that is Alpha plus Beta Brass, you get things like Muntz metal, 40% Zinc which is used in architectural works or valve stem.

Or the Naval Brass which has Zinc as well as Tin, you get it for marine construction, propeller shaft so that these things get a very good corrosion resistance, so that is about the 2 types of Brasses that are developed from Copper.

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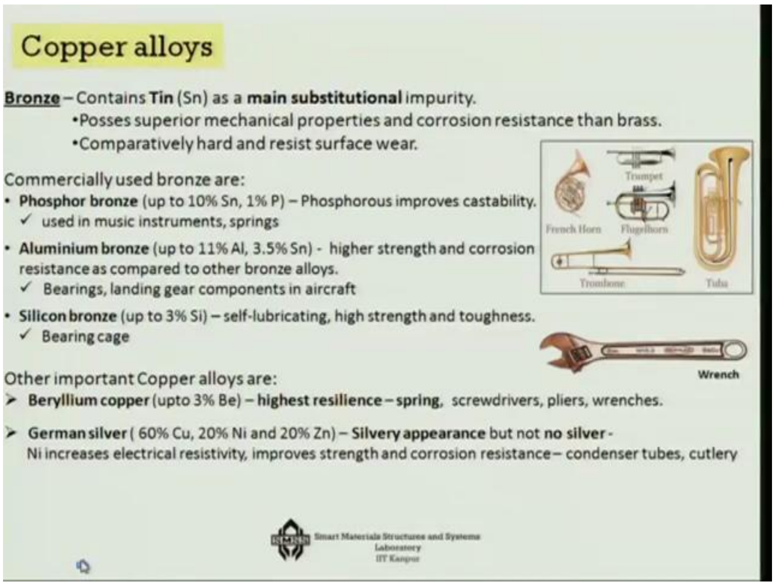

There is of course a very important variation of Copper alloy, which is Bronze. An entire part of civilisation is categorized it as Bronze Age right. So and in it instead of Zinc, Tin is the main substitutional impurity. Now this also gives a better mechanical property as well as better corrosion resistance than Brass, but it is comparatively hard and resists the surface wear.

For example, if you use the Phosphor Bronze, about 10% Tin and 1% Phosphorus, then it is used in music instruments and springs because it has a very good castability. If you go for Aluminium bronze, about 11% Aluminium and 4% Tin, you get a high strength and corrosion resistance and is used in bearings, landing gear components, et cetera.

If you go about 3% of Silicon, Silicon Bronze. It is self lubricating, high strength and toughness and hence it is generally used for bearing cages. Also, Copper has 2 relatively less used, but important other alloy Beryllium Copper. It has highest resilience, so it is used for springs, screwdrivers, pliers, wrenches, et cetera.

And the German silver which is about 60% Copper, 20% Nickel and 20% Zinc, this one looks like silver, it has silvery appearance, but it is not silver okay, so that is because it is Copper, Nickel and Zinc. And nickel increases the electrical resistivity, improves strength and corrosion resistance, so it is not only used for this type of things, but also used for condenser tubes, cutleries, et cetera. The German silver which has considerable amount of Coppers, amount of Nickel and some amount of Zinc in it, so that is about the Copper alloys. Next we are going to talk about nickel.

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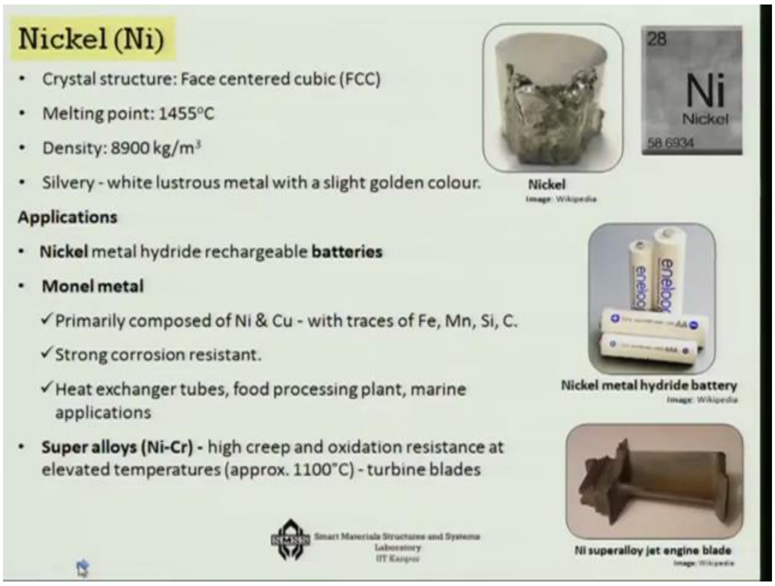

Now, Nickel is also even higher density in comparison to Copper 8900, but it has also similar FCC structure and the melting point is pretty high 1455 degrees centigrade. It is also silvery white lustre of metal, metallic lustre that is why, when it is used with Copper this lustre predominates and you get German silver out of it.

And application wise it is used nowadays very much in batteries and also in some alloys with Copper like one is very famous Monel metal primarily composed of Nickel and Copper with traces Of Iron, Manganese, Silicon and Carbon. It has a strong corrosion resistance and it is used in heat exchanger tubes, food processing plants, marine applications, et cetera, wherever there is a chance of corrosion and this is of very good use.

Of course, the other use of Nickel is in super alloys. Super alloys are something which is used in jet engine blades and it for that you need a high creep and oxidation resistance at a high temperature like 1100 degrees centigrade and there Nickel-Chromium alloys work in a fantastic manner, so these are the super alloys when Nickel is basically used. Next we are going to talk about Cobalt okay.

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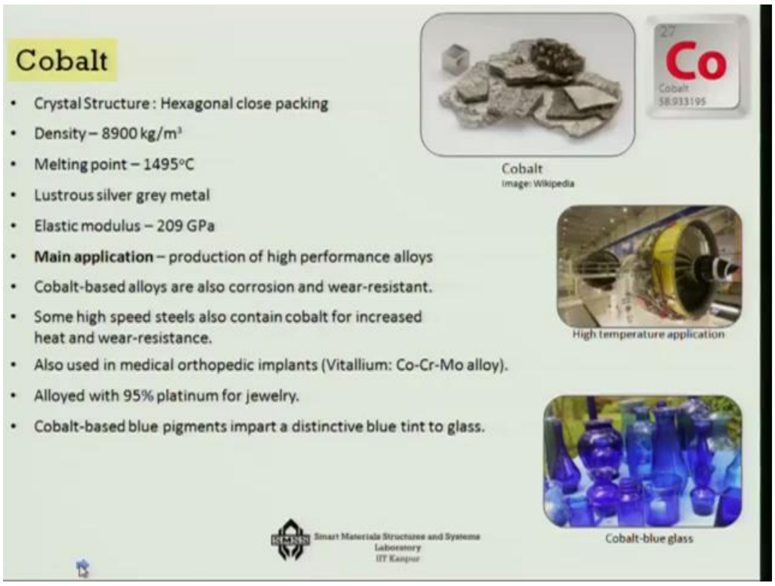

So Cobalt already we have seen that it is used for example with Steel as an alloy or also with other metals, but on its own Cobalt has had the Hexagonal close packing HCP. Density similar to Nickel 8900, melting point also is very high and the lustre is silver grey, elastic modulus is about 209 gigapascal consider about like Steel, main application is for high performance alloys particularly when just like Nickel and Zinc you need a corrosion and wear resistance, the Cobalt comes into picture.

Some high-speed Steels contain cobalt, I already talked about them for heat and wear resistance, some medical orthopedic implants, Cobalt, Chromium and Molybdenum together, there is a Vitallium which is used in medical orthopedic implants and they are sometimes alloyed with Platinum, 95% Platinum and 5% Cobalt for jewellery applications.

Interestingly, it is also having some uses with ceramics, glasses, gives a distinctive blue tint Cobalt blue glass, Cobalt is also used. So basically it has high-temperature anticorrosive applications. Now finally, so far we have talked about various types of nonferrous alloys, but all of them are having crystal structures like Hexagonal close pack structure or FCC structure.

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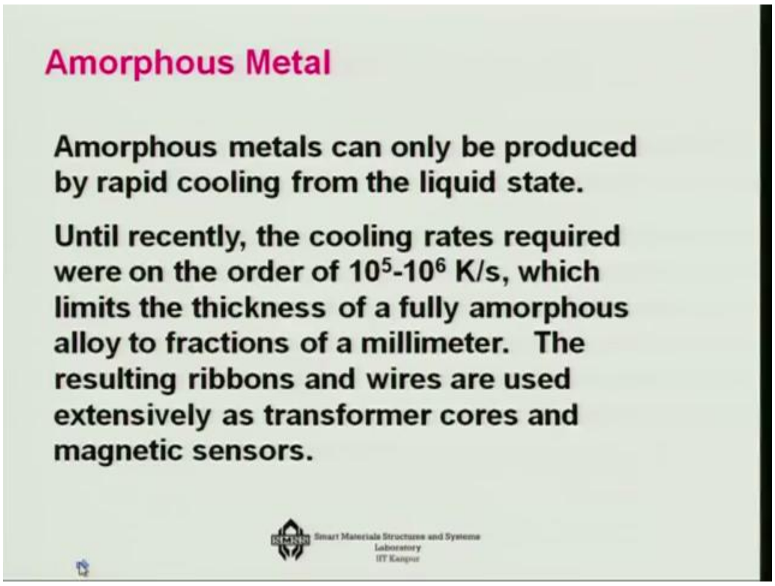

Now can metal not have an amorphous shape that is, can we not have metals which has no regular crystal structure? Yes we can, but to do that you have to have a rapid cooling from the liquid state. Now, until recently the cooling rate required is of the order of 10 to the power 5 to 10 to the power 6 Kelvin per second so, so fast you are supposed to cool it if you want to really make a metal amorphous.

So naturally even if you can make it, you can make it something like a fraction of a millimeter thickness that means you can make some ribbons and wires, etc, which you can use for transformer cores or as magnetic sensors. Why should we be going for amorphous state is because with the amorphous shape, we are supposed to get more machinability, the ductility, et cetera okay while sacrificing some of the properties maybe like the thermal resistance or conductivity.

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Now the bulk metallic glass is something which its cooling rate is bought down to something like 1 to 100 Kelvin per second and that is possible because of some kind of eutectic mixture that you are that today we can do for preparing this. For example, you can see that this is a Bulk Metallic Glass structure and you can see that in the same picture that there is no grain okay unlike this polycrystalline metal structure, where you can see that so many grain boundaries of there.

So as there are grain boundaries what we are going to get, one is that we are going to get the dislocation resistance, dislocation cannot spread across the boundaries, which means that you are going to get resistance in terms of really forming the system and on the other hand, in this particular case you can get a very good formability of the system.

But you are going to keep sound the good properties of the metal like good elastic modulus; you are also going to get better properties in terms of some of the things like the resistivity of the system, etc. So that is how the bulk metallic glass is coming out to be a very good material which can be used for some of the very specific applications where instead of ceramics because ceramics are brittle. That brittleness is not there in metals, so that is where you can actually substitute it.

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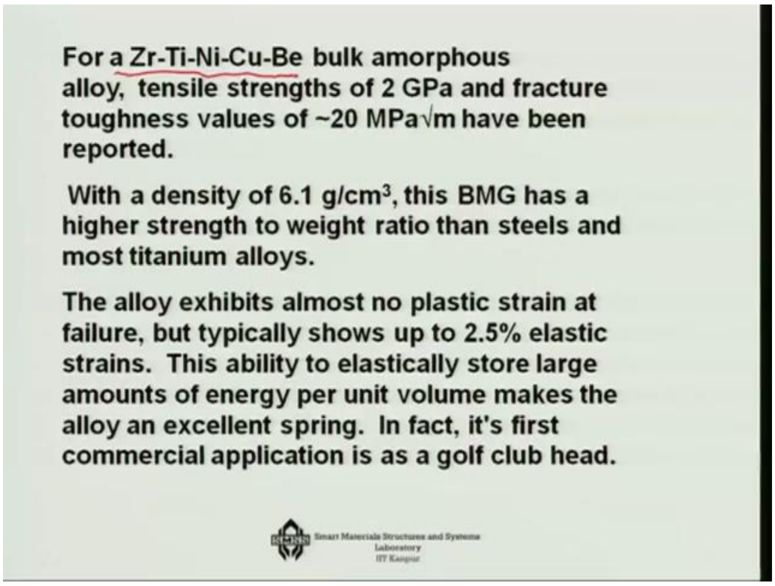

This is one of the examples that if you use the Zirconium, Titanium, Nickel, Copper and Beryllium in terms of a mix and then if you use this rapid cooling technique, you get a tensile strength of about 2GPa. And the fracture toughness, you get high fracture toughness, 20 megapascal square root meters. And the density is much lower, so that is another advantage of an amorphous state; the density is about 6.1% cube.

And this alloy exhibits almost no plastic strain at failure, but typically shows up to 2.5% elastic strains. So that you compare with metals generally, it is something like 0.1%. So the elastic strain becoming 2.5% is a very high value. In fact, its first commercial application was in golf club head, so that is the good part of the Bulk Metallic Glass.

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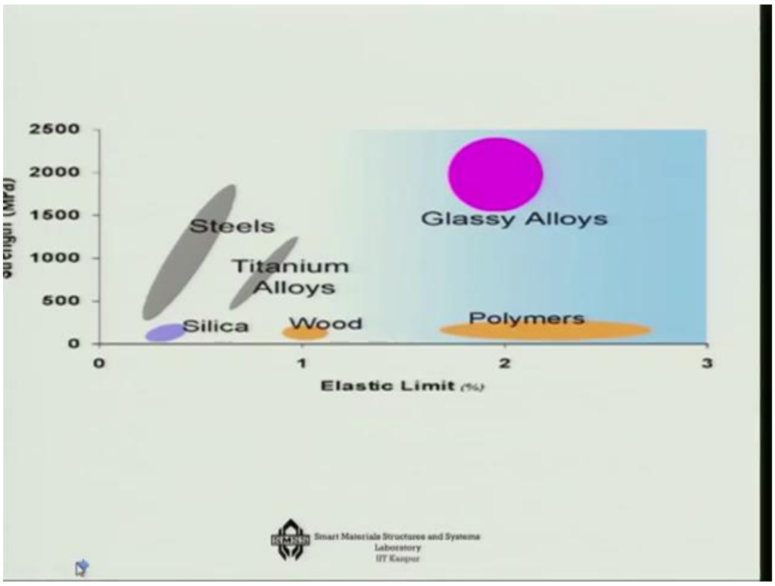

So in this last picture if you look at it that in terms of strength if you can make the glassy alloys, you are going much higher above the Steel that is where the advantage of the glassy alloys is. And if you look at the percentage strain also, you can go much higher above the Steel Aluminium, et cetera, something like which we can compare only with polymers.

So that is the good thing of it that you get a much higher level of strain, but very high level of strength, so that combination makes the glassy alloys like Bulk Metallic Glasses to be a very unique new material. This is where we are going to put an end of our metallic alloys okay, so in the next lecture we are going to come up with metal strengthening and metal corrosion, thank you.