

Basics of Mechanical Engineering-2

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Week 01

Lecture 04

Engineering Materials (Part 3 of 3)

Welcome to the next lecture on Engineering Materials. Till now, we have gone through the basics and classification of materials.

Contents



- Introduction
- Key characteristic
- Classification of non-ferrous materials and alloys
- Aluminium and its alloys
- Copper and its alloys
- Zinc and its alloys
- Nickel and its alloys
- Lead and alloys
- To recapitulate

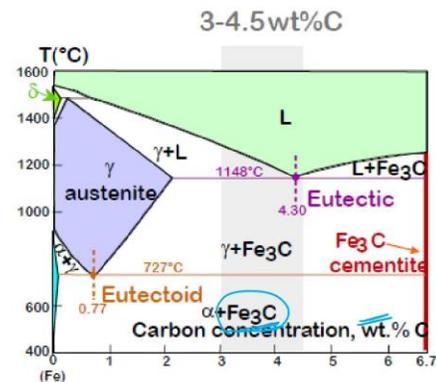


In this lecture, we will try to see the majority of them on non-ferrous structures or non-ferrous materials. First, we will have a brief introduction. Then, we will cover key characteristics.

Then, the classification of non-ferrous materials and alloys. The majority of the classifications include aluminium, copper, zinc, nickel, and lead. Titanium is also there, but I have just given you a glimpse of the entire spectrum of materials. Finally, there will be a small recap. When we move out of the iron-iron carbide diagram or from ferrous materials to non-ferrous materials, cast iron is one element that is very predominant.

Cast Iron

- The cast irons are the ferrous alloys with greater than 2.14 wt. % carbon, but typically contain 3-4.5 wt. % of C as well as other alloying elements, such as **silicon** (~3 wt.%) which controls kinetics of carbide formation.
- These alloys have relatively low melting points (1150-1300°C), do not form undesirable surface films when poured, and undergo moderate shrinkage during solidification. Thus can be easily melted and amenable to **casting**



It has been used in the past for several applications. Utensils have been made, bases have been made, and statues have been made. Cast iron has been there for quite some time. During the industrial revolution, many machine beds were made out of cast iron. For several applications, they noted that toughness is very good, and it has lubrication properties, among other things.

So now, let us try to understand what Cast Iron is and where it comes from. When you go back to the iron-iron carbide diagram, if you see carbon content more than 2.15, I will put it here somewhere; it is 2.5, so 2.15. Anything above 2.15 to somewhere around 4.5, This area is called Cast Iron. So the difference is, in iron, you try to diffuse carbon, you keep on diffusing carbon, and it becomes Cast Iron.

So when you see a blacksmith, what he does is he takes a piece of steel, puts coal all around it, and starts burning the coal. So many times what happens when the coal starts

burning is that the iron gets into a red-hot condition. There is always a diffusion of carbon from the charcoal into the iron. So that is called Fe₃C. So, ferrous carbide.

So, this is Fe₃C, a compound which is formed or an alloy which is formed by the diffusion of carbon into iron. So, Cast Iron are the ferrous alloys with greater than 2.14 weight percentage of carbon but typically containing 3 to 4.5 weight percentage of carbon. So it is not only carbon; there are other alloying elements which are also added, like silicon. So this tries to control the kinetics of carbide formation. So, when I said C here, iron cementite, Fe₃C cementite, right?

Fe₃C is cementite. So, you can see here Fe₃C is formed, okay? So, these alloys have a relatively low melting point, do not form undesirable surface films when poured, and undergo moderate shrinkage during solidification, thus they can be easily melted and are amenable to casting. When we take metal to a molten state, then when it is poured into a die or into a mold, it will always demonstrate a property of shrinkage. If the shrinkage is very large, then it becomes too difficult to control the geometry of the output.

Whereas here, the interesting part is that the cast iron alloys have a relatively low melting point and do not form undesirable surface films. What are the surface films? Like oxidation forming, a slurry forming, or a sludge forming, or a thin layer on the top which is forming, which is undesirable because when you try to pour it, this layer also tries to chip in along with the material and gets into the mold or in the die, creating a defect. So cast iron does not form any undesirable surface films when pouring and undergoes moderate shrinkage during solidification.

Cast Iron



- (CI)
- CI is a type of iron that contains more than 1.7% carbon, usually in between 2% and 4.5% C.
 - The pig iron is mixed with scrap of iron and steel to produce CI.
 - Its produced by cupola furnace.
 - CI is the cheaper metallurgical material available to the engineer.
 - CI is hard and brittle.



The cast iron, which is also called by the acronym CI, is a type of iron that contains more than 1.7% carbon, usually between 2% and 4.5%.

The pig iron is a mixture with the scrap of iron and steel to produce cast iron. So, generally, the cast iron is produced in a cupola furnace. Cast iron is the cheaper metallurgical material available to engineers. Stainless steel and all need refinement. In the process of generating iron, the pig iron from pig iron to cast iron, they all go by that.

When carbon is reduced more and more or refined more and more, you get mild steel, low carbon steel, and stainless steel. Cast iron is hard and brittle. So it will always be used at the base. So there will not be much elastic load or fatigue load on it.

Type of Cast Iron

- Ferrous metal containing about 2%–4.5% carbon is called CI.
- There are several kinds of CIs, each having some specific properties.
- These are listed as follows:
 1. Grey CI ✓
 2. White CI ✓
 3. Mottled CI ✓
 4. Malleable CI ✓
 5. Spheroidal CI ✓
 6. Spongy CI ✓
 7. Chilled CI ✓
 8. Inoculated CI ✓

There are multiple types of cast iron. The ferrous cast iron is obtained between 2 to 4.5% of carbon, which is called CI. So the list of CI includes grey cast iron, white cast iron, mottled cast iron, malleable cast iron, spheroidal cast iron, sponge cast iron, chilled cast iron, and inoculated cast iron. So you have different types of cast iron. We will see one or two of them in detail.

Strength in Cast Iron

- Tensile strength = 250 MPa
- Poisson's ratio = 0.17
- Shear modulus = 51 GPa
- Compressive strength = 1000 MPa
- Tensile modulus = 110 GPa

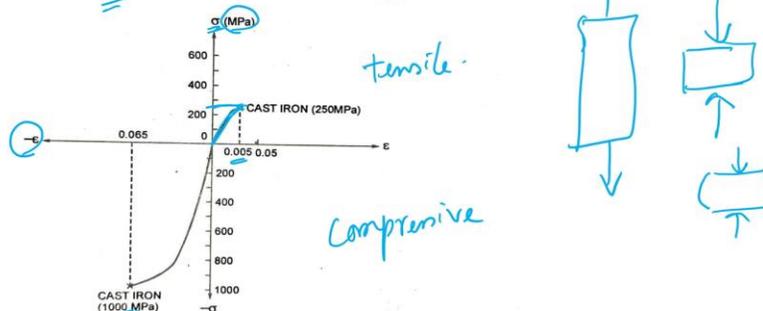


Fig. 11.5 Stress-strain curve of grey cast iron in tension and compression

So the strength of cast iron, if you see, the y-axis is a plot of stress, and the x-axis is a plot of strain.

So on the x-axis, you can see the plot of strain. So when you look into it, you can see the cast iron ultimate tensile strength is around 200 or 250 MPa. The tensile strength is around 250 MPa. The compressive strength is around 1000 MPa. So here it is tensile load, and here it is compressive load.

When you try to stretch the cast iron, you will get 250 MPa. When you try to compress it, you get 1000 MPa. So it is very clear that cast iron can be used for compressive loads. And here, the strains, if you see, are around 0.005. And when you see in compression, it is 0.065.

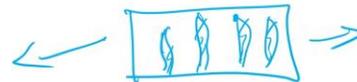
So what happens is, it tries to bulge and then it tries to break. So the shear modulus is around 51 GPa. The compressive stress is around 1000 MPa. And the tensile modulus is around 110 GPa. The Poisson's ratio value is around 0.17. So it is better for compression compared to tension.

Grey Cast Iron

Temp



- Grey CI is obtained when CI is cooled slowly from the molten state.
- The combined carbon then has time to separate out and to remain present in free graphite form.
- Grey CI has a low tensile strength because of the presence of graphite flakes at the crystal boundaries. Gray iron has a gray fracture surface with finely faced structure. A large Si content (2-3 wt. %) promotes C flakes precipitation rather than carbide.
- It is also self-lubricating and absorbs vibrations, has good resistance to compressive loads and is used for making frames that are not subjected to shock loads.
- It can be used in a cast form only and is not suitable for hot or cold working due to high carbon content.
- It can be welded, but with difficulty. It is commonly known as graphitic CI and finds maximum use among all other kinds of CIs.
- It contains flake form of graphite whose tips are sharp. Due to sharpness of tips, they become source of stress concentration. This makes strength of CI poor and is responsible for its brittle nature.



Grey cast iron is generally obtained when cast iron is cooled slowly from the molten state. So temperature is the only game changer that tries to bring in all these modifications. So slow cooling leads to grey cast iron. The combined carbon then has time to separate out and remain present in free carbide form.

So, what happens when it is slow cooling? The carbon will have time to get separated out, and it will remain as graphite in green forms. The grey cast iron has low tensile strength because of the presence of flakes. What do you mean? So, suppose you have a piece, and you have flakes. These are all graphite flakes.

So, naturally, when you see these places, there is a discontinuity in the material. So, it will yield or it will have poor tensile strength when you try to pull it. The presence of graphite flakes at the crystal boundary. The grey iron has a grey fracture surface. When you break it, it will give a grey color.

So, that is why it is called grey cast iron. It has a grey fracture surface with a finely faced structure. As I told you, Si is added to promote carbon flakes precipitates rather than carbide formation. If the carbide tries to diffuse into iron, it forms carbides. If it is not allowed, then it forms these flakes, graphite flakes.

So, these graphite flakes, graphite has very good lubricating properties. So, it is self-lubricating, absorbs vibrations, and has good resistance to compressive loads. It can be used only in cast form and is not suitable for hot or cold work due to its high carbon content. When you try to work with it, hot working, cold working, and all, it does not happen. It can be welded, but it is very difficult.

It contains flakes formed of graphite, whose tips have sharp corners. So, due to these sharp corners, the sharp tips become sources of stress concentration leading to failure.

Grey Cast Iron



- The grey CI is very strong in compression, but poor in tension.
- Due to its grey colour, it is called grey CI.
- In CI carbon remains mainly in graphite form.
- It can be given almost any desired shape.
- Since the graphite is an excellent lubricant, the grey CI can be easily machined, and the chips break off readily.
- However, brittleness, lack of ductility and poor shock resistance prohibit their use in parts subjected to high tensile stress or suddenly applied loads.



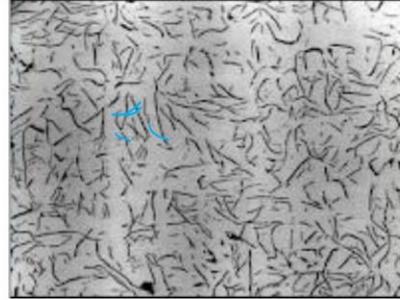
Grey cast iron is very strong in compression, which we have already discussed. It gives you a grey color, which we have also discussed. Graphite is formed instead of carbides.

It can be given any desirable shape. The only thing is, you should be very careful with the surface-to-volume ratio. The surface-to-volume ratio means that the volume of the material should be sufficient enough compared to the surface area. Since graphite is an excellent lubricant, grey cast iron can be easily machined. However, brittleness leads to a lack of ductility and poor shock resistance, which always tries to put a limitation on the use of this material in engineering.

Grey Cast Iron



- Grey CI containing about 2%–4.5% C.
- The structure is marked by the presence of graphite flakes in ferrite/pearlite matrix.
- In the microstructure, the black image is of graphite flakes and the white image is of ferrite matrix.
- The graphite flakes are of about 0.05–0.1 mm length and occupy approximately 10% of the metal volume.



50 to 100 microm



https://malayasteel.blogspot.com/2011/04/graphite-structures-in-cast-irons_6779.html

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This is how Grey Cast Iron looks. The structure is marked by the presence of graphite. You can see here, these are all graphite. In the microstructure, the black image is of graphite flakes, and the white image is of the ferrite matrix. Ferrite is iron-dominated. The graphite flakes are about 0.05 to 0.1 millimeters, that is to say, 50 to 100 microns in length, and approximately 10% of the metal volume.

White Cast Iron



- It comprises of cementite phase.
- White iron has a characteristic white, crystalline fracture surface. Large amount of Fe₃C are formed during casting, giving hard brittle material.
- White CI is obtained when CI is cooled rapidly and the carbon does not get time to separate out.
- It is hard and brittle.
- It can be machined by grinding only.
- White CI has a more even distribution of carbon within its structure and is heated for a prolonged time in the presence of iron oxide to reduce the carbon content.
- It is used to produce malleable CI.
- Due to the presence of cementite, it is extremely hard besides being strong and brittle.



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So White Cast Iron comprises the cementite phase. Grey is graphite, white is cementite. White Cast Iron has a characteristic; it is also called White Iron. White Iron has a characteristic white and crystalline fractured surface. It has a large amount of Fe₃C formed during casting.

It is very hard and brittle. The moment you have more of the cementite phase, it always increases the hardness. So, wherever you want to have wear resistance property, especially on moving surfaces, you would prefer to use White Cast Iron over Grey Cast Iron. White Cast Iron is obtained by rapidly cooling cast iron; grey is obtained by slow cooling. Rapid cooling of cast iron leads to cementite. That is to say, it tries to move inside and freeze, and the carbon does not get time to separate out.

It moves inside iron; it is frozen. It is hard and brittle. It can be machined but not with a heavy depth of cut. For example, if you want to chisel and make a statue, it is very difficult to do using White Cast Iron. It is easier to make with Grey Cast Iron.

White Cast Iron has a more even distribution of carbon within its structure and is heated for a prolonged time in the presence of iron oxide to reduce the carbon. So it is used for producing Malleable Cast Iron. In the presence of cementite, it is extremely hard. So now, we saw hard.

Malleable Cast Iron



- It is produced from white CI on prolonged heating at 900°C followed by slow cooling. Due to this process, cementite decomposes to ferrite. Content of Si is kept less than 1% so as to avoid graphitization.
 - In malleable CI, the edges of graphite flakes act as stress raisers and the heating process changes the size and shape of flakes, making the material more ductile and malleable.
 - Malleable CIs are a cheap substitute of steel forgings and are often used for pipe fittings.
 - Pearlitic malleable CI has an increased manganese content (about 1%), which acts as carbide-stabilizing element and improves the shock-resistant properties.
- **It is used as-**
1. Parts of agriculture machinery and implements ✓
 2. Pipe fittings, Parts of railway rolling stock ✓

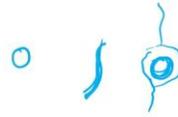
Next, let us see Malleable Cast Iron. It is produced from White Cast Iron. That is the source. With prolonged heating at 900 degrees Celsius followed by a slow cooling process. So you have already formed a White Cast Iron, in which you have not given enough time for the carbon to move and form graphite. Now, what you do is, you take that and then heat it up to 800 and 900 degrees Celsius for a prolonged time, followed by slow cooling.

Due to this process, cementite, which is formed, tries to decompose into ferrite. And the silicon, which is kept, is less than 1% so as to avoid graphitization. So silicon also plays an important role in avoiding graphitization. So, then this cast iron becomes easy for doing malleable or ductility operations. In malleable cast iron, the edges of the graphite flakes act as stress risers, and the heating process changes the shape and size of the flake, making the material more ductile and malleable.

So it is cheap and a substitute for steel forging, and it is used for pipe fitting. In those days, you can see malleable cast iron pipes were made for big pipes. The pearlitic malleable cast iron has an increasing manganese content up to 1%, which acts as a carbon stabilizer and improves the shock resistance property. So, because of this, it has been used in agricultural machinery as well as pipe fittings. So, grey cast iron is used for the base.

White cast iron is very hard. Malleable cast iron, which is used for making machinery and implements, can take toughness as well as being better than cast iron.

Spheroidal Graphite Cast Iron (or Nodular CI)



- It contains graphite in the form of spherical nodule. Since there are no sharp tips, condition of stress raiser does not exist, and brittleness is unnoticed.
- Spheroidal CI is produced by adding Mg or Ce to molten iron. Content of Si is about 2.5% in it.
- This has good casting properties and better mechanical properties than the grey CI.
- Spheroidal Cast iron can be partially hot- or cold-worked, machined or welded.
- It is a good substitute for steel forgings.
- **Its uses** include crankshafts, pump cases, gears, etc.

Spheroidal cast iron or nodular cast iron. It contains graphite in the form of spherical nodules. So what was like this in the grey cast iron now is going to be made into spheres.

Since there are no sharp edges in these spheres formed, the condition of stress risers does not exist, and the brittleness is unnoticed. So, if at all you have a crack, the crack goes here and then goes around this pure spheroidal nodule and then continues. So, there is a lot of relaxation of stress, whatever is there. The Spheroidal Cast Iron is produced by adding Mg or Ce to the molten iron. The content of Si is up to 2.5%.

It has good casting properties and better mechanical properties. We always go for Spheroidal Cast Iron when we are trying to make a bell or something like that. The Spheroidal Cast Iron can be partially hot or cold worked, machined, or welded. It is a good substitute for steel forging. It is used for crankshafts, pump casings, and gears, etc.

Spheroidal Graphite Cast Iron was used in the initial days for water mills or wherever we had a gear, heavy gear, bull gear, wherein they had an opening and closing of a gate, they used Spheroidal Casting. It was very heavy. The pump casing was also made out of it.

Wrought Iron



- Wrought iron is refined pig iron with a low carbon content, less than 0.1% and usually approximately 0.02%.
- Its purest form of iron.
- It is produced in less quantities because of relatively high cost.
- Wrought iron is very ductile because of its low carbon content.
- It can be easily worked and welded although machining is more difficult.
- It is tough and resistant to atmospheric corrosion.
- It is used in those applications where a visual warning of failure is required, such as link chains where overloading causes a considerable increase in length of the links.



Wrought Iron. Wrought iron is refined pig iron, where the carbon content is very low, less than 0.1%, and usually approximately 0.02%. It is the purest form of iron. Why do you need the purest form of iron? You need it because after that, you can start playing with the properties. It is produced in smaller quantities because it is relatively costly.

So you have a nascent material. From the nascent material, now you add whatever you want: silicon, magnesium, manganese, cerium. Anything you want, you keep adding to it. So, wrought iron is very ductile because it has low carbon content. So, carbon is the key player there.

It can be easily worked, although machining is very difficult. It is tough, and it also has corrosion resistance properties. It is used in applications where a visual warning of failure is required, such as link cranks, where overload causes a considerable increase in the length of a link. So, slowly it will get stretched because it has ductility properties.

Wrought Iron



- Wrought iron is a mechanical mixture of pig iron and uniformly distributed silicate slag.
- It possesses the important properties of ductility, malleability and toughness.
- It is suitable for machine parts to be shaped by forging.
- It also has excellent welding properties.



Wrought iron is a mechanical mixture of pig iron and uniformly distributed silicated slag. It has an important property of ductility, malleability, and toughness. I am sure, by this time, you will be able to distinguish between the ductility property and the malleability property. It is suitable for machine parts, as it has excellent welding properties. The reason why the welding property is always discussed is that when you want to make a large, massive structure, it is too difficult to produce through casting.

So, you will make small, small pieces and try to join them. So, when you try to join them, welding becomes a very important process. So, whether the material allows joining similar-similar material or similar-dissimilar material.

Introduction to Non ferrous Alloys



- Non-ferrous materials are metals and alloys that do not contain iron in significant amounts.
- These materials are distinguished by their unique set of properties, making them invaluable in various industrial applications.
- They are widely recognized for their corrosion resistance, which makes them ideal for use in harsh environments.
- Their lightweight nature is critical in industries like aerospace and automotive, where weight reduction directly impacts performance and efficiency.
- Additionally, their high electrical and thermal conductivity ensures their extensive use in electrical systems, electronics, and renewable energy technologies.



Now, let us move on to other non-ferrous alloys. The other non-ferrous alloys are aluminium, titanium, chromium, copper, magnesium, nickel, cobalt, and lead.

All these are other non-ferrous alloys. They also play a very important role, depending on the requirements. Non-ferrous materials are metals and alloys that do not contain iron in significant amounts. Maybe a few traces can be present. It is not that Fe will not be present.

Fe traces will be there, but predominantly it will not have iron. These materials are distinguished by their unique set of properties. We will see the unique set of properties in the upcoming slide. Their corrosion resistance property is very important, which makes them ideally suited for harsh environments. It can be used for making a container in a saline atmosphere.

It can be an underwater tank or something similar. It can be a sewage tank. All these things are corrosive environments. Their lightweight nature is critical in industries like aerospace and automobile. Additionally, electrical properties and thermal conductivity ensure their use in electrical systems, electronics, and renewable energy technology.

Today, what we are trying to do is, when we try to make a holder, an electrically conducting as well as a strength-giving member. So if these two can be blended together,

then it gives wonderful properties as well as being lightweight. Where will it be used? For example, a kettle. The electric kettle.

An electric kettle has to be lightweight, it has to be corrosion-resistant, it has to have electrical properties, and it also has to have thermal conductivity. So, all these things are to be brought together in one place.

Introduction to Non ferrous Alloys



- Non-ferrous materials are non-magnetic, a property that enhances their suitability for sensitive applications in electronics and precision instruments.
- Their malleability and ductility allow for complex shaping and forming, supporting innovation in design and manufacturing.
- These highly recyclable materials maintain the quality through repeated cycles, contributing significantly to sustainable practices and resource conservation.
- Due to these versatile properties, non-ferrous materials are crucial in advancing technologies in construction, energy, transportation, healthcare, and marine engineering, solidifying their position as fundamental components in modern engineering and technology.

So, non-ferrous materials are non-magnetic, which enhances their suitability for sensitive applications in electronics and precision instruments. See, the non-magnetic property is very important. When you try to pass current through a coil, it will try to generate EMF. So this EMF, or electromagnetic induction, will try to hamper the performance of nearby equipment.

So, the non-magnetic properties are very important. Their malleability and ductility allow for complex shaping and forming. These highly recyclable materials, compared to cast iron alloys, are easier to recycle because the temperatures are very low, and you can have better control. These highly recyclable materials maintain their quality through repeated cycles. So, the first time you recycle, you still get almost similar properties.

So, they contribute significantly to sustainable practices. Due to their versatile properties, non-ferrous materials are crucial in advanced technology, construction, energy,

transportation, healthcare, marine engineering, solidifying their position as a fundamental component in modern engineering and technology. So, more and more materials used today are non-ferrous materials.

Introduction



Non-ferrous material in powder form

Types Of Alloy Metals



Products of Non-Ferrous alloy



So, when you look into all the alloys, zinc alloy, aluminum alloy, magnesium alloy, copper alloy, chromium alloy, and titanium alloy are all there. So, each of them finds its own niche in its own areas.

For example, bronze, brass, copper combinations, aluminium, then you can have nichrome, titanium Ti6AlV4, beryllium copper, nickel, then you will have copper nickel, then you will have niobium.

Aluminium (Al)

The primary ore of aluminum (Al) is bauxite, a sedimentary rock that contains aluminum minerals:

- Gibbsite ($\text{Al}(\text{OH})_3$) ✓
- Boehmite ($\gamma\text{-AlO}(\text{OH})$) ✓
- Diaspore ($\alpha\text{-AlO}(\text{OH})$) ✓
- Kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) ✓
- Goethite ($\text{FeO}(\text{OH})$) ✓
- Hematite (Fe_2O_3) ✓
- Anatase (TiO_2) ✓
- Ilmenite (FeTiO_3 or $\text{FeO}\cdot\text{TiO}_2$) ✓



So, when we talk about aluminium, the primary ore of aluminium is bauxite. It is a sedimentary rock that contains minerals like $\text{Al}(\text{OH})_3$, $\gamma\text{-AlO}(\text{OH})$, $\alpha\text{-AlO}(\text{OH})$, $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$, FeOOH , Fe_2O_3 , TiO_2 , and FeTiO_3 . So, these are all part of the sedimentary rock like bauxite, where they try to use it as a starting raw material and then refine it to get aluminium.

Aluminium (Al)

Characteristics

- **Lightweight:** Aluminum has a low density, making it one of the lightest metals, ideal for applications where weight reduction is crucial.
- **Corrosion Resistance:** It forms a protective oxide layer, making it resistant to corrosion, especially in marine and industrial environments.
- **Malleability and Ductility:** Aluminum can be easily shaped and formed, allowing for versatile manufacturing.
- **High Strength-to-Weight Ratio:** It can be alloyed to enhance strength while remaining lightweight, ideal for aerospace and automotive uses.
- **Recyclable:** Aluminum can be recycled endlessly without losing its properties, promoting sustainability.

So, aluminium has multiple properties, and these properties can be common for almost all non-ferrous alloys. Lightweight, except for certain ones, for example, lead alloys are heavy, but apart from that, they are all lightweight. Aluminium is lightweight and low density, making it one of the lightest materials. Corrosion resistance because it quickly forms an oxide layer on the top, which protects it from corrosion. Malleable and ductile, it can be given a shape and drawn into a wire. High strength-to-weight ratio.

So, because it is lightweight, for this lightweight, whatever strength we have is very high. Then it is recyclable.

Aluminium (Al)/Ti/Mg

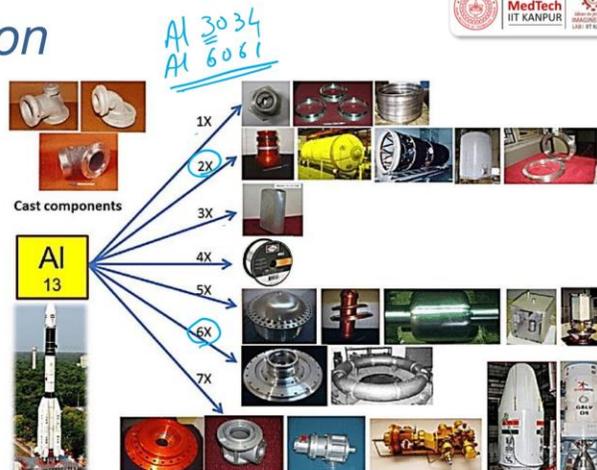
Applications:

- **Aerospace:** Used in aircraft and spacecraft components due to its lightweight and high strength.
- **Automotive:** Used in car body parts, wheels, and engine components to reduce weight and improve fuel efficiency.
- **Construction:** Utilized in window frames, doors, roofing, and structural components for its corrosion resistance.
- **Electrical:** Commonly used in electrical wiring and power transmission due to its good conductivity.
- **Packaging:** Widely used for making cans, foil, and other packaging materials because it preserves food and is recyclable.



It finds its application; aluminium, titanium, magnesium, all these find a huge application in the aerospace industry, automotive industry, construction industry, electrical industry, and packaging industry. All of these three, aluminium alloys, titanium alloys, magnesium alloys, they almost have very similar properties like this.

Aluminium Application



https://link.springer.com/chapter/10.1007/978-981-10-2134-3_2

https://www.researchgate.net/figure/Spectrum-of-aluminium-alloys-used-in-space-applications-Practically-every-grade-of_fig3_358484374 59

So, when you talk about aluminium alloy, it is always Al 3034 or 6061. So, aluminium will always be, aluminium alloy will always be given a code. So, this code represents the 1x, 2x, 3x, 4x, 5x, 6x, 7x. So, this x is given. So, this is 1, 2, 3, the base number 1, 2, 3, 4, 5. x is the other three combinations, right? So, depending upon the aluminium alloy 1X, 2X code, 3X code, they are finding a lot of applications.

Generally, we will try to prefer aluminium 6X code because it finds a lot of applications or 2X code, right. 2X is 2021, 6061, something like that.

Aluminium (Al) Alloys

Aluminium-magnesium alloy (5-10% Mg, 90-95% Al)

Characteristics:

- Lightweight with high strength-to-weight ratio.
- Excellent corrosion resistance (marine environments)
- Good weldability and formability.
- Non-magnetic, resistant to stress corrosion cracking
- Non-toxic and safe for use.



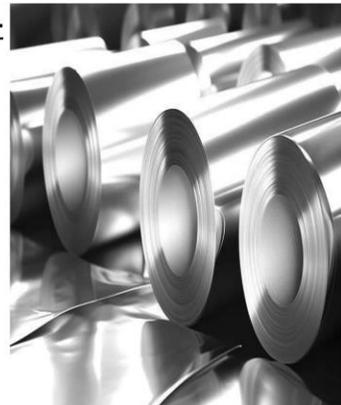
So, aluminium magnesium alloys in which 5 to 10 percent of magnesium is added, 90 to 95 percent is aluminium. This is extensively used for making aluminium wires. So, lightweight with high strength ratio, excellent corrosion resistance, good weldability and formability, non-magnetic resistance to stress corrosion, crack, etc. It is non-toxic, so it is finding a lot of applications.

Aluminium (Al) Alloys

Duralumin (4-5% Cu, 0.5-1.0% Mg, 0.5% Mn, 94-95% Al)

Characteristics:

- Age-hardening for increased strength over time.
- Superior stress and impact resistance.
- Lightweight with exceptional strength.
- High toughness under heavy load.



When we see aluminium alloy, duralumin which is 4 to 5 percent of copper, 0.5 to 1 percent of magnesium, 0.5 percent of manganese and 94 to 95 percent of aluminium alloy. Age hardening for increasing strength over a period of time happens. It gives superior stress and impact resistance. Age-hardening is a phenomenon which will be dealt with in the heat treatment discussion.

Lightweight with exceptional strength, high toughness with very heavy loads. These are all the properties of Duralumin, which is finding a lot of applications in the aerospace industry today.

Aluminium (Al) Alloys

Aluminium - Silicon Alloy (5-12% Si, 88-95% Al)

Characteristics:

- Better castability for complex shapes.
- Higher wear resistance for durability in high-stress uses
- Corrosion resistance in humid or salty environments
- Lower thermal expansion for dimensional stability



Then, the aluminium-silicon alloy also finds a lot of applications. Better cast stability for complex surfaces. It has very high wear resistance in high-stress usage.

Corrosion resistance in humid as well as salty environments. Low thermal expansion for dimensional stability. These are all combinations of aluminium with silicon.

Aluminium (Al) Alloys

Aluminum- Copper alloy (3-5 % Cu, 95-97 % Al)

Characteristics:

- High strength, fatigue resistance with moderate corrosion resistance.
- Ensures structural integrity in demanding applications.
- Tailored via heat treatment for varying needs.
- Maintains strength at elevated temperatures.



Aluminium with copper: 3 to 5 percent of copper is mixed with aluminium. So, 95 to 97 percent of aluminium is there.

High strength, fatigue resistance, and moderate corrosion resistance are present. Ensures structural integrity in demanding applications. Tailored via heat treatment for various needs. So, aluminium-copper is also finding lightweight applications. This is for conductivity. Maintains high strength at elevated temperatures.

Copper (Cu)

Characteristics:

- Excellent electrical and thermal conductivity.
- Corrosion-resistant, forming a protective patina.
- Highly ductile and malleable, allowing easy shaping.
- Non-magnetic, making it useful in specific electronic applications.
- Antimicrobial properties, reducing bacterial growth on surfaces.
- Easily recyclable without losing quality.



Let us move to the other alloy, which is copper-based alloy. Copper-based alloy always provides excellent electrical resistance and conductivity, which is generally not so high with aluminium. It has corrosion resistance and forms a protective patina on its surface. Highly ductile and malleable, allowing it to be shaped easily; copper is easy to shape, and brass and bronze are all copper-based.

Non-magnetic, making it suitable for several electronic applications. Anti-microbial property and reduction of bacterial growth on the surface are achieved with copper-based alloy. That is why we use copper-bottom flasks and other items. Easily recyclable without losing much of its quality.

Copper (Cu)

Brass (60-90 % Copper and 10-40 % Zinc)

Characteristics:

- Malleable and ductile.
- High strength and resistance to corrosion.
- Exhibits a gold-like appearance.
- Good machinability and thermal conductivity.



Brass, which is a combination of zinc and copper. So, 60 to 90 percent copper, wherein 10 to 40 percent can be zinc. It is malleable and ductile. We make brass statues, small murti statues, whether of God, Sardar Vallabh Patel, or Mahatma Gandhi, as it is malleable and ductile. High strength, resistance to corrosion, and a gold-like appearance are very important. Gold-like appearance, good machinability, and thermal conductivity are its properties. Brass statues are very famous, and brass utensils are also very famous.

Copper (Cu)

Bronze (88-95% Cu, 5-12% Sn, 0.5-6% Al, 1-4% Si, 0.5-5% Mn, 0.01-0.35% P)

Characteristics:

- High strength and hardness.
- Excellent corrosion resistance, especially in seawater.
- Resists metal fatigue and wear.
- Can be cast into intricate shapes.



Bronze is a combination of copper and tin, 88 to 95 percent copper, 5 to 12 percent tin, 0.5 to 6 percent aluminum, 1 to 4 percent silicon, 0.5 to 5 percent manganese, and 0.01 to 0.35 percent phosphorus. All these elements are mixed together to create a very beautiful material for making intricate statues. They are all made out of bronze. High strength and hardness.

It has excellent corrosion resistance, especially in seawater. That is why when you see all these murtis being washed with various materials. For example, water, then some honey, milk, and other substances. The pH content of all those substances keeps changing. But even after multiple exposures, the statue is able to retain its form because of its excellent corrosion resistance. It resists metal fatigue and wear and can be cast into intricate shapes.

Nickel (Ni)

Nickel Bronze (70-90% Cu, 10-30% Ni)

Characteristics:

- High corrosion and wear resistance, especially in seawater.
- High strength and excellent mechanical properties.
- Excellent resistance to oxidation and high temperatures.
- Suitable for bearings and marine applications.



Moving on to nickel bronze, which finds excellent application in marine fittings. It has high corrosion and wear resistance, especially in seawater. For example, water tanks along the coast always have valves made out of nickel bronze. They have high strength and excellent mechanical properties. Excellent resistance to oxidation and high temperature. Suitable for bearing as well as marine applications. In marine applications, we always use nickel bronze as the material.

Nickel (Ni)

Nickel-Chromium alloy (50-70% Ni, 15-30% Cr)

Characteristics:

- High-temperature strength and oxidation resistance.
- Superior mechanical properties in extreme conditions.
- Magnetic properties (depending on composition).
- Ideal for high-temperature applications such as turbine blades.



Nickel chromium alloy is also available, which contains 50 to 70 percent nickel and 15 to 30 percent chromium. Chromium means it is resistant to corrosion.

High temperature strength and oxidation resistance. So, that means if you make a nickel chromium alloy gear and expose it to 300, 400, or even 600 degrees Celsius, nothing will happen to the shape and size of the teeth, right? So, it has oxidation resistance. Superior mechanical properties in extreme conditions. When there is a high temperature application, nickel chromium alloys are used. Magnetic properties depend upon the composition, ideal for high temperature applications such as turbine blades.

Nickel (Ni)

Inconel Alloys

Composition: Primarily **Nickel (Ni)**, with **Chromium (Cr)**, **Iron (Fe)**, **Molybdenum (Mo)**, **Titanium (Ti)**, **Aluminium (Al)**, and other elements depending on the specific alloy (e.g., Inconel 625, Inconel 718, etc.).

Characteristics:

- Retains strength at elevated temperatures.
- Performs well in harsh environments.
- Resists deformation under high-temperature stress.
- It can be welded with special procedures.



The other important application of nickel is Inconel. Inconel contains primary nickel with chromium, iron, molybdenum, titanium, aluminum, and other elements depending upon the specific alloy. Inconel 625 and Inconel 718 are used extensively in aerospace, turbine blades, and marine applications, retaining strength at very high elevated temperatures. For example, in thermal power plants or turbines, gas turbines, and all these places, they are used extensively in coal. It is slightly heavier compared to aluminum, but it has very high temperature resistance properties.

Performs very well in harsh environments. It resists deformation under high-temperature stresses. It has good weldability properties.

Nickel (Ni)

Inconel alloys Applications

Aerospace, power generation, Flanges, chemical processing, marine, jet engines, turbine blades, exhaust systems, gas turbines, reactors, and high-temperature components.



So, Inconel finds a lot of applications: aerospace, power generation, flanges, chemical processing, marine, jet engines, turbine blades, exhaust systems, gas turbines, and high-temperature applications. So, Inconel finds a lot of usage nowadays.

Lead (Pb)

Characteristics:

- High density and malleability, Soft and easily molded into various shapes.
- Excellent corrosion resistance in certain environments.
- Toxicity and environmental concerns limit its use in certain applications.
- Poor mechanical strength at high temperatures



Lead has high density and malleability. It is soft and easily moldable into various shapes. It has excellent corrosion resistance. Its toxicity and environmental concerns limit it to certain applications. It has poor mechanical strength at high temperatures.

That is why it is used extensively for electronics applications. As you know, lead is very soft but very heavy. Lead-tin alloys, which have 90 to 95 percent lead and 5 to 10 percent tin. They are soft and malleable with good corrosion resistance. They are extensively used in batteries.

Non-toxic in some applications but toxic in others, selectively non-toxic applications. Low melting point makes it ideal for soldering, and it is widely used for electrical and electronics soldering purposes. It has very good electrical properties and is a soft material.

Zinc (Zn)



Characteristics:

- Protects against rust, especially in outdoor and industrial environments.
- Suitable for die-casting and alloy production
- Easily shaped for various applications.
- Good Thermal and Electrical Conductivity is Used in electronic components.
- It can be reused without losing quality(Recyclable).

Zinc has very good protective resistance, zinc coating, galvanizing zinc coating, right. It protects from rust, especially when used in outdoor and industrial environments.

It is suitable for die casting and alloy production. It has various uses; zinc is used in various applications. It has good thermal and electrical properties. In such a way, it is used in electronic materials. It can be recycled very easily while maintaining its properties.

Zinc (Zn) Alloys

Zinc-aluminium alloy (85-95% Zn, 5-15% Al)

Characteristics:

- High strength, good casting properties
- Excellent corrosion resistance, especially when galvanized.
- High fluidity in casting.
- Cheaper than other high-strength alloys.



Zinc alloys, such as zinc-aluminium alloys, contain 85 to 95 percent zinc and 5 to 15 percent of alloys. They are extensively used for making nuts and bolts for required applications. High strength and good casting properties are present. Excellent corrosion resistance when galvanized. High fluidity in casting. It is cheaper than other strong alloys.

To Recapitulate

- Purpose of studying different engineering materials and its application?
- Different type of ferrous and non-ferrous materials with examples of each?
- Properties of metals and application?
- Composite material and the type
- What is a key advantage of composites over traditional materials?
- What the role of different tool steels in the engineering materials?.
- Role of different type of cast iron in engineering materials.

To recap, what we have seen in the three lectures, whatever it is, one, two, and three, the purpose of studying different engineering materials and their applications was addressed. Different types of ferrous and non-ferrous materials with examples of each were seen. The properties of metals and their applications were addressed. We also introduced composite materials.

The key advantage of composites over traditional materials was also discussed. The role of different tool steels in engineering materials was seen. Different types of cast iron in engineering materials and the use of alloys were addressed.

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These are the references which we have gone through.

	Polymer	metal	Ceramic
		Fe	Non Ferrous
① Nut & Bolt - temporary joining	• • • • • •		
② tumbler - 	• • • • • •		
③ Plate - dining	• • • • • •		

metals → SS, Al, Ino

Before I close, I would like to give you an assignment which you do not have to submit, but an assignment for you after undergoing all this basic understanding: how do you make a proper choice of material?

Let us take three examples. One, let us take a nut and bolt, which is used for temporary joining. Next, let us take a tumbler, which has a high aspect ratio. Three, let us try to take a plate, okay. So, these are the three examples.

Now, what I want is for you to make a table like this. In that table, what you will do is try to choose three alternative materials. For example, you can choose polymer, metal, and ceramic. Or, within metals, you can try to include ferrous and non-ferrous. So, you can try to create a table.

So, for each of these items, when I mention a plate, I mean a dining plate. A nut and bolt is essentially for joining. So, you can try to see what alternatives I can have for the same application. For example, you cannot make a nut and bolt out of ceramic. So, what I would suggest is that you try to take three different categories under metals. One is stainless steel, another is aluminium, and the third could be Inconel, or whatever it is.

You can choose that, and then list all the properties that are very important for this application, for this application, and for this application. For example, a tumbler should

have corrosion resistance. A tumbler should be light in weight. If you decide to make it from polymer, that is okay. Then, please justify all the reasons.

When you try to do it with metals, for example, I will use stainless steel, fine. I will use something else, fine. And then when you try to use a tumbler, sometimes you will also drink tea. So, when you drink tea, if the thermal conductivity is very high, it is difficult to hold. So, you will try to look for a low thermal conductivity.

So, then you might choose polymer or you might choose ceramic like glass. So this exercise will try to give you one application, what are all the possible different types of materials I can choose. And after you choose, what are all the properties which made you think that this is the best choice. That is what I want through this exercise. You don't have to submit it to me.

When you do it, do it with sincerity. List down all the mechanical properties, all the physical properties, and then start filling them. When I say physical, it is going to be density, electrical conductivity, thermal conductivity. These are all physical. When I say mechanical, you will try to talk about ductility, all these things, right?

So you make a table that will try to provide a very good understanding of this lecture based on what we have done. With that, thank you so much for your patient listening.