Civil Engineering Materials
SAB 2112

Introduction to Ferrous, Non-Ferrous & Composite Materials

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CONTENT SCHEDULE – 5th Meeting

1. Non-ferrous metal - types and characteristics, use of non-ferrous metal in construction
2. Latest construction materials - polymer, glass, composite material, cement based products

Introduction

Metals form about a quarter of the earth crust by weight

One of the earliest material used dated back to pre-historic time

Some of the earliest metals used include: copper, bronze and iron

Stone age → Bronze age → … →'discovery' of steel →Industrial Revolution in the 18th century

All metals except gold are generally found chemically combined with other elements in the form of oxides and sulphates. Commonly known as **ores**.

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Commonly available metal forms

- The basic elements of all metals are found naturally occurring within the earth. After they are extracted in the from of ore they are refined and processed in a variety of ways to produce usable materials. Metals are commonly available for manufacturing use in a wide range of forms and sizes.

www.ferretrollforming.com/aboutus.htm

http://thomonthenet.com/ContemporaryGlass/JoshSimpson_Megaworld13_large.jpg

www.afcd.gov.hk/.../cou_vis_cou_mos.html

Mining for Iron Ore in Ma On Shan until 1981

Pure Metals and Alloys

Metal that are not mixed with any other materials are known as pure metals. Metals listed in the Periodic Table are pure metals
E.g. Iron (Fe), Copper (Cu) and Zinc (Zn)

Alloys are **mixtures** of two or more metals formed together with other elements/materials to create new metals with improved properties and characteristics.
E.g. Brass (Copper and Zinc),
Stainless steel (steel and chromium)

Alloy = metal A + metal B + … + other elements

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Ferrous Metals & Non-Ferrous Metals

Ferrous metals are metals that contain iron
E.g. Steel (iron and carbon)

Non-ferrous metals are metals that do not contain iron
E.g. Zinc (pure metal), Bronze (Copper and tin)
(non-ferrous may contain slight traces of iron)

Ferrous Metal = alloy metals that contains iron
(Primary base metal is iron)

Non-ferrous Metal = alloy metals that do not contain iron
Primary base metal does not contain iron)

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Types of metal

- Two significant groups
  - Ferrous metals – contains iron
  - Non-ferrous metals – do not contain iron
- Alloys
  - The process of bringing together two or more metals, often with other elements
- *Define the above and add examples*

Classification

Metals can be divided into 2 groups

Metals

Ferrous Metals	Non- Ferrous Metals
Iron	Aluminum
Low Carbon Steel	Copper
Medium Carbon Steel	Brass
High Carbon Steel	Bronze
Cast Iron	Zinc
Stainless Steel	Lead
Tool Steels	Tin
Others	Others

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Ferrous

- These are metals which contain **iron**. They may have small amounts of other metals or other elements added, to give the required properties.

  All ferrous metals are **magnetic** and give little resistance to corrosion

Non-Ferrous Metals

- These are metals which do not contain any iron. They are not magnetic and are usually more resistant to corrosion than ferrous metals.

  Examples are **aluminium, copper, lead. zinc and tin.**

Ferrous Metals Chooser Chart

Name	Composition	Properties	Uses
Mild Steel	0.15 to0.30% carbon	Tough, high tensile strength, ductile. Because of low carbon content it can not be hardened and tempered. It must be case hardened.	girders, Plates, nuts and bolts, general purpose.
High Speed Steel	medium carbon, tungsten, chromium and vanadium.	Can be hardened and tempered. Can be brittle. Retains hardness at high temperatures.	Cutting tools for lathes.
Stainless Steel	18% chromium, and 8% nickel added.	Corrosion resistant	Kitchen draining boards. Pipes, cutlery, aircraft.
High Tensile Steel	Low carbon steel,, nickel,and chromium.	Very strong and very tough.	Gears, shafts, engine parts.
High Carbon Steel	0.70% to 1.40% carbon.	The hardest of the carbon steels. Less ductile, tough and malleable.	Chisels, hammers, drills, files, lathe tools, taps and dies.
Medium Carbon Steels	0.30% to 0.70% carbon.	Stronger and harder than mild steels. Less ductile, tough and malleable.	Metal ropes, wire, garden tools, springs.
Cast Iron	Remelted pig iron with small amounts of scrap steel.	Hard, brittle, strong, cheap, self-lubricating. Whitecast iron, grey cast iron, malleable cast iron.	Heavy crushing machinery. Car cylinder blocks, vices, machine tool parts, brake drums, machine handle and gear wheels, plumbing fitments.

Non-Ferrous Metals Chooser Chart

Name	Composition	Properties	Uses
Aluminium	Pure Metal	Greyish-White, soft, malleable, conductive to heat and electricity, It is corrosion resistant. It can be welded but this is difficult. Needs special processes.	Aircraft, boats, window frames, saucepans, packaging and insulation, pistons and cranks.
Aluminium alloys-Duraluminium)	Aluminium +4% Copper+1%Manganese	Ductile, Malleable, Work Hardens.	Aircraft and vehicle parts.
Copper	Pure metal	Red, tough, ductile, High electrical conductor, corrosion resistant, Can work hard or cold. Needs frequent annealing.	Electrical wire, cables and conductors, water and central heating pipes and cylinders. Printed circuit boards, roofs.
Brass	65% copper +35%zinc.	Very corrosive, yellow in colour, tarnishes very easily. Harder than copper. Good electrical conductor.	Castings, ornaments, valves,forgings.
Lead	Pure metal	The heaviest common metal. Soft, malleable, bright and shiny when new but quickly oxidizes to a dull grey. Resistant to corrosion.	Protection against X-Ray machines. Paints, roof coverings, flashings.
Zinc	Pure metal	A layer of oxide protects it from corrosion, bluish-white, easily worked.	Makes brass. Coating for steel galvanized corrugated iron roofing, tanks, buckets, rust-proof paints
Tin	Pure metal	White and soft, corrosion resistant.	Tinplate, making bronze.
Gilding metal	85% copper+15% zinc.	Corrosion resistant, golden colour, enamels well.	Beaten metalwork, jewellery.

Why nonferrous?

Nonferrous

- Light weight
- Stiffness –strength to weight ratio
- High temperature properties
- Oxidation resistance
- Corrosion resistance
- Biocompatibility
- Thermal/electrical conductivity

↓

High cost

Depending on extraction and production

Density of Metals

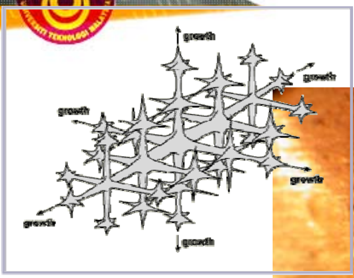
Metal	Density ($g.cm^{-3}$)
Iron	7.87
Steel	7.80
Aluminium	2.70
Magnesium	1.74
Titanium	4.54
Copper	8.96
Zinc	7.13
Nickel	8.89
Lead	11.36
Silver	10.49
Gold	19.32

Source: http://www.sut.ac.th/engineering/metal/pdf/Nonferrous/01_Introduction%20to%20nonferrous%20metallurgy.pdf

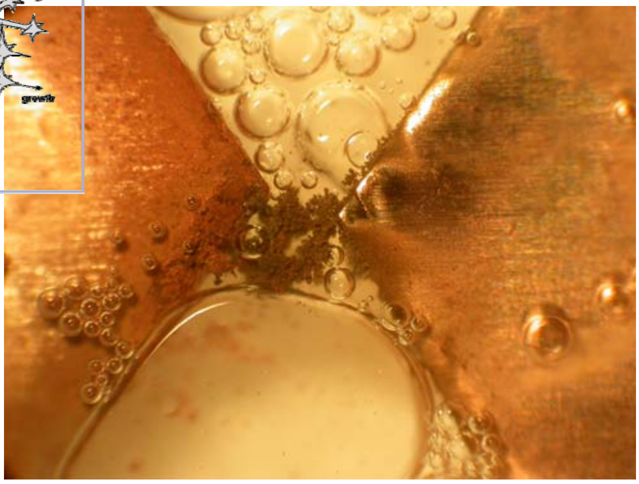
Metallic Structures

- This **crystalline structure** gives metals their **properties** (strength, stiffness, ductility, conductivity & toughness).
- Each **dendrite** grows in a **geometric pattern** consistent with the lattice structure until each one touches its neighbour. At this point the dendrites begin to thicken to form a totally solid **grain** of metal.
- The grain boundaries between are visible under a microscope, each grain having the same structure but a different orientation. This boundary is a narrow zone (perhaps three atoms) in which the atoms are not properly spaced according to the lattice structure.

Metallic Structures

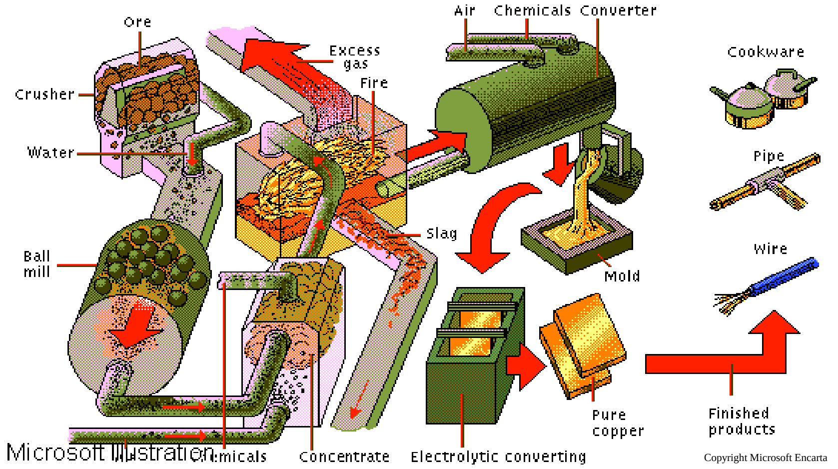


Growth of metal dendrite



Copper dendrites

Copper production



Saource from: **(C) Coláiste Lorcáin Engineering** 17

Aluminium and its alloys

Advantages:

- Light weight
- High corrosion resistance
- High electrical and thermal conductivities
- High ductility
- Easily deformable

Applications

- Building/construction
- Container
- Packaging
- Transportation
- Electrical conductors
- Machinery/equipment

Building/ construction

Containers

Light-weight bike

Magnesium and its alloys

Advantages:

- Weight saving
- High machinability

Disadvantages:

- Difficulty in melting process due to high reactivity.

Magnesium side panels

Applications

- Used as alloying element for aluminium, steel and nodular (SG) cast iron.
- Die casting for aerospace
- Transport industry.
- Light weight bodies.

Handy cam & mobile phone bodies

Titanium and its alloys

Advantages:

- High strength to weight ratio
- Moderate-high temperature properties
- Corrosion resistance
- Biocompatibility
- Shape memory

Disadvantages:

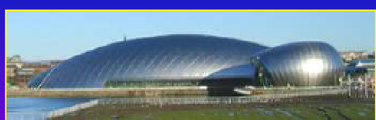
- High cost
- Difficulty in extraction
- Limited in high performance applications

Applications

- Structure of high speed aircrafts
- 75% in aerospace
- Chemical industry

Turbine blades

Hip-joint component



National science centre, Scotland

Copper and its alloys

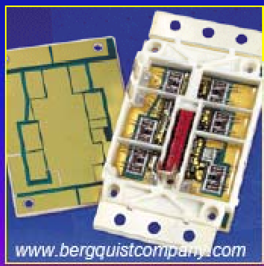
Advantages:

- High electrical conductivity
- High thermal conductivity
- High corrosion resistance
- Good ductility and malleability
- Reasonable tensile strength.

Applications

- Electrical conductance
- Plating on components
- Give different copper alloys - brasses and bronzes.

Copper trolley wires



Electronic products

Copper plating

Zinc and its alloys

Advantages:

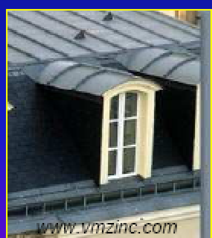
- Fast rate of die casting
- Excellent atmospheric corrosion resistance.
- Ability to form a well-adhering coating on steel.

Applications

- Used for galvanic protection in steel and decorative finish.
- Used in die casting.

Disadvantages:

- Cannot be strain hardened.



Zinc roof protection

Zinc diecast

Nickel and its alloys

Advantages:

- Tough and ductile
- Good high and low temperature strength
- High oxidation resistance
- Good corrosion resistance

Disadvantages:

- High cost
- Not normally mixed with cheaper alloying metals

Applications

- Applications required necessary corrosion or heat- resisting properties
- Special engineering applications
- Turbine blades in combustion section

Turbine blades

Aerospace flow bodies

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Composite Theory

- In its most basic form a composite material is one which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own.
- In practice, most composites consist of a bulk material (the ‘matrix’), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix. This reinforcement is usually in fibre form.

Composite Main Groups

- Today, the most common man-made composites can be divided into three main groups:
  - **Polymer Matrix Composites (PMC’s)** – These are the most common and will be discussed here. Also known as FRP - Fibre Reinforced Polymers (or Plastics) – these materials use a polymer-based resin as the matrix, and a variety of fibres such as glass, carbon and aramid as the reinforcement.
  - **Metal Matrix Composites (MMC’s)** - Increasingly found in the automotive industry, these materials use a metal such as aluminium as the matrix, and reinforce it with fibres such as silicon carbide.
  - **Ceramic Matrix Composites (CMC’s)** - Used in very high temperature environments, these materials use a ceramic as the matrix and reinforce it with short fibres, or whiskers such as those made from silicon carbide and boron nitride.

Composite Properties

- Overall, the properties of the composite are determined by:
  - i) The properties of the fibre
  - ii) The properties of the resin
  - iii) The ratio of fibre to resin in the composite (Fibre Volume Fraction)
  - iv) The geometry and orientation of the fibres in the composite

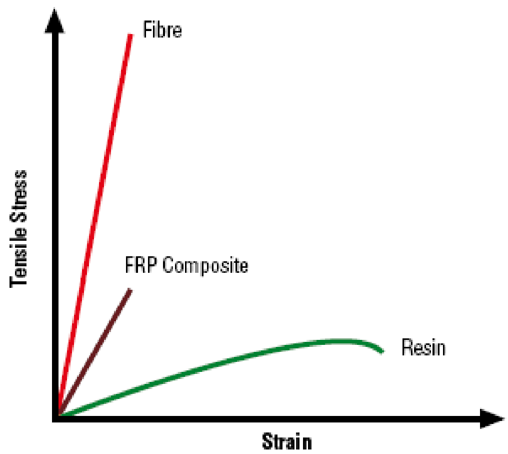
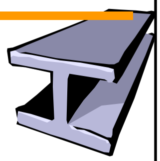


Fig. 1

INTRODUCTION - Composite

- Fibre Reinforced Polymers (FRP) can no longer be considered as exotic materials suitable only for niche applications where the performance demands justify very high prices, such as in aerospace or premium sporting goods markets.
- Today high performance FRP materials are starting to challenge that most ubiquitous of engineering materials, steel, in everyday applications as diverse as automobile bodies and civil infrastructure.
- It would be naive to suggest that FRP will displace steel from its dominant role; however, continuous advances in the manufacturing technologies and performance of FRP have intensified the competition in a growing range of applications leading to significant growth in market acceptance.

BACKGROUND OF THE PROBLEM

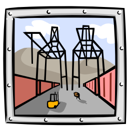


Steel are getting expensive & shortage!

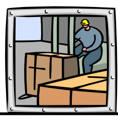
Corrosion problems!

(Davalos et. al., 2001), (Bakis et. al., 2002).

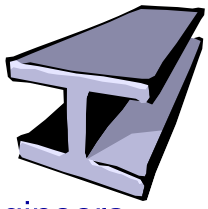
Weighty!



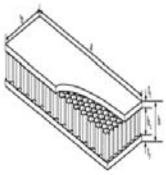
Cost increased!

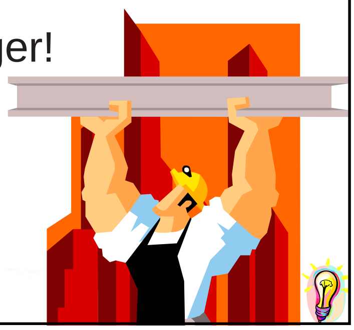


Introduction



- Fiber-reinforced polymer (FRP) composites
  - attractive materials to structural engineers,
    - high specific stiffness and strength,
    - high corrosion resistance.
- FRP are up to 6 times stronger!
  - than Steel (SPS System, 2004)





Composite Theory

- Recently, composite materials made of fibers embedded in a polymeric resin, also known as fiber-reinforced polymers, have become an alternative to steel reinforcement for concrete structures.
- Aramid fiber reinforced polymer (AFRP), carbon fiber reinforced polymer (CFRP), and glass fiber reinforced polymer (GFRP) rods are the commercially available products for the construction industry.
- They have been proposed for use in lieu of steel reinforcement or steel prestressing tendons in nonprestressed or prestressed concrete structures (ACI 440R 1996).

Composite Theory

- The problems of steel corrosion are avoided with the use of FRPs because FRP materials are nonmetallic and noncorrosive.
- In addition, FRP materials exhibit several properties including high tensile strength, that make them suitable for the use as structural reinforcement.
- Furthermore, codes and design guide provisions have been recently prepared for the use of FRP bars in concrete structures for bridges and buildings (ACI 440H 2000; CSA 2000; ISIS-Canada 2000).

Definition of FRP Composites

- Not all plastics are composites. In fact, the majority of plastics today are pure plastic, like toys and soda bottles. When additional strength is needed, many types of plastics can be reinforced (usually with reinforcing fibers).
- This combination of plastic and reinforcement can produce some of the strongest materials for their weight that technology has ever developed...and the most versatile.

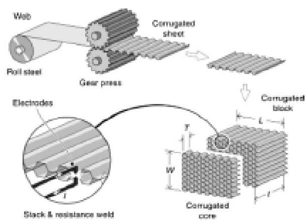
Definition of FRP Composites

- "A combination of such that there is a sufficient aspect ratio (length to thickness) to provide a discernable reinforcing function in one or more directions."
- "..as a polymer (plastic)matrix, either thermoset or thermoplastic, that is reinforced (combined) with a fiber or other reinforcing material with a sufficient aspect ratio (length to thickness) to provide a discernable reinforcing function in one or more directions."

- FRP composites are different from traditional construction materials such as steel or aluminum.
- FRP composites are anisotropic (properties only apparent in the direction of the applied load) whereas steel or aluminum is isotropic (uniform properties in all directions, independent of applied load).
- Therefore, FRP composite properties are directional, meaning that the best mechanical properties are in the direction of the fiber placement. Composites are similar to reinforced concrete where the rebar is embedded in an isotropic matrix called concrete.

Benefits

1. Light weight
2. High strength-to-weight ratio
3. Directional strength
4. Corrosion resistance
5. Weather resistance
6. Dimensional stability
   - low thermal conductivity
   - low coefficient of thermal expansion
7. Radar transparency
8. Non-magnetic
9. High impact strength
10. High dielectric strength (insulator)
11. Low maintenance
12. Long term durability
13. Part consolidation
14. Small to large part geometry possible
15. Tailored surface finish



The benefits & ideal for structural applications

- **High Strength and Stiffness Retention**
  - composites can be designed to provide a wide range of mechanical properties including tensile flexural impact and compressive strengths And unliketensile, flexural, impact and compressive strengths. And, unlike traditional materials, composites can have their strengths oriented to meet specific design requirements of an application.
- **Light Weight/Parts Consolidation**
  - FRP composites deliver more strength per unit of weight than most metals. In fact, FRP composites are generally 1/5th the weight of steel. The composite can also be shaped into one complex part, often times replacingassemblies of several parts and fasteners. The combination of these two benefits makes FRP composites a powerful material system structures can be partially or completely pre-fabricated at the manufacturer's facility, delivered on-site and installed in hours.

The benefits & ideal for structural applications

- **Creep (Permanent Deflection Under Long Term Loading)**
  - The addition of the reinforcement to the polymer matrix increases the creep resistance of the properly designed FRP part. Creep will not be a significant issue if the loads on the structure are kept below appropriate working stress levels.
- **Fire Performance of Composites**
  - FRP composites can burn under certain conditions. Composites can be designed to meet the most stringent fire regulations by the use of special resins and additives.
  - Properly designed and formulated composites can offer fire performance approaching that of most metals performance approaching that of most metals

The benefits & ideal for structural applications

- **Resistance to Environmental Factors**

  Composites display excellent resistance to the corrosive effects of:
  - ***Freeze-thaw:*** because composites are not attacked by galvanic corrosion and have low water absorption, they resist the destructive expansion of freezing water.
  - ***Weathering and Ultra-Violet Light:*** FRP composite structures designed for weather exposure are normally fabricated with a surface layer containing a pigmented gel coat or have an ultraviole (UV) inhibitor included as an additive to the composite matrix.
  - Both methods provide protection to the underlying material by screening out UV rays and minimizing water absorption along the fiber/resin interface.
  - ***Chemicals and Temperature:*** Composites do not rust or corrode and can be formulated to provide long-term resistance to nearly every chemical and temperature environment. Of particular benefit, is composites ability to successfully withstand the normally destructive effects of de-icing salts and/or saltwater spray of the ocean.