Tishk International University
Mechatronics Engineering Department
Manufacturing Technology Week 6/11/2025

Material property

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Objective

- By the end of this class, students should be able to:
- Identify different types of failure in materials.
- Understand the meaning of **fatigue** and **creep**.
- Explain the **causes**, **stages**, and **prevention** of these failures.
- Recognize **real-world examples** where fatigue and creep occur.

What is **Fracture of Materials**

Fracture of Materials
When a material is subjected to a **stress greater than its strength**, it eventually **fails and breaks** into two or more pieces — this is known as **fracture**.
In tensile testing, two main types of fractures are observed: **ductile fracture** and **brittle fracture**.

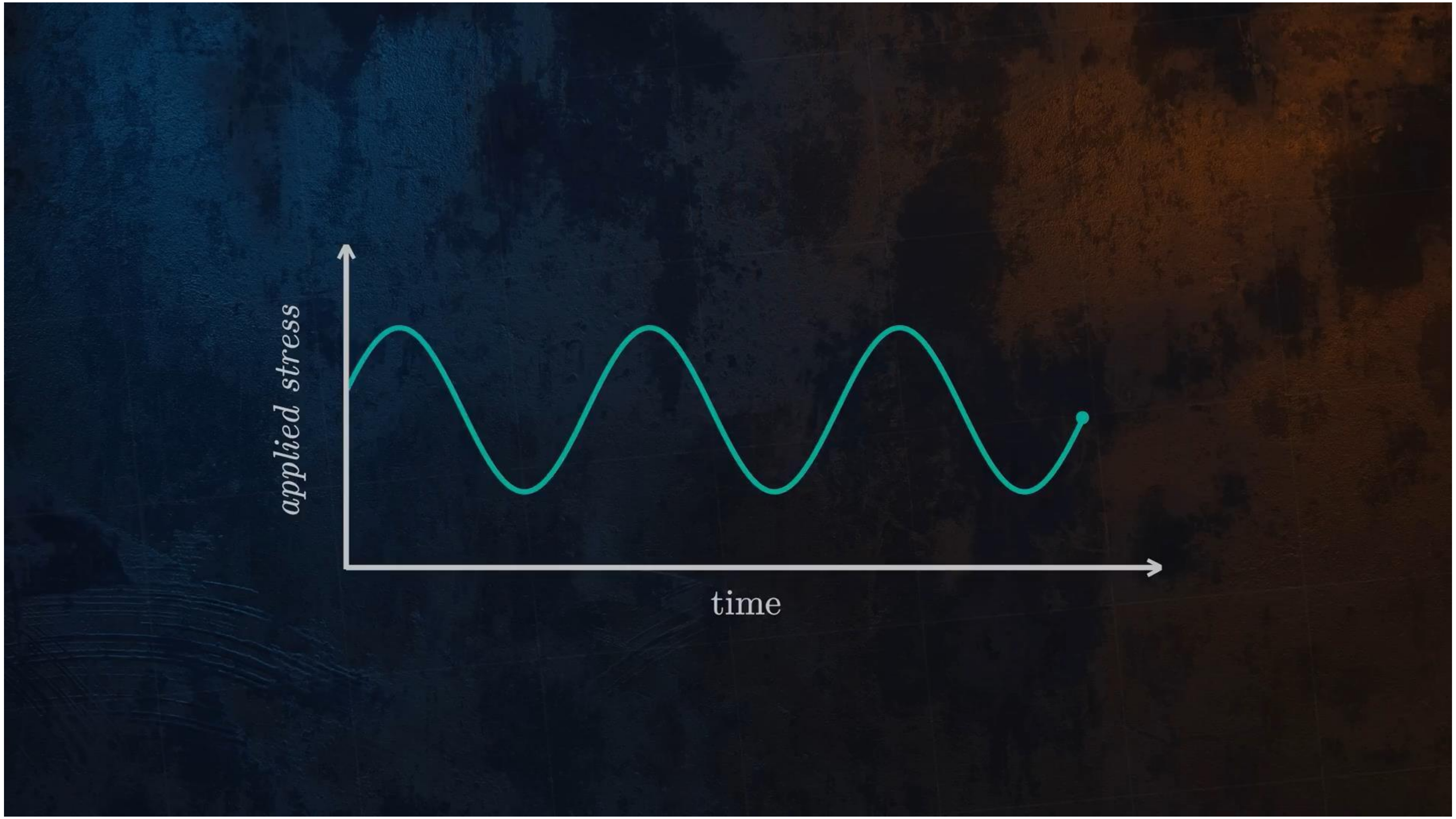
1. Ductile Fracture

- Occurs **after significant plastic deformation**.
- The material undergoes noticeable **necking** (reduction in cross-sectional area) before breaking.
- The fracture surface usually appears **rough and fibrous**.
- Example: **Mild steel**.

2. Brittle Fracture

- Occurs **suddenly**, with **little or no plastic deformation**.
- Initiated by the **growth of a small internal crack** until the material fractures completely.
- The fracture surface appears **flat and shiny**.
- Example: **Cast iron or glass**.

Video

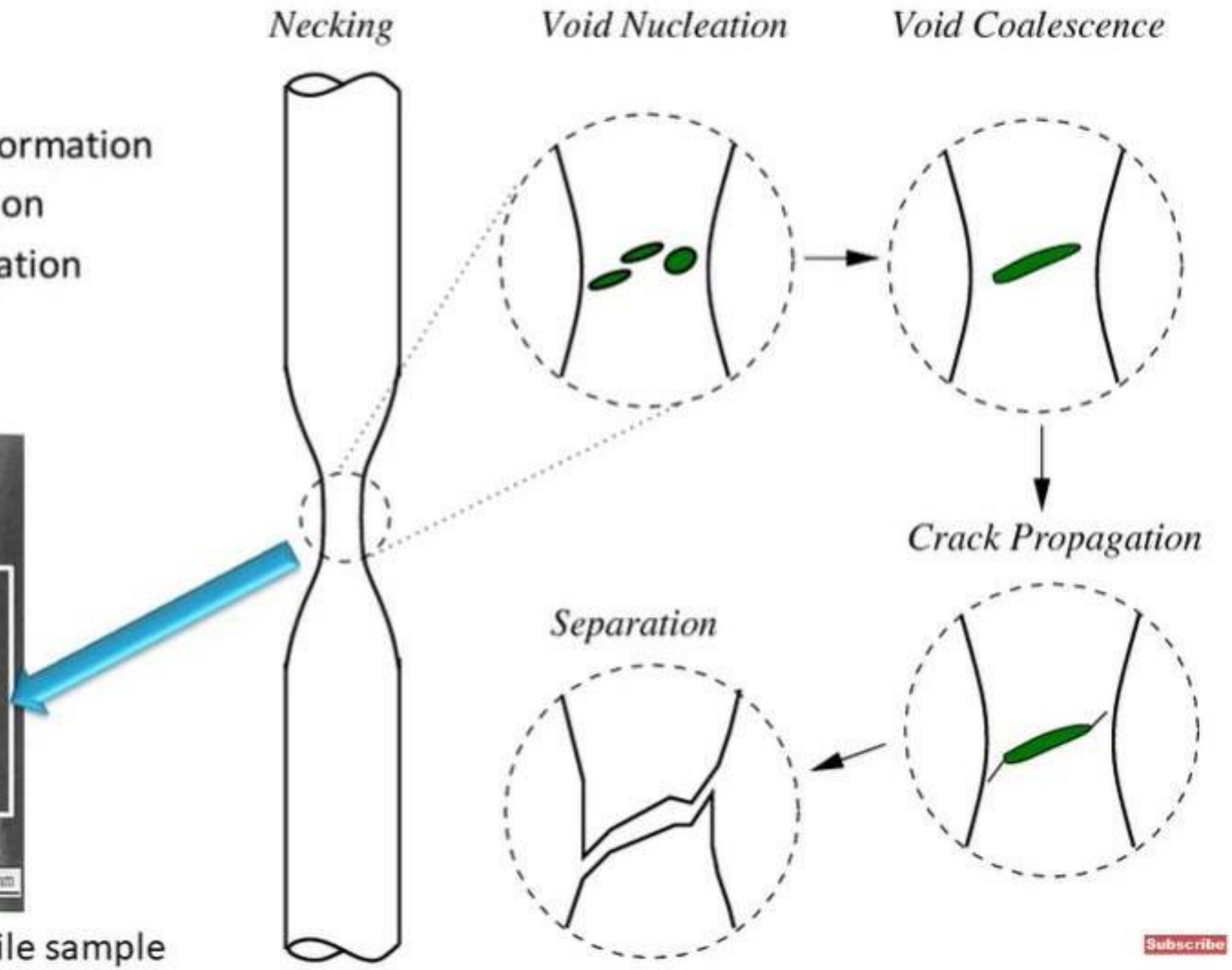


https://www.youtube.com/watch?v=o-6V_JoRX1g

Mechanism of Ductile Failure

a) Necking
b) microcracks formation
c) Crack formation
d) Crack propagation
e) fracture

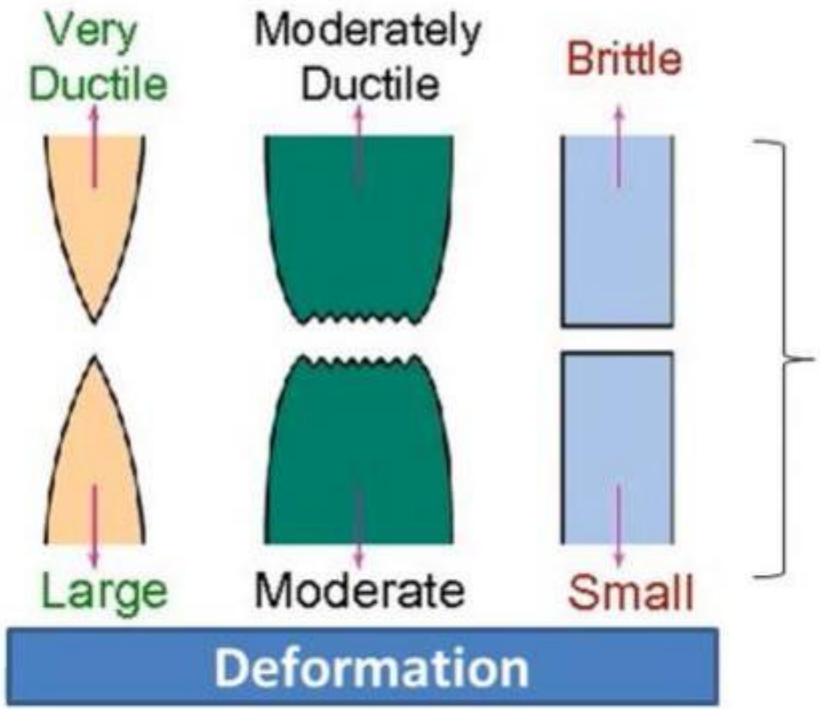
LM image of a tensile sample



Ductile to Brittle Failure

Ductile to brittle failure: depends on microstructure, molecular structure, time, temperature and strain rate

Ductile failure
Gives warning
Before failing



Brittle failure
Fast and sudden
No warning

3. Other Types of Fracture

Apart from ductile and brittle failures, materials can also fail due to:

- **Fatigue Fracture:**

Caused by **repeated or fluctuating stresses** over time, even if the stress level is below the material’s ultimate strength.

Common in rotating shafts, springs, and aircraft components.

- **Creep Fracture:**

Occurs when a material is subjected to **constant stress at high temperature** for a long period.

The material **slowly deforms** and eventually fractures.

Seen in turbine blades and steam pipes.

Video Example on Fatigue failure in airplane

Tensile Test

How it happens: A standardized sample (usually a rod or flat strip) is gripped at both ends and slowly pulled apart in a tensile testing machine. The machine measures the force (load) and the elongation (stretching) of the sample as it is pulled.

What it shows: The test continues until the sample breaks. The results provide a stress-strain curve, showing elastic and plastic behaviour, yield strength, ultimate tensile strength, ductility (how much it stretches before breaking), and the mode of failure (ductile or brittle).

Video On tensile Test

https://www.youtube.com/watch?v=FpO2KImasNo

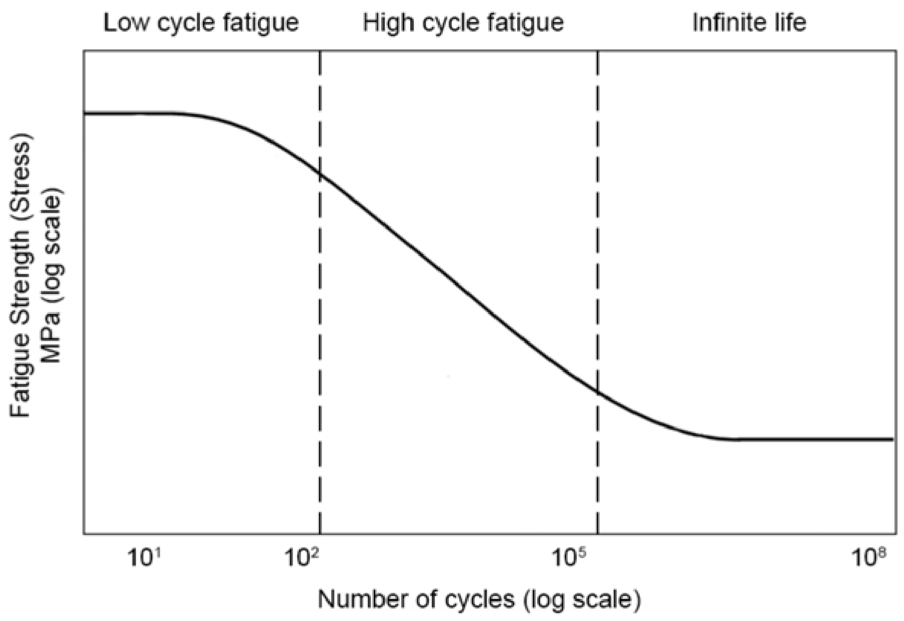
Fatigue Test

A fatigue test is a mechanical test where a material is repeatedly loaded and unloaded (cyclic loading) to simulate real-world conditions such as vibrations, fluctuating forces, or oscillating movements. The main goal is to measure how many cycles of repeated stress a material can endure before it fails or cracks, even if the applied stress is below the material's normal strength.

Fatigue Test Details

•How it’s done: A sample is mounted in a fatigue testing machine. A fluctuating force (tension, compression, bending, or twisting) is applied, cycling from high to low, thousands to millions of times. The number of cycles until fracture is recorded.

Real example: Airplane wings and car axles undergo fatigue tests to ensure they won’t suddenly fail during repeated usage over many years.



Video On Fatigue Test

https://www.youtube.com/shorts/VRrbqsuc4Ko

Creep test

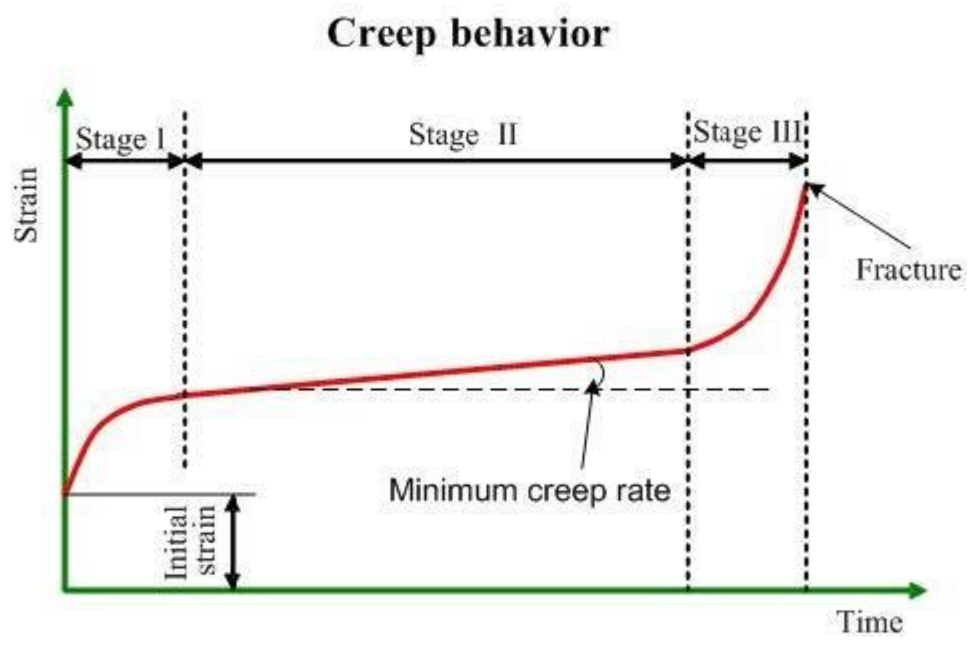
A creep test is a mechanical examination that measures how a material slowly deforms under a constant load or stress at elevated temperatures over time. It tracks strain as it changes with time to understand the material's long-term deformation behavior. This test is critical for materials expected to operate under sustained high loads and temperatures, such as metals and alloys used in turbines, boilers, and engines.

The purpose of a creep test is to identify:

The rate of deformation (creep rate) during different creep stages (primary, secondary, tertiary).

The time to rupture or failure under constant stress and temperature.

How a material’s mechanical properties evolve over prolonged exposure.



Video On Creep Test

https://www.youtube.com/watch?v=FztoEU87B90

Ferrous Material

1. Introduction

- **Ferrous materials** are metals that **contain iron** as their main element.
- **Non-ferrous materials** do not contain significant iron.
- Ferrous materials are **strong, hard, and inexpensive**, but **prone to corrosion and rust**.
- Their **properties can be improved** by **heat treatment** or by **adding alloying elements**.

2. Iron and Steel Iron (Fe) is soft and pure; melting point ≈ 1540°C.Steel is an alloy of iron and carbon (0–2%); stronger and harder than pure iron. The hardness and strength increase with carbon content (up to about 1.3%).Cementite (Fe_3C) makes steel hard but brittle.

Types of steel

- Steel is divided into two main types: **plain carbon steel** and **alloy steel**.
- **Plain carbon steel** contains mainly iron and carbon as its alloying elements.
- **Alloy steel** includes other elements such as **chromium, nickel, tungsten, molybdenum,** and **vanadium**, which significantly change its properties.
- All steels naturally contain small amounts of **sulphur (S), phosphorus (P), manganese (Mn),** and **silicon (Si)**.
- **S** and **P** are harmful, so their content is kept below **0.05%**.
- **Mn** (up to 0.8%) and **Si** (up to 0.3%) are not harmful; Mn even reduces sulphur's negative effects.
  These small amounts do not make the steel an alloy steel. However, if Mn or Si are added intentionally in higher amounts to improve properties, the steel becomes **alloy steel**.

Plain Carbon Steel Types:

Type	Carbon %	Properties	Common Uses
Low Carbon (Dead Mild)	<0.15	Very ductile, soft, weldable	Tubes, thin sheets
Mild Steel	0.15–0.3	Good strength, weldable	Structural works
Medium Carbon	0.3–0.7	Strong, less ductile	Shafts, axles, tools
High Carbon	0.7–1.3	Very hard, brittle	Cutting tools, dies

As carbon % increases → Strength ↑, Hardness ↑, Ductility ↓

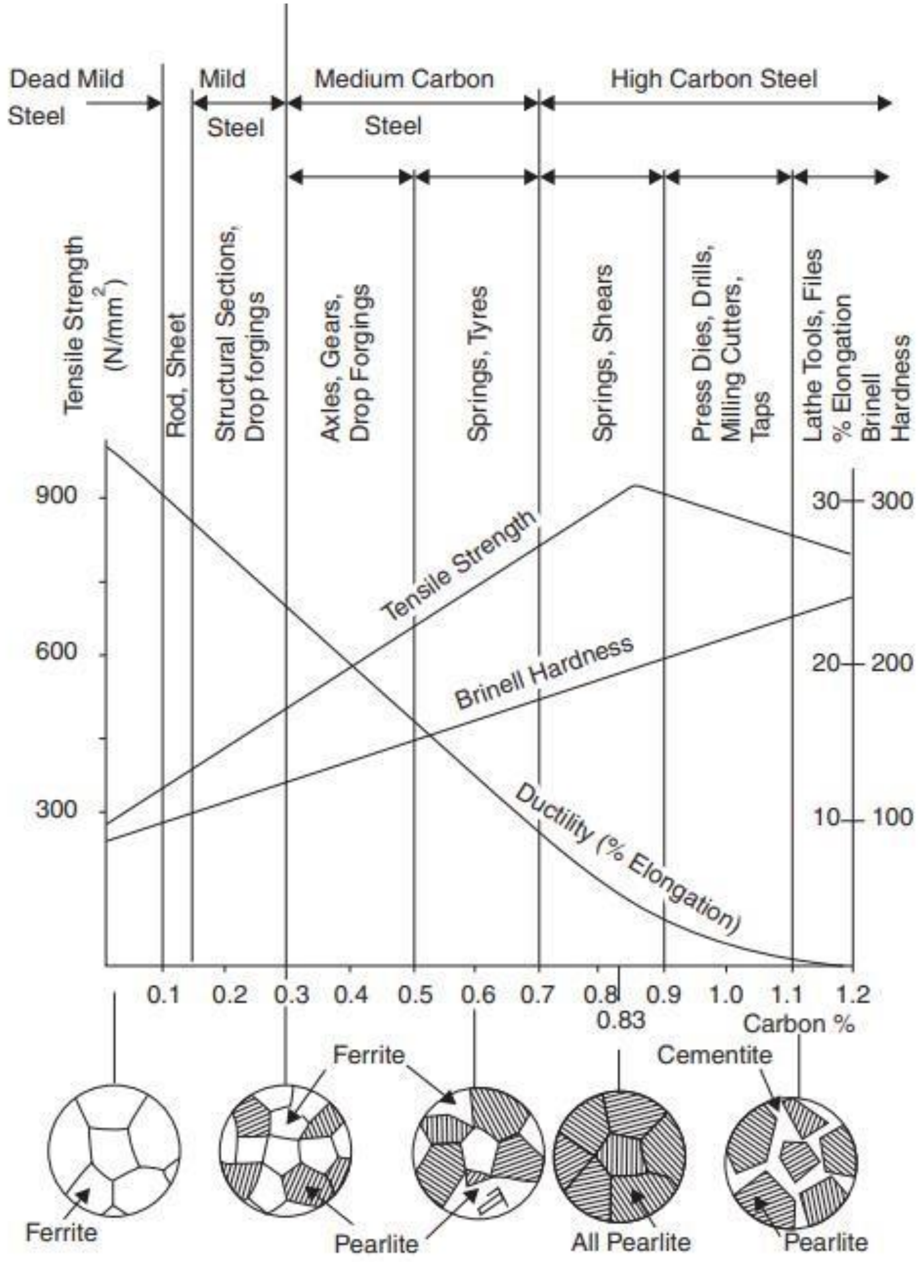


Fig. 2.1 Microstructure, mechanical properties, and uses of plain carbon steels

Graph Summary (Fig. 2.1)

The **graph shows the relationship** between **carbon content** and:

- **Tensile strength** → increases with carbon %.
- **Brinell hardness** → increases with carbon %.
- **Ductility (% elongation)** → decreases with carbon %.

It visually demonstrates how higher carbon makes steel stronger but less ductile.

Wrought Iron

- **Purest form of iron**, contains very little carbon and slag.
- **Soft, tough, malleable**, but expensive — now rarely used.
- Used in **chains, hooks, old gates**.

Alloy Steels

- Contain alloying elements to improve specific properties.
- **Advantages:**
  - Better **hardenability** and **strength**
  - **Corrosion resistance** (e.g. stainless steel)
  - **Red hardness** (for cutting tools)
- Improved **toughness** and **heat resistance**

Major Types:

1. **Stainless Steels**
   1. **Ferritic:** cheap, magnetic, Cr 6–12%, used in coins, dairy equipment.
   2. **Martensitic:** hardenable, used for knives, screws.
   3. **Austenitic (18/8):** best corrosion resistance, used in utensils, chemical plants.
2. **Tool Steels**
   1. Designed for **hardness and red hardness**.
   2. **High-Speed Steel (HSS):** retains hardness up to 625°C; used for cutting tools.
   3. Composed of **W, Cr, V, Mo, C**.
3. **Special Alloy Steels**
   1. **Mn Steel:** work-hardening, wear-resistant (railway crossings).
   2. **Ni Steel:** corrosion resistant, used in turbine blades.
   3. **Cr Steel:** strong, used in heaters.
   4. **Si Steel:** magnetic, used in electrical machines.

Cast Iron

Cast iron is a class of iron-carbon alloys containing more than 2% carbon (usually between 2% and 5%) and 1–3% silicon. It is a hard, brittle material with a crystalline structure that is strong in compression but weak in tension. Cast iron is produced by melting iron and adding carbon and silicon along with small amounts of other elements like sulfur, manganese, and phosphorus. It has a lower melting point than steel and good fluidity when molten, making it easy to cast into complex shapes.

Cast Iron

- **Carbon >2% (typically 3–4%)**, much in **graphite form**.
- **Produced in cupola furnaces** using pig iron and scrap.
- **Properties:** brittle, high compressive strength, easy to cast and machine, corrosion resistant.

Types of Cast Iron

Type	Carbon Form	Characteristics	Uses
Grey	Graphite flakes	Brittle, self-lubricating	Machine beds, pipes
White	Cementite	Very hard, brittle	Rolls, malleable iron base
Malleable	Treated white iron	Tough, ductile	Fittings, small parts
Nodular	Graphite spheres (Mg added)	Strong, ductile	Gear housings, crankshafts
Alloy	With Ni, Cr, Mo, etc.	Wear C heat resistant	Engine parts, piston rings

Heat Treatment of Carbon Steels

Process	Purpose	Method	Effect
Annealing	Soften, relieve stress	Heat → soak → cool slowly	Increases ductility
Normalizing	Refine grains	Heat → air cool	Improves strength C structure
Hardening	Increase hardness	Heat → quench	Increases hardness, decreases ductility
Tempering	Reduce brittleness	Reheat → cool	Balances hardness C toughness
Case Hardening	Harden surface only	Add carbon to surface	Hard outer layer, soft core

Video steel Production

https://www.youtube.com/watch?v=OjWWcsocnJk

Wrought Iron

WROUGHT IRON It is the purest form of iron; although it may contain traces of carbon. It is usually made by "puddling process" and besides iron contains a small quantity of slag. It is very costly and its use has been almost totally replaced by cheaper steel. However, for some components like chain-links and chain-hooks wrought iron is still the preferred raw material. In old havelis/houses, one can still see iron railings and gates made of wrought iron.

Application

Non ferrous Material

- **Non-ferrous metals** are metals that **do not contain iron** in significant amounts.
- Common examples: **Copper, Aluminium, Tin, Lead, Zinc, Nickel, Magnesium, Antimony**.
- They are widely used for their **corrosion resistance, conductivity, and light weight**.

Copper

- **Properties:** Reddish-brown, corrosion resistant, excellent conductor of heat C electricity, ductile, and malleable.
- **Uses:** Electrical wires, coils, utensils, and decorative items.
- **Alloys:**
  - **Brass (Cu +Zn)** →Used for fittings, tubes, and decorative works.
  - **Bronze (Cu +Sn)** →Used for bearings, pumps, and sculptures.
  - **Cupro-nickel (Cu +Ni)** →Used for coins, marine fittings, and thermocouples.
- **Note:** India imports 50–60% of its copper needs.

Aluminium

- **Extracted from:** *Bauxite ore* (abundant in India).
- **Properties:** Silvery-white, lightweight (⅓ of steel's density), corrosion resistant, good conductor, ductile, and malleable.
- **Uses:**
  - Electrical transmission lines (replacing copper).
  - Aircraft, vehicles, and household utensils.
  - Packaging foils and beverage cans.
- **Important Alloys:**
  - **Duralumin (Al + Cu + Mg + Mn)** → Strong, used in aircrafts.
  - **Alclad (Al-coated duralumin)** → More corrosion resistant.
  - **Al–Si alloy (5–15% Si)** → Used in pistons (heat resistant).

Tin

- **Properties:** Silvery-white, corrosion resistant, low melting point.
- **Uses:** Alloying element in solders and bronzes, tin plating for corrosion protection.
- **Alloys:** Tin + Lead → Soft solder.

Lead

- **Properties:** Heavy, dull grey, corrosion resistant, soft, malleable, self-lubricating.
- **Uses:** Roofing, plumbing, acid containers, and pencil leads.
- **Alloying Use:** Added in small amounts to steel or bronze for machinability.

6. Zinc

- **Properties:** Bluish-grey, corrosion resistant, low melting point, high fluidity.
- **Uses:**
    - Coating steel (galvanizing → **G.I. sheets**).
    - Die-casting parts and torch batteries.
    - In **brass (Cu + Zn)** alloy.

Important Copper Alloys

Alloy	Main Elements	Properties / Uses
Brass	Cu + Zn	Ductile, corrosion resistant, used in fittings, tubes
Bronze	Cu + Sn	Strong, durable, used in bearings, bells, valves
Phosphor Bronze	Cu + Sn + P	High strength, fine castings
Leaded Bronze	Cu + Sn + Pb	Self-lubricating, easy machining
Gun Metal	88% Cu, 10% Sn, 2% Zn	Bearings, pumps, valves
Aluminium Bronze	Cu + Al	High strength, jewelry
Silicon Bronze	Cu + Si	Marine fittings
Manganese Bronze	Cu + Zn + Mn	Ship propellers
Beryllium Bronze	Cu + Be	Springs, bellows
Cupro-Nickel	Cu + Ni	Marine fittings, coins, resistors

Nickel Alloys

Alloy	Composition	Use
German Silver	Cu +Ni +Zn	Electrical contacts, jewelry
Monel Metal	Ni +Cu	Marine and chemical equipment
Nichrome	Ni +Cr	Heating elements
Inconel / Incoloy	Ni +Cr +Fe	High-temperature and electrical industries

Metal	*Tensile strength N/mm²*	*Colour*	*Specific Gravity*	*M.P. (°C)*	*Few important properties*
Copper	160	Reddish brown	8.9	1083	Good conductor, soft, ductile and malleable
Aluminium	60	White	2.7	660	Good conductor, very soft, ductile and malleable
Tin	13	Silvery white	7.3	232	Good appearance, acid resistance, soft
Lead	15	Dull grey	11.4	327	Very heavy, good corrosion resistance against H_2SO_4
Zinc	155	Bluish, white	7.1	419	Good corrosion resistance and fluidity when molten

Note: For comparison, tensile strength of Iron is 270 N/mm^2.

Difference Between Ferrous and Non ferrous Materials

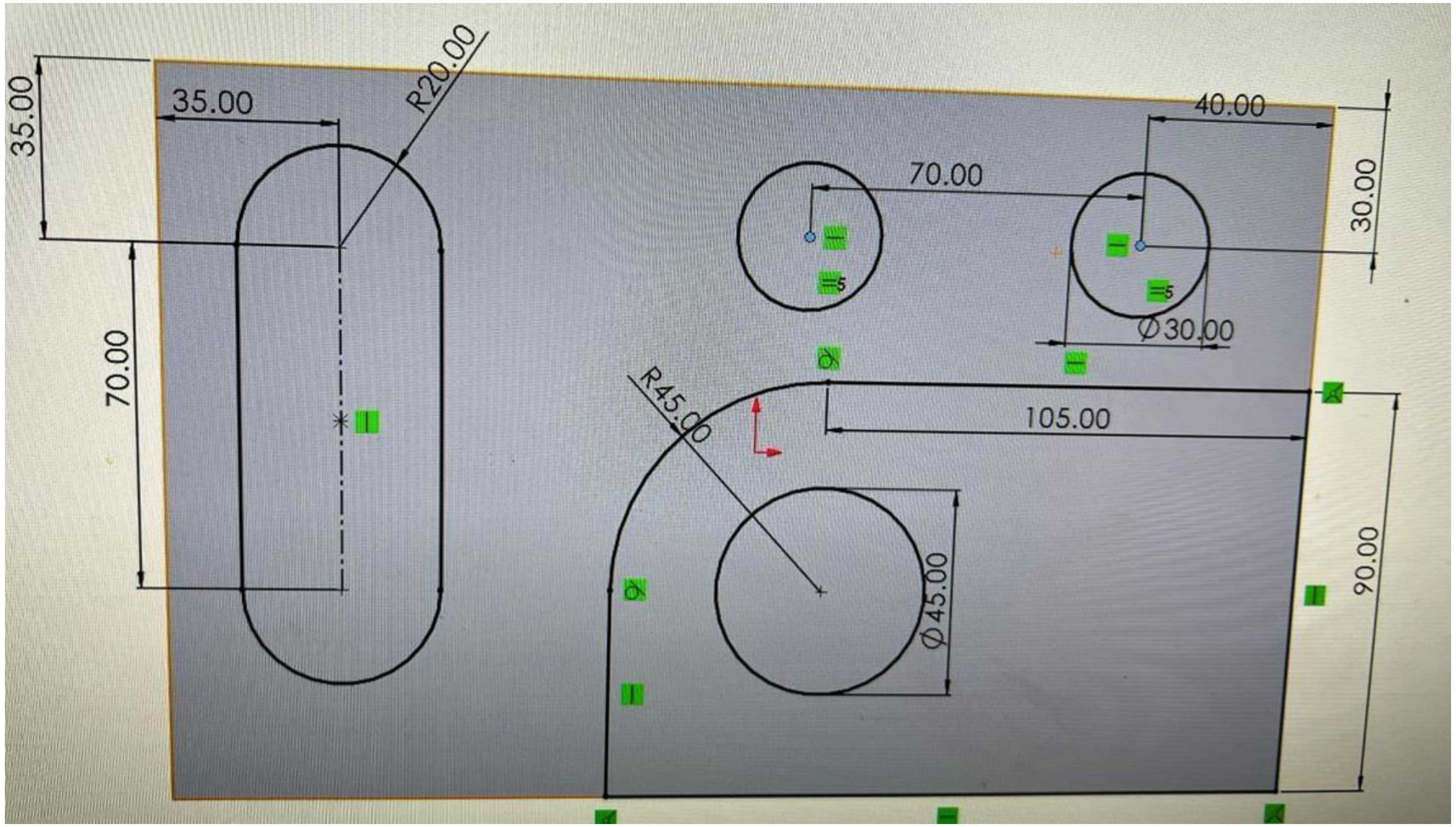
Property	Ferrous Material	Non-Ferrous Material
Main Element	Iron	No significant iron
Strength	High	Varies, usually lower
Corrosion	Prone to corrosion	Resistant to corrosion
Magnetic	Usually magnetic	Non-magnetic
Examples	Steel, Cast Iron	Aluminum, Copper, Brass
Weight	Heavier	Lighter

Homework

1. Differentiate between ferrous and non-ferrous materials.
2. What are characteristic properties of copper and aluminium, which make them useful to mankind?
3. Differentiate between bronzes and brasses. Mention two applications of each.
4. Write a short note on aluminium and its alloys.
5. What are the different types of brasses you know? Distinguish between Naval and Admiralty
brass.
6. What are cupro nickel? What are their main properties and applications?

Milling Operation Using SolidWorks

- Create a 3D model of a workpiece.Define a milling setup using SolidWorks CAM.
- Generate tool paths for roughing and finishing operations.
- Simulate the milling process and observe material removal.
- Analyze and interpret machining time and efficiency



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Question

- What is fracture of materials, and what are the main types?
- What are the characteristics of ductile fracture? Give an example.
- What are the characteristics of brittle fracture? Give an example.
- What are other types of fracture like fatigue and creep?
- Define ferrous materials and non-ferrous materials.
- What are the key properties of iron and steel?
- What is the difference between plain carbon steel and alloy steel?
- List types of carbon steel and their common uses.
- How does carbon content affect strength, hardness, and ductility of steel?
- What are the properties and uses of wrought iron?
- What are alloy steels and list some examples.
- Explain the types and uses of cast iron.
- Describe common heat treatment processes of carbon steels.
- What is wrought iron and its common uses.
- List common non-ferrous metals and their properties.
- Describe key properties and uses of copper and its alloys.
- What are the properties and uses of aluminum and its alloys?
- What are the properties and uses of tin and lead?
- What are the properties and typical uses of zinc?
- List important copper alloys with composition and uses.
- Differentiate between ferrous and non-ferrous materials.
- Explain characteristics and applications of brasses and bronzes.