Metals – I

(Ferrous alloys)

Instructor : Prof. Bishakh Bhattacharya
Dept. of Mechanical Engineering
IIT Kanpur
India

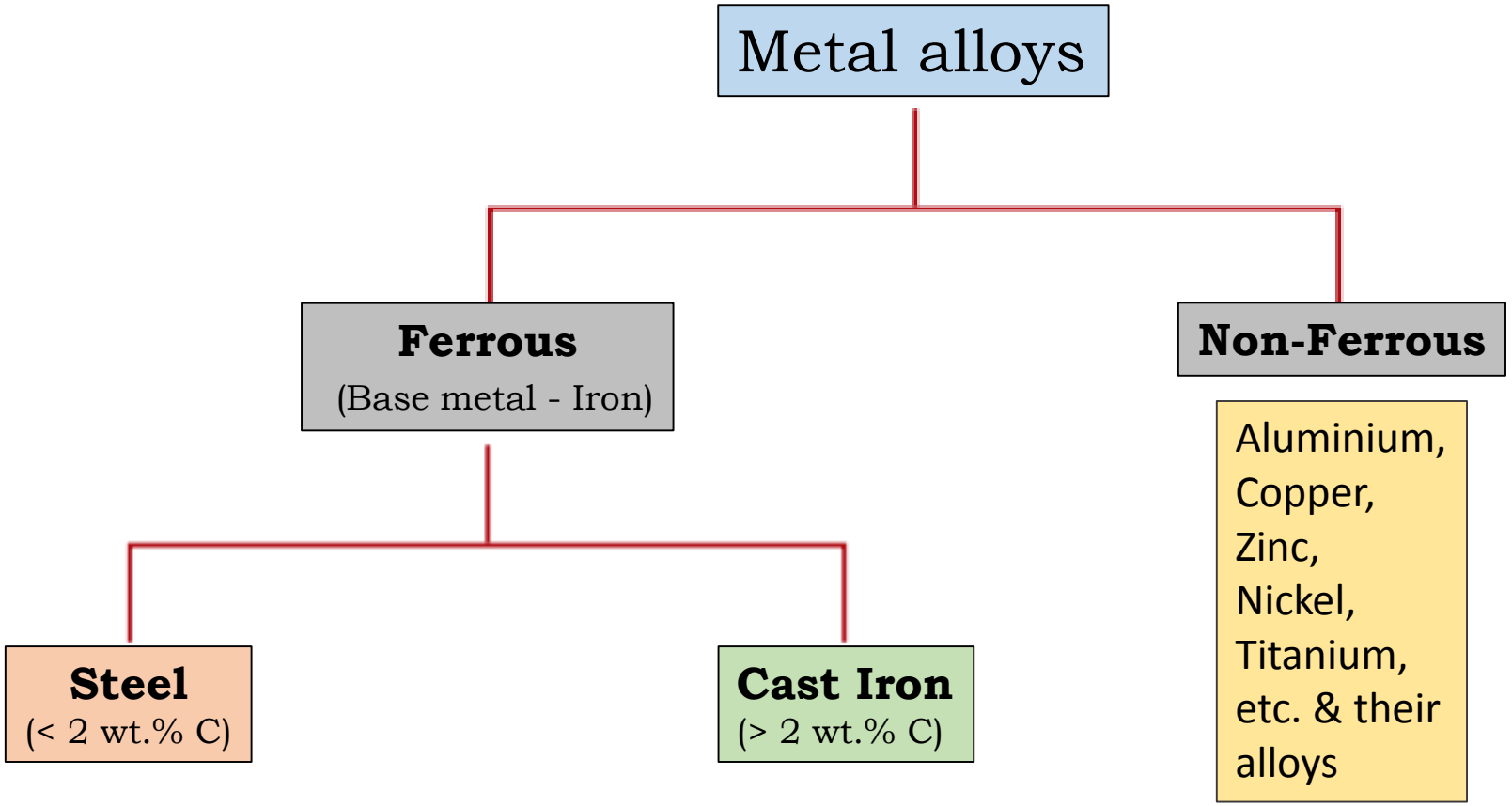
E-mail : *bishakh@iitk.ac.in*

Smart Materials Structures and Systems
Laboratory
IIT Kanpur

Content

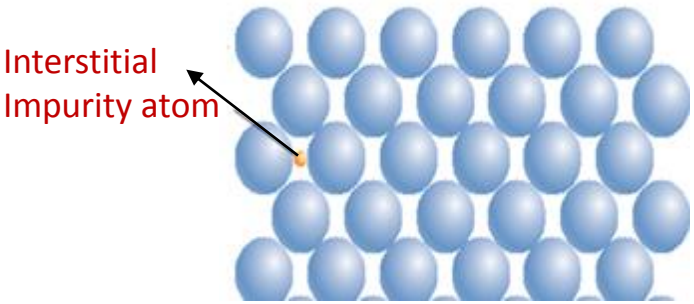
- ✓ **Classification of Ferrous alloys**
- ✓ **Types of steel**
- ✓ **Effect of impurities**
- ✓ **Cast Iron**

Classification of Metal Alloys



Iron

- The Iron Age began about 3000 years ago and **continues till today**.
- Carbon forms an **interstitial solid solution** when added to **iron** to form **Steel** as the **atomic radius** of the carbon (0.071 nm) atom is **much less** than that for iron (0.124 nm).
- Use of iron and steel has changed drastically the human development.
- Iron posses **allotropy** - exist in two or more **different forms** in the **same** physical **state**.
  - ✓ T < 770^{o}C : Ferrite (α-iron), Ferromagnetic, BCC crystal structure.
  - ✓ T = 770 - 912^{o}C : β–iron, paramagnetic, BCC crystal structure.
  - ✓ T = 912 -1394^{o}C : γ-iron (austenite), FCC crystal structure.
  - ✓ T = 1394-1538^{o}C : δ-iron, BCC crystal structure.



Reference: W.D Callister, 7 Ed.

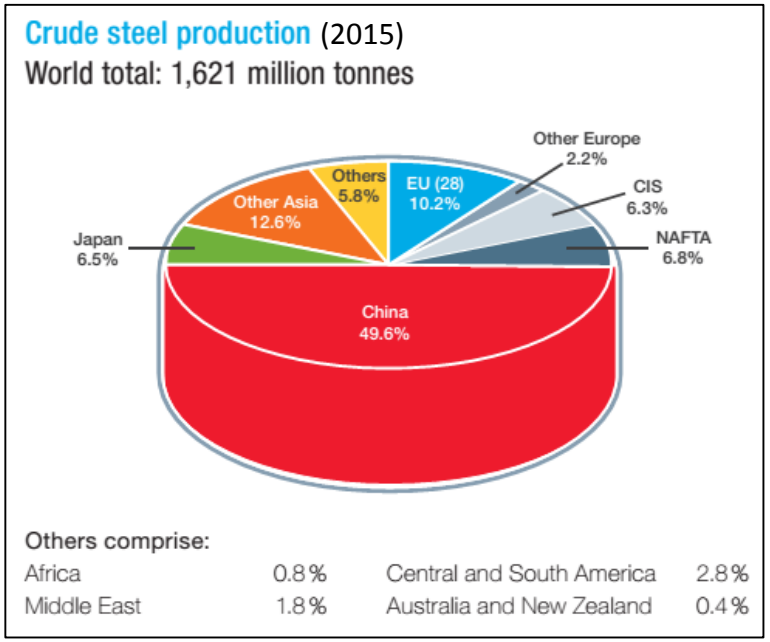
Another allotropic form called Hexaferrum at 10GPa pressure

Iron becomes Anti-ferromagnetic!

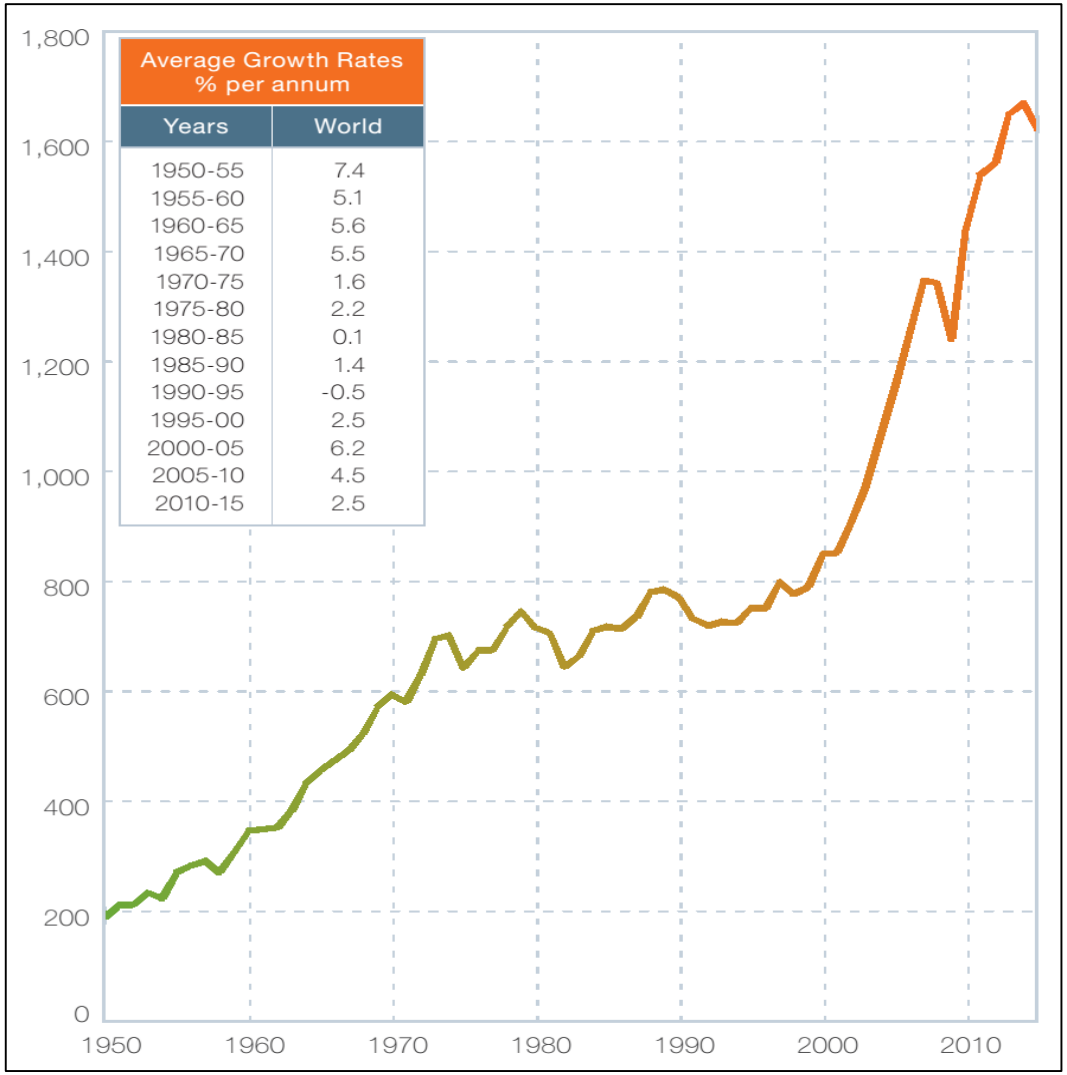
World Crude Steel Production (1950 - 2015)

Reference: World Steel Association Report - 2016

- World crude steel production reached **1,621 million tonnes** for the year **2015**, in which **China** accounted for about **50 %** of the **global market for steel** (by volume).



CIS: Commonwealth of Independent States
NAFTA: North American Free Trade Agreement(USA, Canada, Mexico)
EU: European Union



SMSS
Smart Materials Structures and Systems Laboratory
IIT Kanpur

Top Steel Producing Countries & Companies (2015)

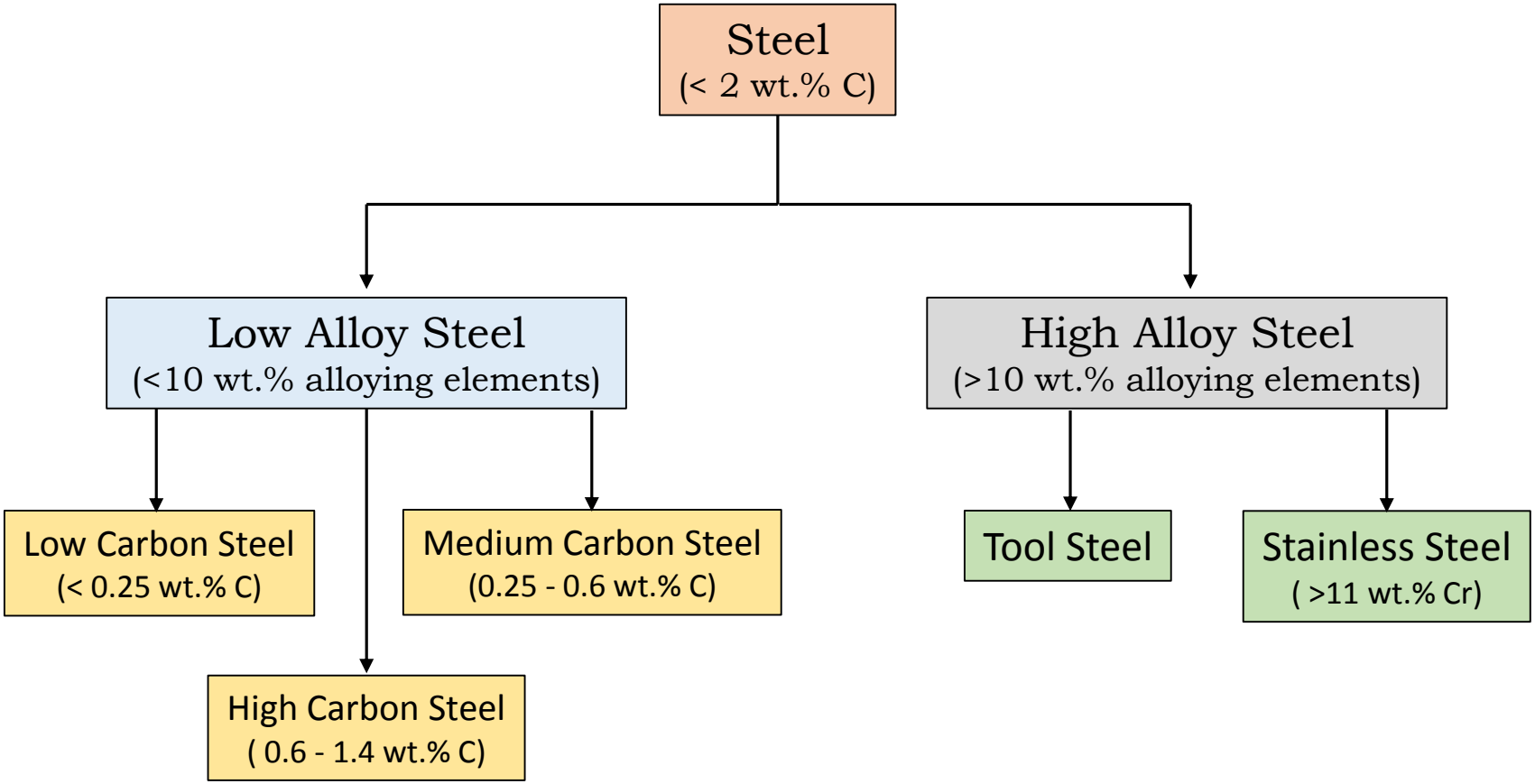
Rank	Country	Million tonnes per annum
1	China	803.8
2	Japan	105.2
3	**India**	**89.4**
4	United States	78.8
5	Russia	70.9
6	South Korea	69.7
7	Germany	42.7
8	Brazil	33.3
9	Turkey	31.5
10	Ukraine	23.0

Reference: World Steel Association Report - 2016

Rank	Company	Million tonnes per annum (2015)
1	Arcelor Mittal	97.14
2	Hesteel Group	47.75
3	NSSMC	46.37
4	POSCO	41.97
5	Baosteel Group	34.94
6	Shagang Group	34.21
7	Ansteel Group	32.50
8	JFE Steel Corporation	29.83
9	Shougang Group	28.55
10	**Tata Steel Group**	**26.31**
26	**SAIL**	**14.34**
30	**Jindal Steel Limited**	**12.42**

Rank 10, 26 & 30 are held by Indian group of companies

SMSS
Smart Materials Structures and Systems Laboratory
IIT Kanpur



Low alloy steel is further divided into Plain carbon steel and Alloy steel of respective category.

As per **American Iron and Steel Institute** (AISI) definition for **Plain carbon steel:**

- ✓ When no minimum content is specified for alloying element (Cr, Co, Mo, Ni, Ti, W, V, Zr, etc.) to be added to obtain a desired effect.

OR

- ✓ When the specified minimum amount for copper (Cu) does not exceed 0.40 percent.

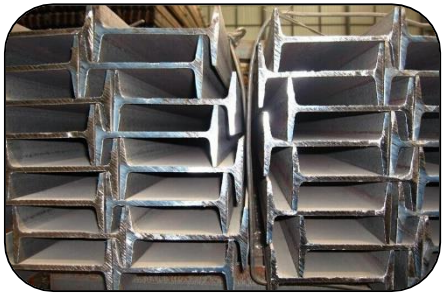
OR

- ✓ When the maximum content for any of the following elements does not exceed the percentages: Manganese (1.65), Silicon (0.60), Copper (0.60).

- Effects of increasing carbon content in steel are:
  - ✓ Increase in hardness & strength.
  - ✓ Decrease in weldability.
  - ✓ Decrease in ductility.
  - ✓ Decreased machinability (about 0.2 to 0.25 wt.% C provides the best machinability).

Low Carbon Steel

- Contain less than about 0.25 wt.% C (Mild steel).
- Relatively soft and weak.
- Outstanding ductility (25% EL) & toughness.
- Also, high machinability and weldability.
- Least expensive to produce.
- Tensile strength (415-550 MPa).



Low alloy steel:

- Contains alloys such as Cu, V, Ni & Mo up to 10 wt.%
- High strength & corrosion resistance than plain low carbon steel.
- Tensile strength up to 700 MPa.

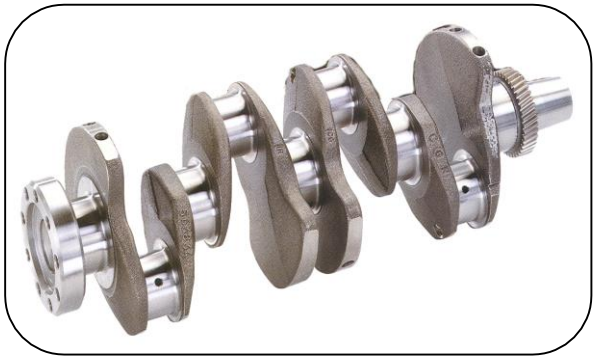
Applications:
Beams, Channels, nuts, bolts, wires, tin cans, etc.

Medium Carbon Steel

- Contain 0.25 - 0.6 wt.% C.
- Stronger than low-C steels but of low ductility and toughness.
- Good wear resistance.
- Plain carbon steel (Tensile strength up to 850 MPa) & alloy steel (Tensile strength up to 1900 MPa)
- **Applications**: Railway wheels & tracks, gears, crankshafts, etc.

Rail wheels

Gears



Crankshaft

High Carbon Steel

- 0.6 - 1.4 wt. % C .
- Hardest, strongest and least ductile carbon steel.
- Can be alloyed with other metals to form very hard and wear resistance material (e.g. Cr, Ni, W, Mo and V).
- **Applications**: Cutting tools, embossing dies, saws, concrete drills, etc.

Die

Circular saw

Concrete drill

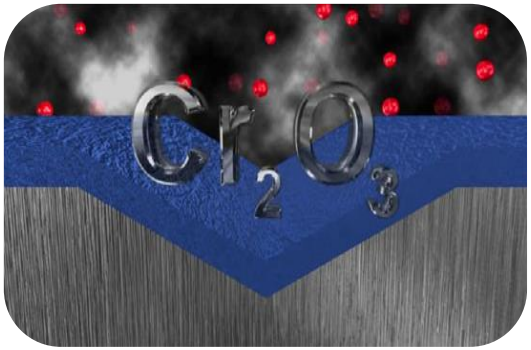
High Alloy Steel(>10 wt.% alloys) - Tool Steel

- ✓ Commonly used in drill bits & other rotating cutting tools.
- ✓ It can withstand higher temperatures without losing its hardness & toughness.
- ✓ **Example**
  - ❖ 18-4-1 HSS: 18% tungsten, 4% chromium, 1% vanadium with a carbon content of 0.6 - 0.7%.
  - ❖ Cobalt high speed steel – increased heat resistance
  - ❖ Molybdenum high speed steel – Mo increases hardness and wear resistance. Also cost effective replacement for tungsten in tool steels.

SMSS Smart Materials Structures and Systems Laboratory IIT Kanpur

High Alloy Steel - Stainless Steel

- Highly resistant to corrosion in a variety of environment.
- Predominant alloy: **Chromium (at least 11 wt.%).**
- **Example**: 18/8 stainless steel - 18% chromium and 8% nickel.
- **Applications**:
  - ✓ Cryogenic vessels.
  - ✓ Food processing equipment's.
  - ✓ Gas turbines parts.
  - ✓ High-temperature steam boilers.
  - ✓ Heat-treating furnaces.
  - ✓ Nuclear power generating units.



Passivation

Christian Friedrich Schönbein

Reference: www.surfox.com

Effect of alloying elements on Steel

S.No.	Element	Effects
1.	Boron (B)	✓ Improves hardenability without the loss of machinability.
2.	Chromium (Cr)	✓ Improves oxidation (at high temperature) and corrosion resistance. ✓ Corrosion resistance may also be enhanced by Ni and Mo additions.
3.	Cobalt (Co) & Tungsten (W)	✓ Improves strength and hardness at elevated temperatures.
4.	Sulphur (S)	✓ Improves machinability when combined with manganese. ✓ Alone it increases brittleness & lowers impact strength and ductility.
5.	Manganese (Mn)	✓ Improves hardenability & wear resistance. ✓ Counteracts the brittleness caused by Sulphur.
6.	Molybdenum (Mo)	✓ Improves hardenability, toughness. ✓ Improves elevated-temperature strength, creep resistance.
7.	Nickel (Ni)	✓ Increases strength and hardness without sacrificing ductility and toughness.
8.	Vanadium	✓ Increases strength, hardness, wear resistance and resistance to shock impact at high temperature.
9.	Titanium	✓ Improves strength. ✓ Deoxidizes steels.

Relative effect on Steel

	Cr	Mn	Mo	Ni	Ti	W	V
Hardenability	++	++	++	+	++	++	+++
High temperature Strength	+		++	++	+	++	++
Ductility & Toughness		+		++			
Wear resistance	+		+		+	++	+
Promote fine grain size			+		++	+	+++
Corrosion resistance	++		+	+			

Hardness is a material property & is a resistance to penetration, scratching, etc.

Hardenability is a way to indicate a **material's potential** to be hardened by heat treatment.

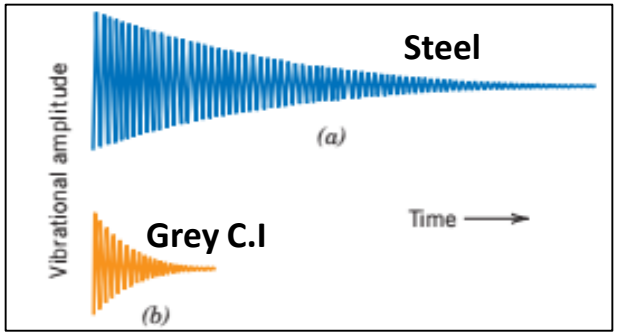
Cast Iron Types

(> 2 wt.% C)

1. Grey Cast Iron

- ✓ Carbon content varies from 2.5 – 4.0 wt.%.
- ✓ Graphite exists in the form of flakes.
- ✓ Graphite flakes gives **self-lubricating** property and **vibration damping** capability.
- ✓ Strength and ductility are much higher under compressive loads.
- ✓ Tensile strength = 120 – 280 MPa.
- ✓ **Application**: Base structures for machines and heavy equipment that are exposed to vibration.

Grey Cast Iron microstructure



Damping capacity

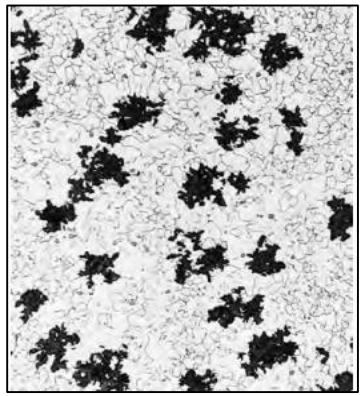
2. White/Chilled Cast Iron

- ✓ No graphite, carbon in the form of carbide (cementite – hardest constituent of iron)
- ✓ Formed by rapidly cooling molten iron.
- ✓ Very hard, wear and corrosion resistant.
- ✓ Almost non - machinable.
- ✓ Application: Rollers in rolling mills.

White Cast Iron microstructure

3. Malleable Cast Iron

- ✓ Formed by **heating white C.I** between 800-900^{o}C for a **prolonged time** in a neutral atmosphere (to prevent oxidation) leads to the decomposition of the cementite, **forming graphite** in the form of **clusters**.
- ✓ Highly shock resistant or tough.
- ✓ Tensile strength = 350 – 450 MPa.
- ✓ Can be hammered to small thickness.
- ✓ **Applications**: Connecting rods, transmission gears, and differential cases for the automotive industry and flanges, pipe fittings, and valve parts.

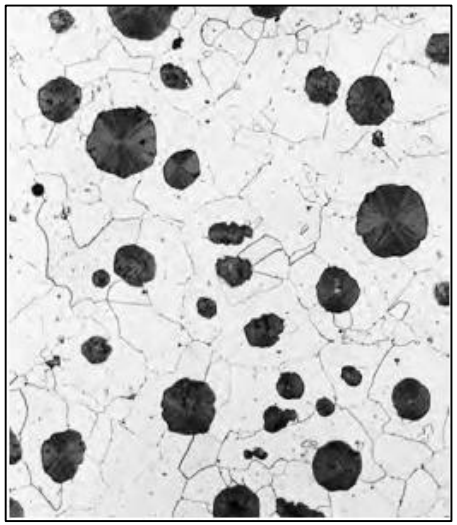


Malleable Cast Iron microstructure

Reference: W.D Callister, 7 Ed.

4. Ductile/Nodular/Spheroidal Cast Iron

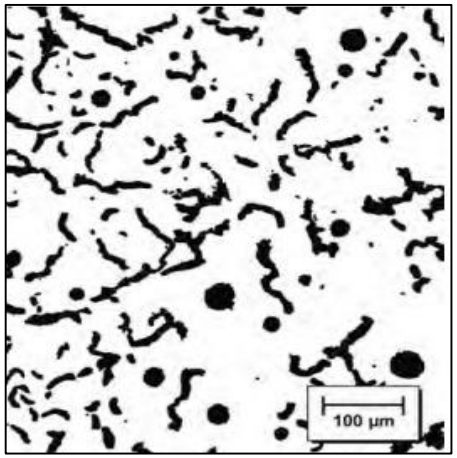
- ✓ Obtained by adding small amount of Magnesium (0.1-0.8%) to molten Grey C.I leading to the formation of graphite in the forms of spheres.
- ✓ High fluidity.
- ✓ High Tensile strength (400 – 900 MPa).
- ✓ Tough, wear resistant.
- ✓ Good machinability and weldability.
- ✓ Designated as SG 900/2 representing tensile strength and % elongation.



Ductile Cast Iron microstructure

5. Mottled/Compacted Cast Iron

- ✓ Product in between Grey and ductile C.I
- ✓ Carbon partly free and combined form.
- ✓ Graphite has worm-like appearance.
- ✓ Higher thermal conductivity.
- ✓ Better resistance to thermal shock
- ✓ Lower oxidation at elevated temperatures
- ✓ Application: diesel engine blocks, exhaust manifolds, gearbox housings, flywheels, etc.



Compact Cast Iron microstructure

Reference: W.D Callister, 7 Ed.

Effect of Impurities on Cast Iron

1. Silicon (Si)

- ✓ Provides formation of free graphite, makes iron soft and easily machinable.
- ✓ Produces sound casting free from blow-holes as having high affinity for oxygen.

2. Sulphur (S)

- ✓ Makes C.I hard and brittle.
- ✓ Above 0.1% makes gives unsound casting.

3. Manganese (Mn)

- ✓ Makes C.I hard by formation of carbide.
- ✓ Keeps control over harmful effects of sulphur.

4. Phosphorous (P)

- ✓ Imparts fusibility & fluidity but induces brittleness.

In the **next lecture**, we will learn:

- **Metals (Non-Ferrous alloys)**
  - ✓Classification
  - ✓Properties

SMSS
Smart Materials Structures and Systems
Laboratory
IIT Kanpur