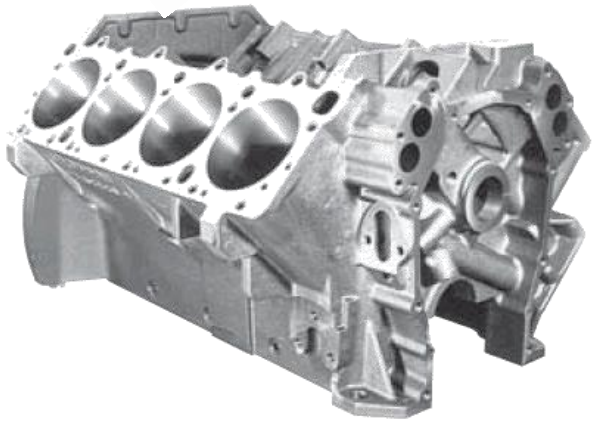
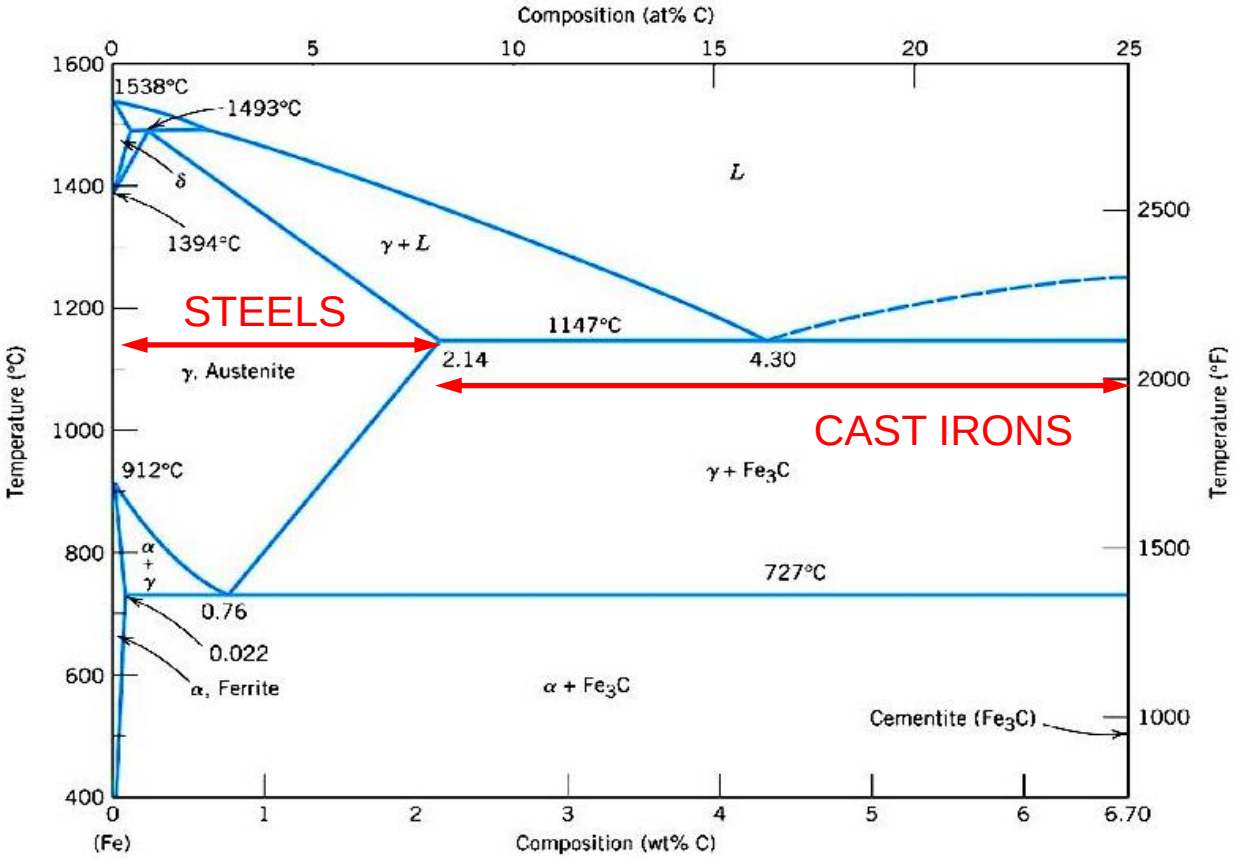
CAST IRONS



MSE 206-Materials Characterization I
Lecture-6

Iron-Carbon (Fe-C) Phase Diagram



- Cast Iron is an alloy of iron and carbon containing 2.1%-6.7% C. In addition, silicon, manganese, sulphur and phosphorus are contained in varying amounts.
- Elements such as nickel, chromium, molybdenum, vanadium can be added to produce alloy cast irons

- **Since carbon makes iron brittle, carbon changes between 2.5% to 4% in commercial cast irons. Additionally, cast irons contain Si as main alloying element between 1-3 %.**

Engineering importance of cast iron

- Cast Irons may often be used in place of steel at considerable cost savings. The design and production advantages of cast iron include:
  - Low tooling and production cost
  - Ability to cast into complex shapes
  - Excellent wear resistance and high hardness (particularly white cast irons)
  - High inherent damping capabilities (gray cast irons)
- They are produced by casting because commercially used cast irons have relatively lower melting points while they are brittle and hard to fabricate.

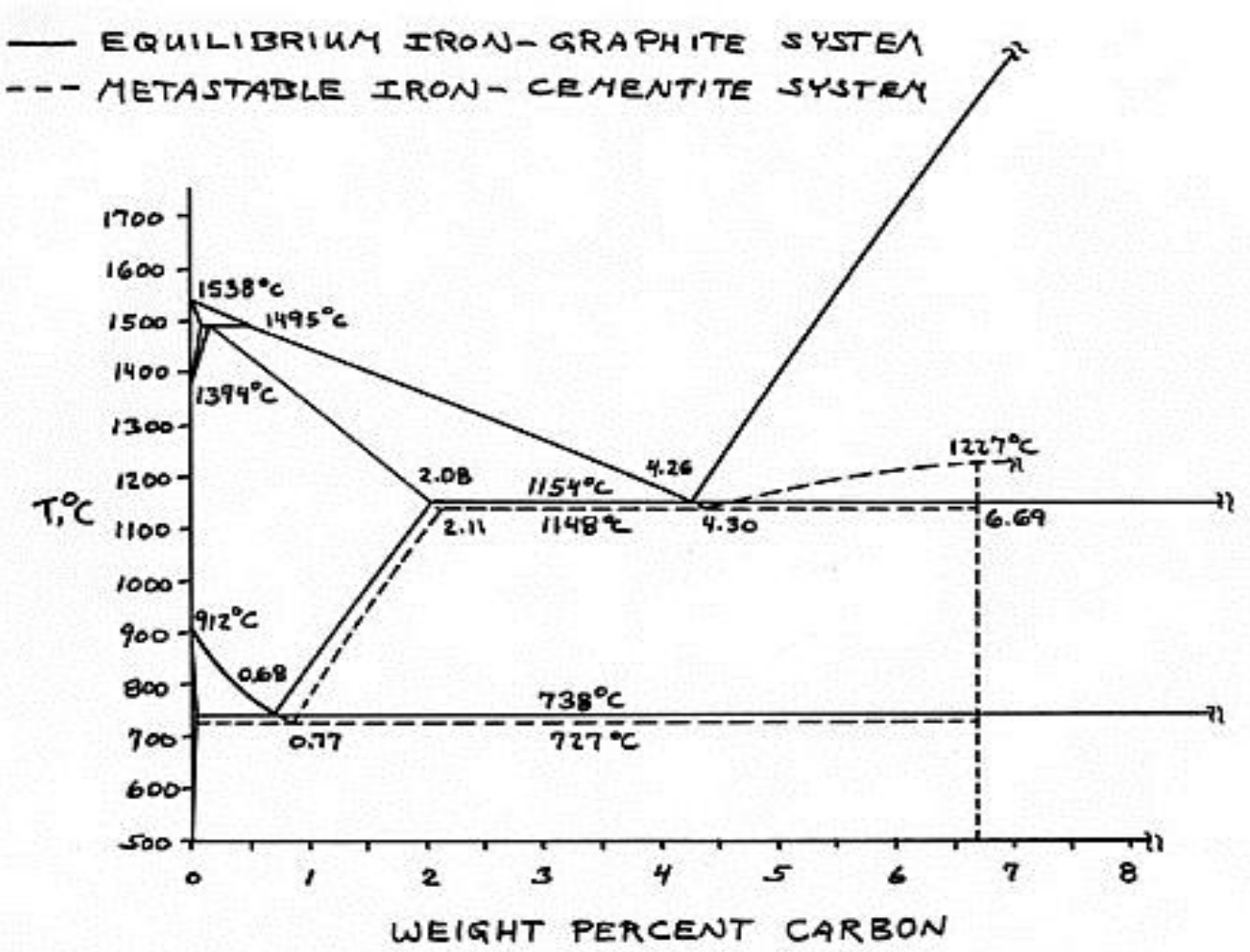
Types of cast iron

- White Cast Iron
- Malleable Cast Iron
- Gray Cast Iron
- Nodular (Ductile) Cast Iron
- Chilled Cast Iron

What determines the type of cast iron?

1) **%Si & %C content:** Increasing Silicon and carbon content retards cementite formation, stabilizes graphite.
2) **Cooling rate:** slow cooling favors graphitization.
3) **Temperature:** At high temperatures (>1000ºC) Fe_3C tends to decompose to form graphite

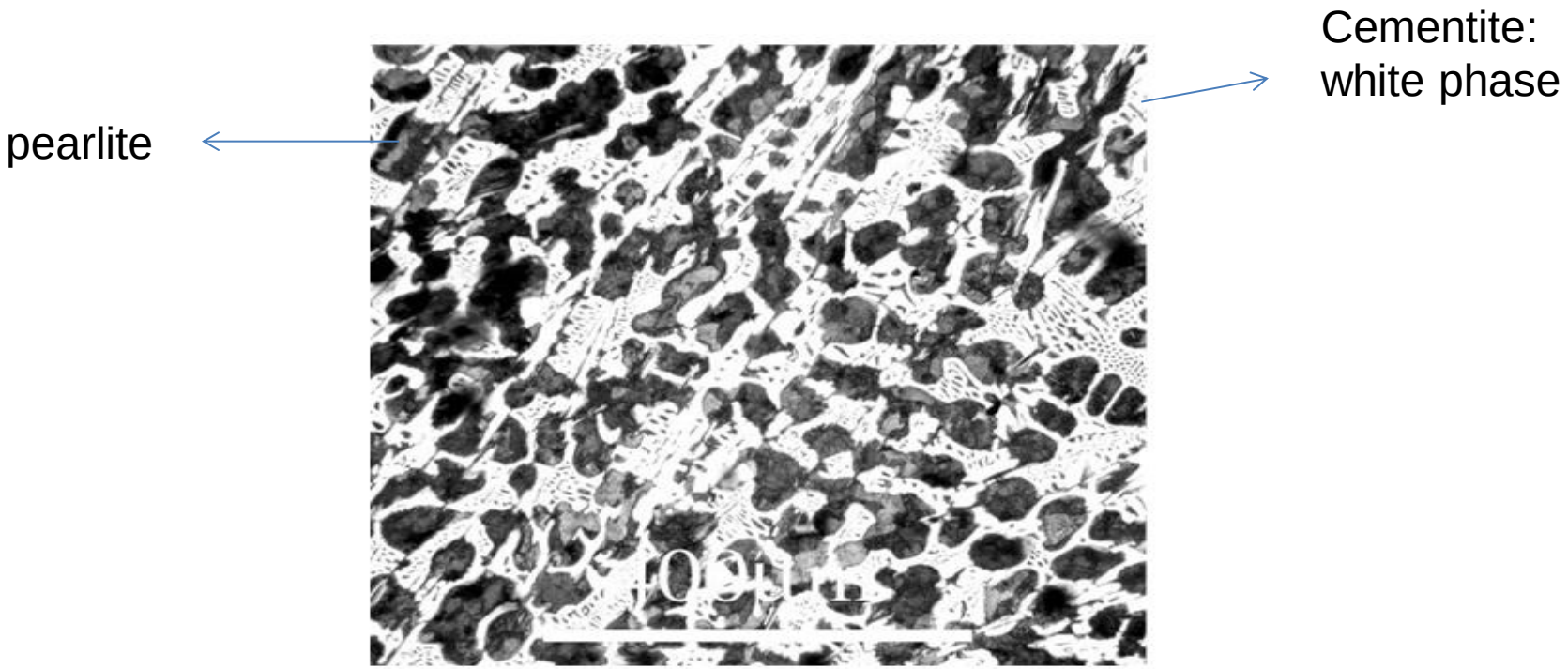
Fe-C and Fe-Fe_3C Systems



- For Gray cast irons Fe-C system is used, whereas Fe-Fe_3C system is used for white cast irons

White Cast Iron

- In **low-silicon** cast irons with **high cooling rates**, most of the carbon exists in cementite instead of graphite
- Such alloys have a white appearance on their fracture surface and therefore called White Cast Iron (WCI)
- Matrix is always cementite for these alloys



White Cast Iron: Properties and Applications

- Used in applications requiring wear resistance:
  - -Cement mixers, extrusion nozzles, spacers, spools in farm machinery
  - -In the textile industry - bearings, mill liners, etc.

- Fe_3C makes WCI hard and brittle. White cast irons have high wear resistance but they are extremely brittle and difficult to machine.

- Most of the WCI is produced to manufacture Malleable Cast Iron.

Malleable Cast Iron

- By malleabilization process white cast iron is converted into Malleable cast iron
- There is a tendency for cementite to decompose into iron and carbon. During malleabilization heat treatment cementite decomposition occurs.

$$Fe_3C \rightarrow 3Fe + C$$

Malleabilization Process;

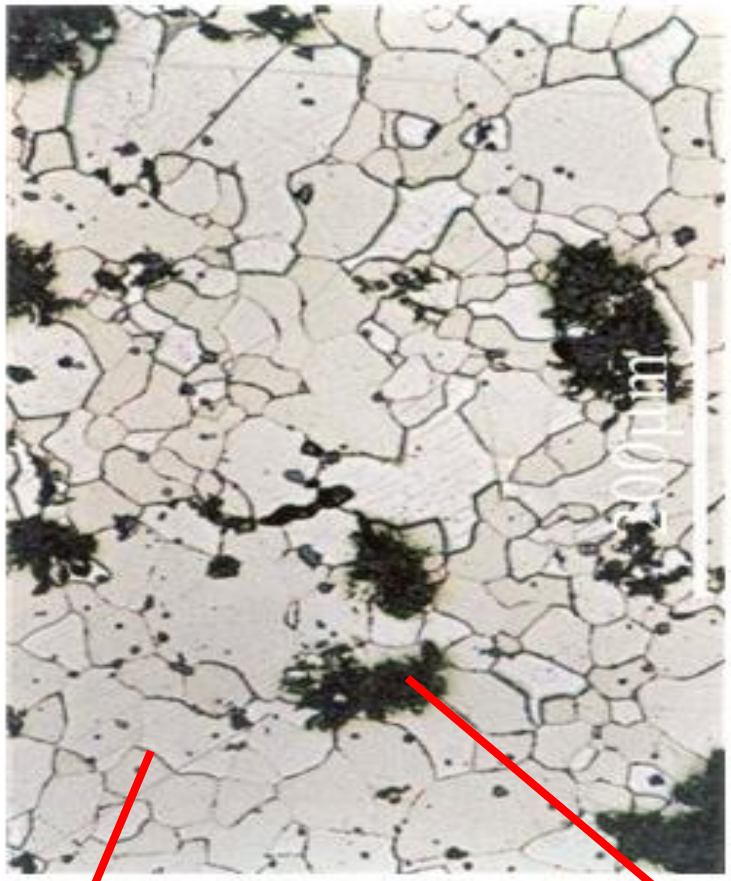
Process contains 2 steps:

Step1-Heat the white cast iron 800-900^{o}C. During holding at this temperature γ occurs and cementite in WCI dissolves ($Fe_3C \rightarrow 3Fe + C$). Graphite nuclei grows in all directions and appear as irregular nodules and spheroids called **temper carbon.** After that the casting is cooled as rapidly as practical to about 760^{o}C.

Step2- The part is cooled from 760^{o}C to room temperature at different cooling rate. (slow, fast, moderate)

Malleable Cast Iron

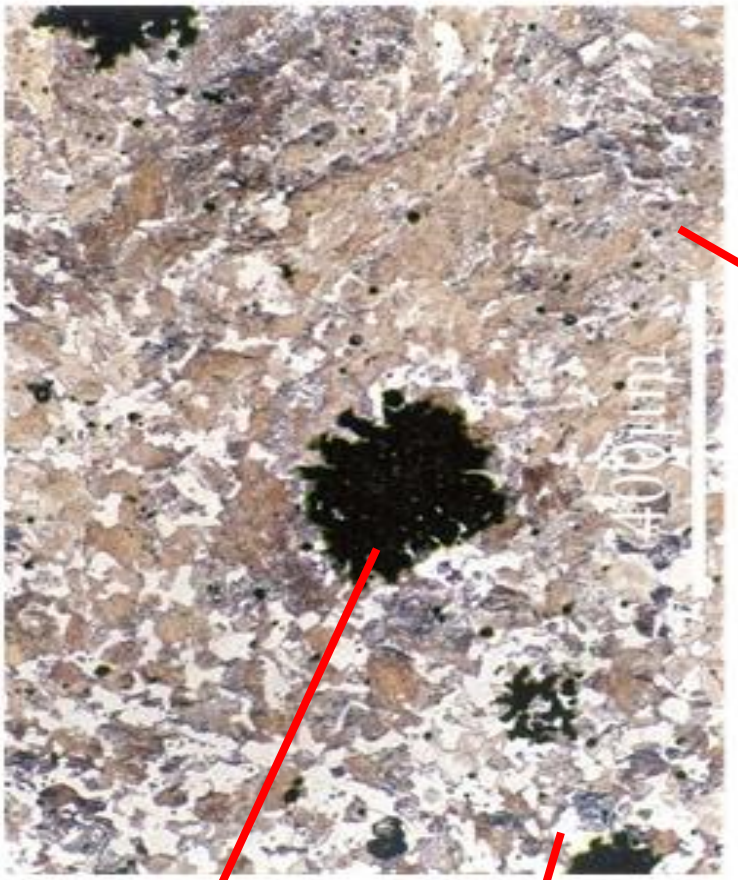
Slow cooling



ferrite

graphite rosettes

Moderate cooling



pearlite

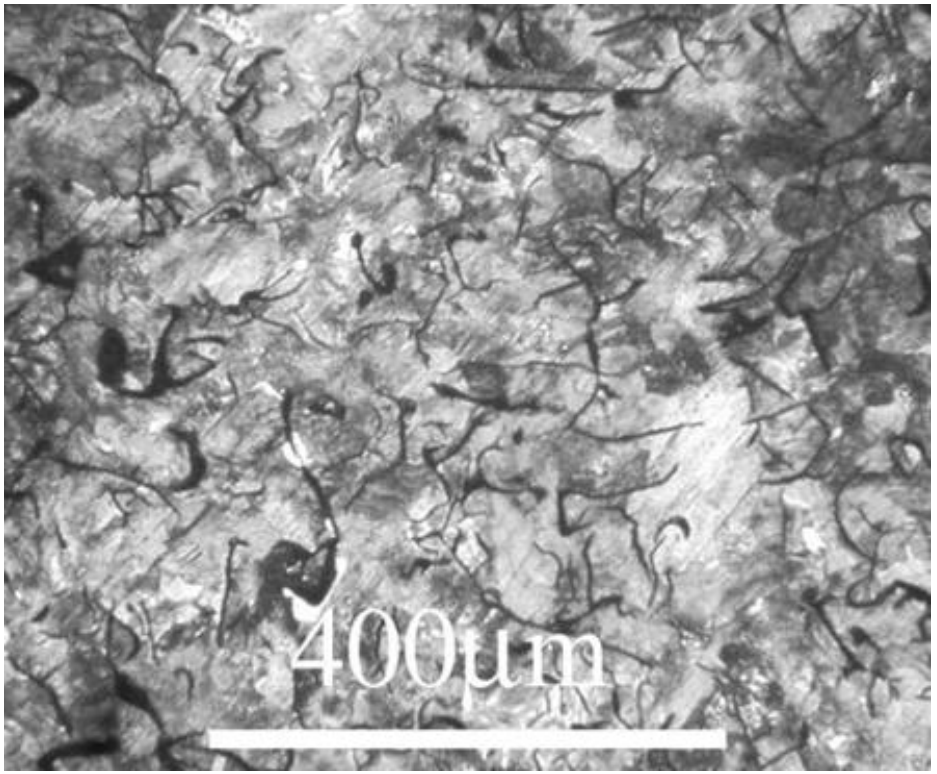
Ferrite (white regions)

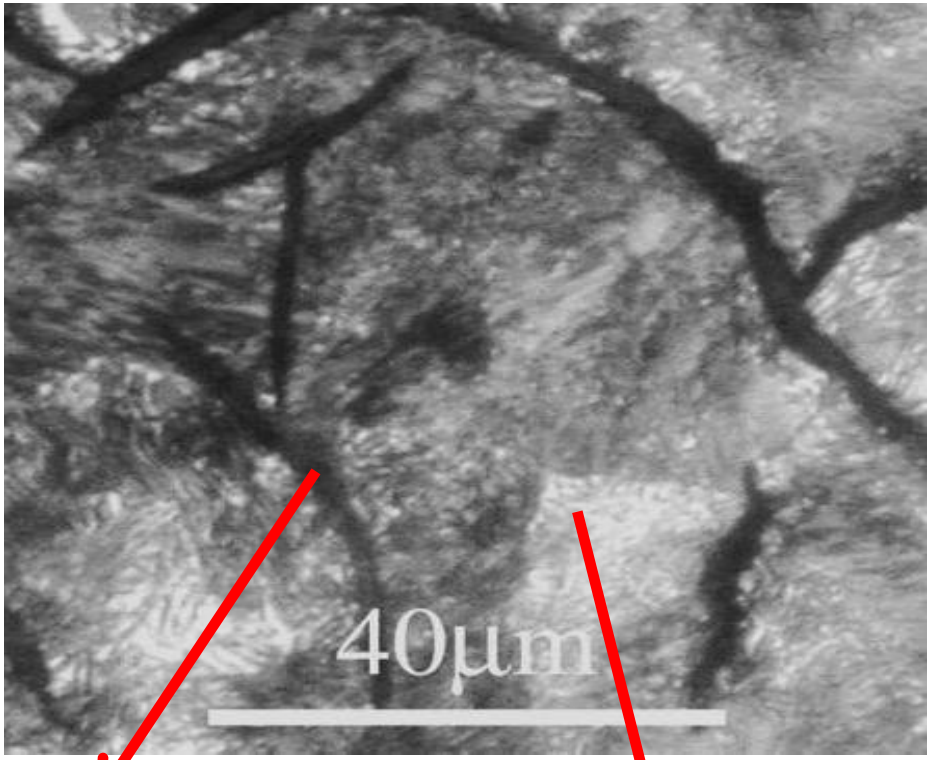
Gray Cast Irons

- Most widely used group of cast irons
- Most gray cast irons are hypoeutectic alloys containing between 2.5 and 4% C
- In high-silicon , high carbon cast irons with slow cooling rate carbon occurs in the form of graphite.
- To examine phase transformations in gray cast irons Fe-C equilibrium phase diagram is used.

Gray Cast Irons: Hypoeutectic Alloys Microstructures

Hypoeutectic Gray Cast Iron with pearlitic microstructures





Gray Cast Irons

Advantages

- Graphite acts as a chip breaker and a tool lubricant.
- Very high damping capacity.
- Good thermal conductivity
- Good dry bearing qualities due to graphite.
- Good corrosion resistance in many common engineering environments.

Disadvantages:

- Brittle (low impact strength) which severely limits use for critical applications.
- Graphite acts as a void and reduces strength. Maximum recommended design stress is 1/4 of the ultimate tensile strength. Maximum fatigue loading limit is 1/3 of fatigue strength
- Changes in section size will cause variations in machining characteristics due to variation in microstructure
- Higher strength gray cast irons are expensive to produce...

Chilled Cast Irons

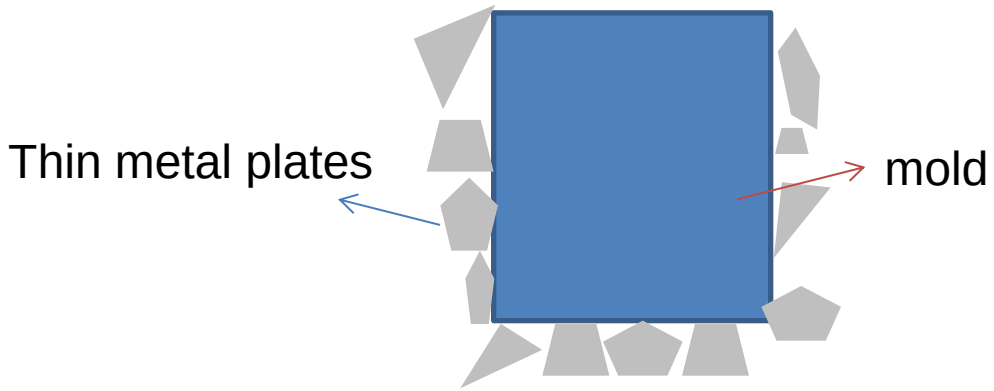
- It is made by casting the molten metal against a metal chiller (results WCI region near the surface and GCI region in interior parts)

Surface: Hard abrasion resistance
Interior : Relatively softer

- The structure is obtained by carefull control of alloy composition and cooling rate.

Chilled Cast Irons

- During production metal liners (chills) are placed on the surface of the mold.

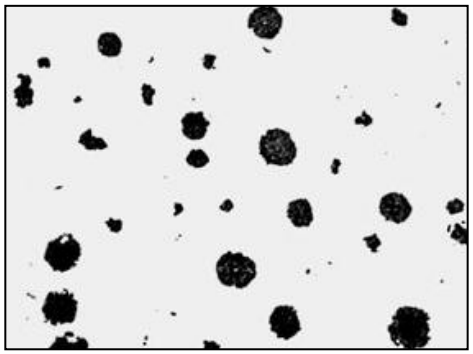


- The depth of WCI layer is controlled by adjusting the amount of metal plates

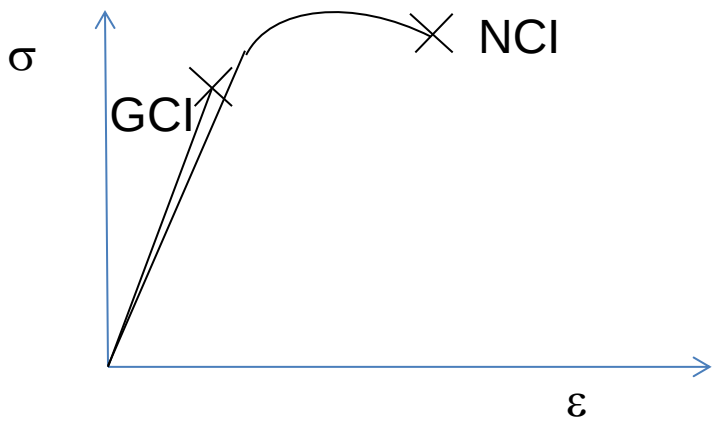
- Thin WCI layer is obtained by using thin metal plates, while thicker WCI region is obtained by heavier metal plates.

Nodular Cast Irons

- Known also as ductile iron, spheroidal graphite iron, spherulitic iron
- Graphite is present as tiny balls and spheroids



- Has higher strength and toughness than gray cast iron



Nodular Cast Irons

- Gray cast irons are mechanically weak and brittle due to sharp tips and brittleness of graphite flakes which act as stress concentration points and produce “notch-effect”.

Production of Nodular cast iron

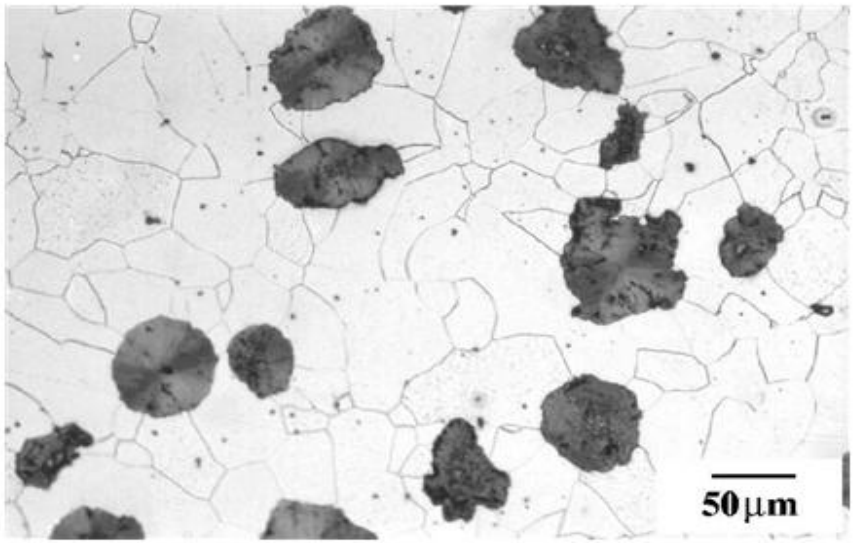
<u>To form graphite as sphere like particles:</u>

✓Calcium Carbide addition to molten Iron to lower the S content to suppress graphite flake formation.

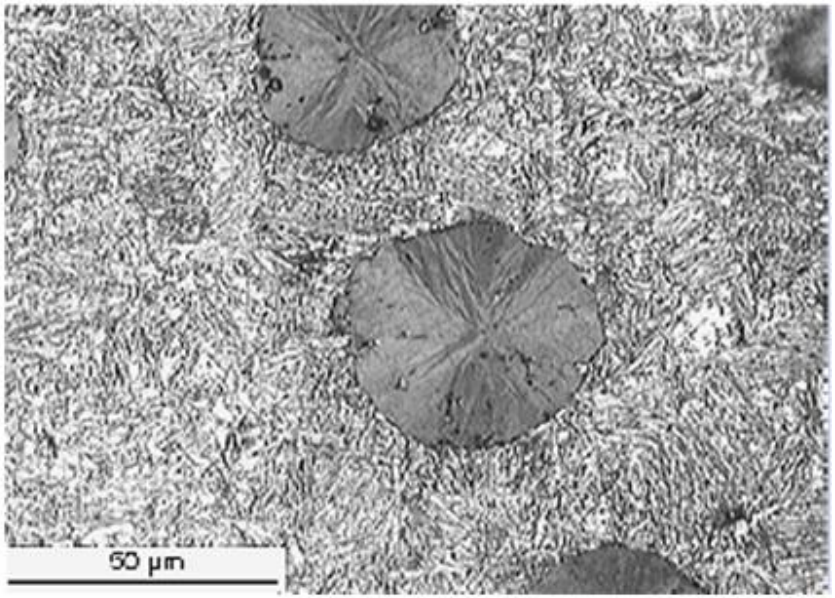
✓Mg or Ce addition to impede directional growth and lead to isotropic growth.

Nodular Cast Irons

- The surrounding matrix will be ferritic upon very slow cooling because all carbon in the matrix diffuses to the nodules resulting in Ferritic nodular cast iron
- *At* moderate or high cooling rates matrix will be pearlitic and at even higher cooling rates it may be bainitic or martensitic.



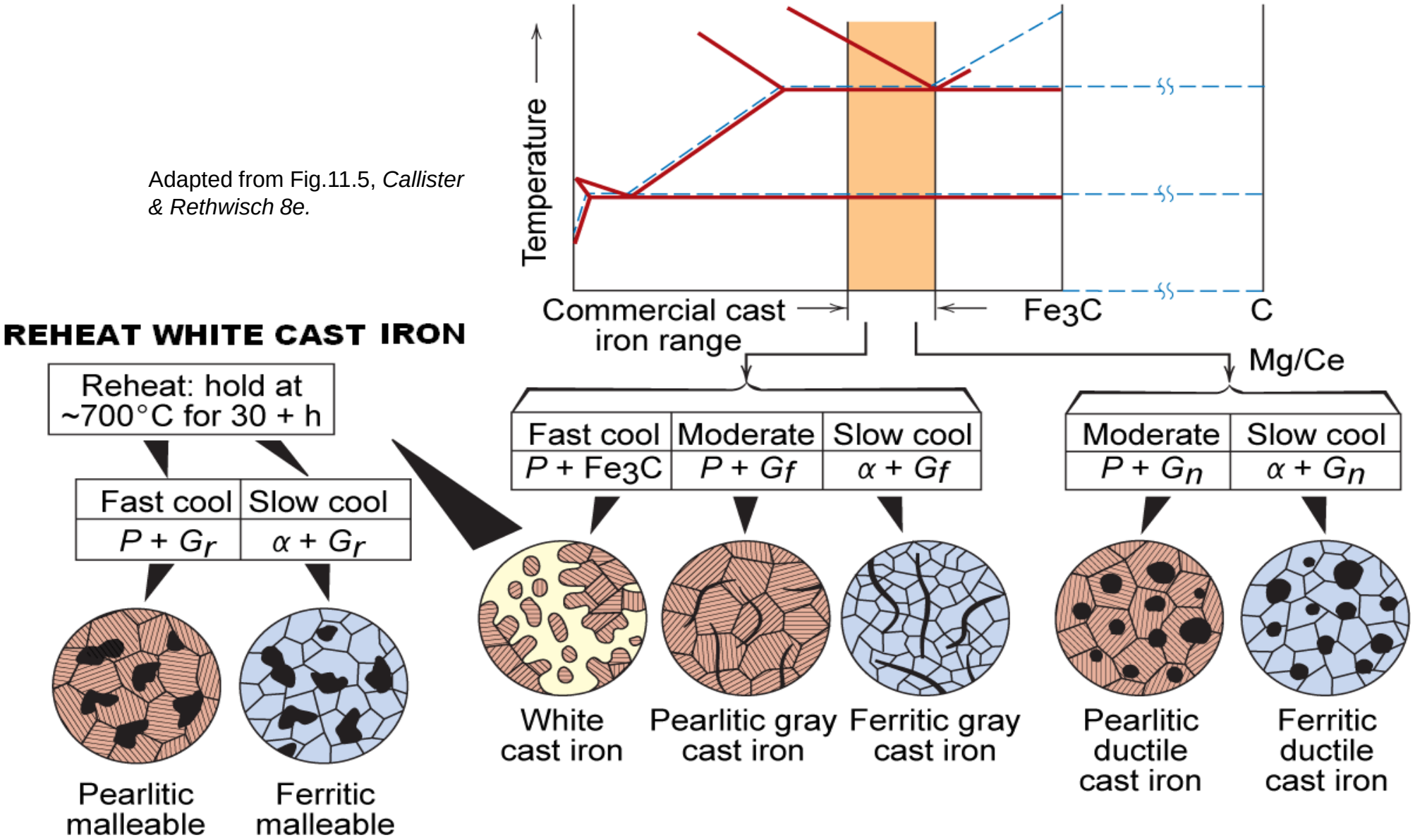
Ferritic Nodular Cast Iron



Pearlitic Nodular Cast Iron

Production of Cast Irons: Summary

Adapted from Fig.11.5, *Callister & Rethwisch 8e.*



Properties of Cast Irons: Summary

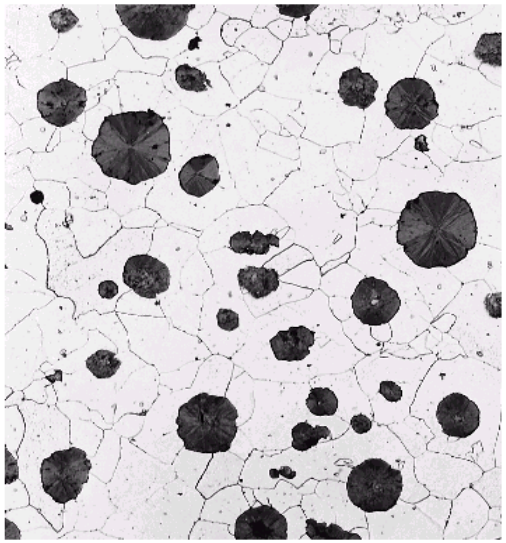
Gray iron

- graphite flakes
- weak & brittle in tension
- stronger in compression
- excellent vibrational dampening
- wear resistant

Adapted from Fig. 11.3(a) & (b), *Callister & Rethwisch 8e.*

Nodular (Ductile) iron

- add Mg and/or Ce
- graphite as nodules not flakes
- matrix often pearlite – stronger but less ductile



Properties of Cast Irons: Summary

White iron

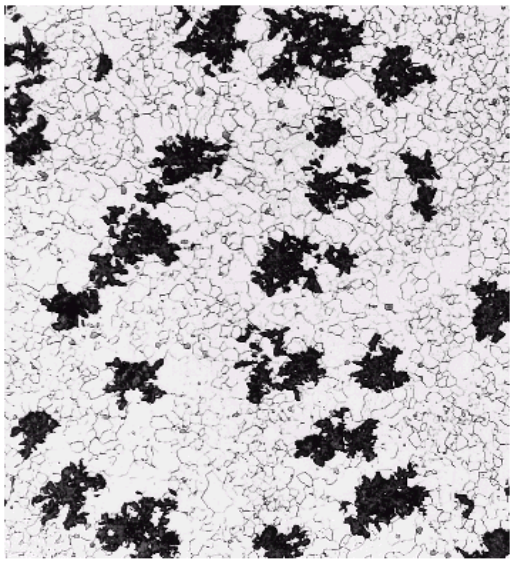
- < 1 wt% Si
- pearlite + cementite
- very hard and brittle

Adapted from Fig. 11.3(c) & (d), *Callister & Rethwisch 8e.*

HEAT TREAT WHITE IRON ABOVE

Malleable iron

- heat treat white iron at 800-900ºC
- graphite in rosettes
- reasonably strong and ductile



Typical Applications of Cast Iron

Grade	UNS Number	Composition (wt%)[a]	Matrix Structure	Mechanical Properties: Tensile Strength [MPa (ksi)]	Mechanical Properties: Yield Strength [MPa (ksi)]	Mechanical Properties: Ductility [%EL in 50 mm (2 in.)]	Typical Applications
				Gray Iron			
SAE G1800	F10004	3.40–3.7 C, 2.55 Si, 0.7 Mn	Ferrite + Pearlite	124 (18)	—	—	Miscellaneous soft iron castings in which strength is not a primary consideration
SAE G2500	F10005	3.2–3.5 C, 2.20 Si, 0.8 Mn	Ferrite + Pearlite	173 (25)	—	—	Small cylinder blocks, cylinder heads, pistons, clutch plates, transmission cases
SAE G4000	F10008	3.0–3.3 C, 2.0 Si, 0.8 Mn	Pearlite	276 (40)	—	—	Diesel engine castings, liners, cylinders, and pistons
				Ductile (Nodular) Iron			
ASTM A536							
60-40-18	F32800	3.5–3.8 C, 2.0–2.8 Si, 0.05 Mg, <0.20 Ni, <0.10 Mo	Ferrite	414 (60)	276 (40)	18	Pressure-containing parts such as valve and pump bodies
100-70-03	F34800		Pearlite	689 (100)	483 (70)	3	High-strength gears and machine components
120-90-02	F36200		Tempered martensite	827 (120)	621 (90)	2	Pinions, gears, rollers, slides
				Malleable Iron			
32510	F22200	2.3–2.7 C, 1.0–1.75 Si, <0.55 Mn	Ferrite	345 (50)	224 (32)	10	General engineering service at normal and elevated temperatures
45006	—	2.4–2.7 C, 1.25–1.55 Si, <0.55 Mn	Ferrite + Pearlite	448 (65)	310 (45)	6	