# Lecture 10:
# Cast Iron

Mmat 380

## Topics to be covered

Cast Irons

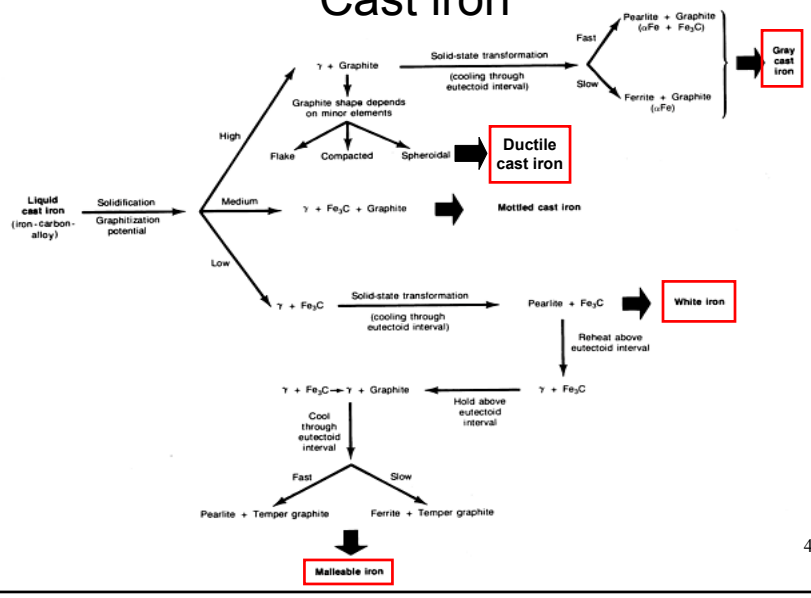
- Classification
  - White
  - Malleable
  - Gray
  - Ductile
- Applications and advantages of cast irons
- Factors affecting graphitization
- Heat treating to control structure

# Cast iron

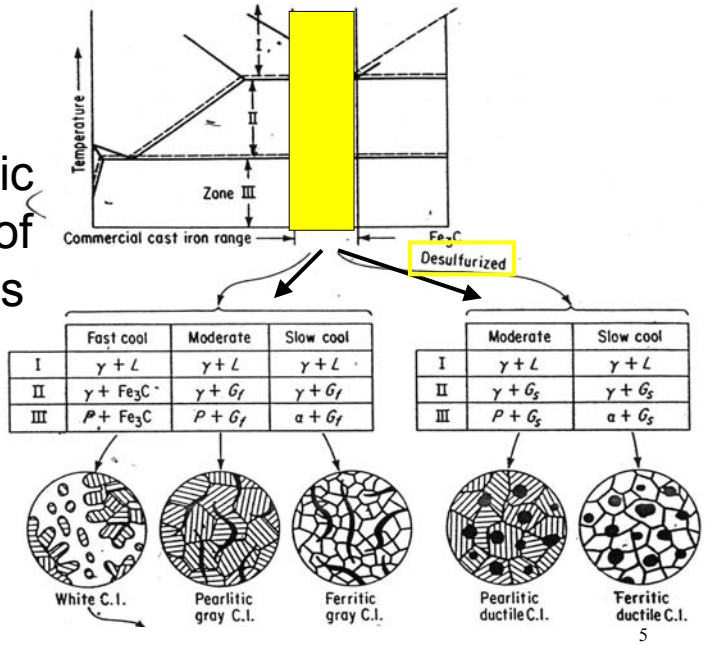
- Family of ferrous alloys
- Cast into desired shape – not worked
- 2-4% C and 1-3% Si
- Instability of $Fe_3C$:
  - Cementite / graphite flakes / graphite nodules



# Cast iron



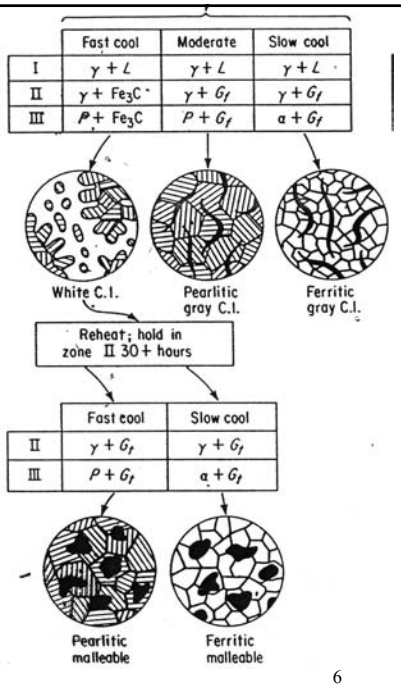
# Schematic of types of cast irons






# Part 2 of schematic

$G_f$ = flake graphite
$G_f$ = graphite-temper carbon
$G_s$ = graphite spheroids
$P$ = pearlite
$\alpha$ = ferrite
$\gamma$ = austenite



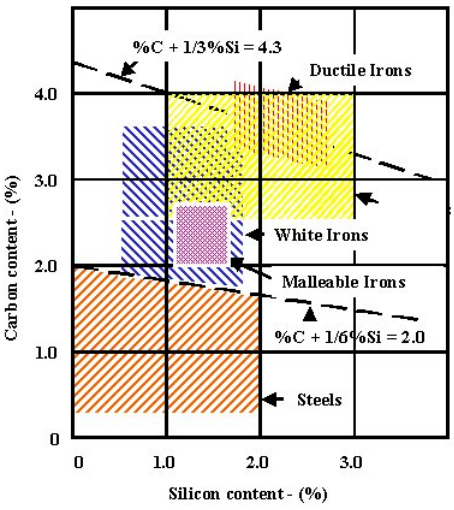
# Classification of cast iron

| | Type of cast iron | Graphite | Ductility | |
|---|---|---|---|---|
| • | White | No | No | Fast cooling rates |
| • | Gray | Flake | No | Slow cooling rates |
| • | Malleable | **Anneal: flake to nodule** | Yes | white iron + annealing heat treatment |
| • | Nodular | Nodular | Yes | additions made so that nodules of graphite form instead of flakes |

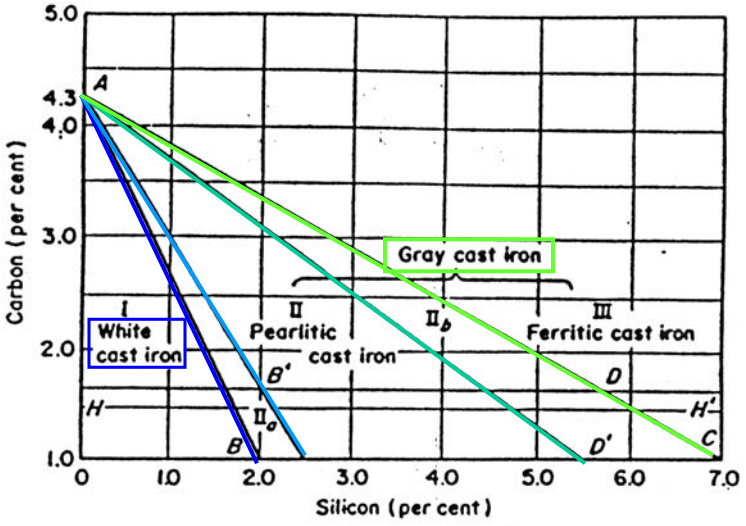


# Factors influencing which will form:

- %C
- %Si
- temperature (cooling rate)



# Composition and type of cast iron






# Cooling rate and type of cast iron

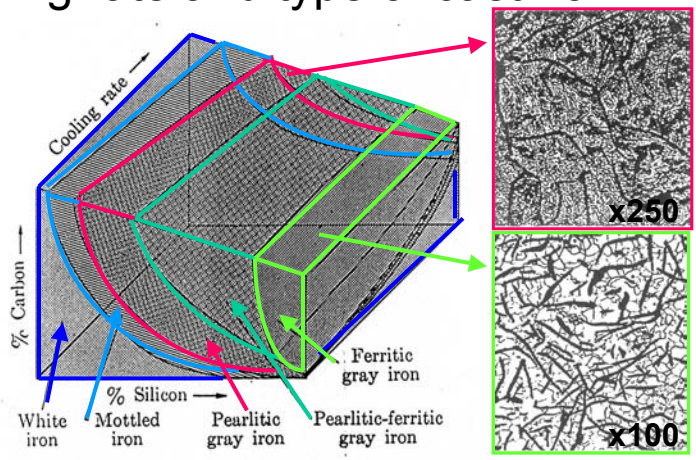
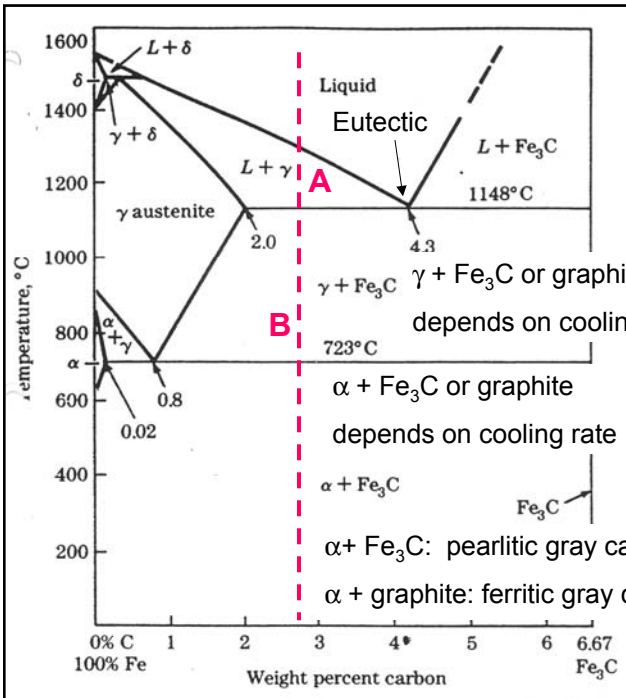



FIG. 5–11. The effect of cooling rate and composition on the structure of cast iron. Mottled cast iron is a mixture of the white and the gray cast iron structures.




On Phase diagram

$\gamma$ + $Fe_3C$ or graphite

depends on cooling rate

$\alpha$ + $Fe_3C$ or graphite

depends on cooling rate

$\alpha$+ $Fe_3C$: pearlitic gray cast irons or

$\alpha$ + graphite: ferritic gray cast irons



# Cast iron: factors affecting graphitization

Metal cools across eutectic T from "A" or from "B"
will $Fe_3C$ or graphite form?

$\gamma$ $\gamma$ + eutectic liquid at "A"

- fast cooling - $\gamma$ + $Fe_3C$ (white cast iron)
- slow cooling - $\gamma$ + graphite (gray cast iron)

$\gamma$ + graphite (gray cast iron) at point "B"

- $\alpha$ + $Fe_3C$ – pearlitic gray cast iron
- $\alpha$ + graphite – ferritic gray cast iron

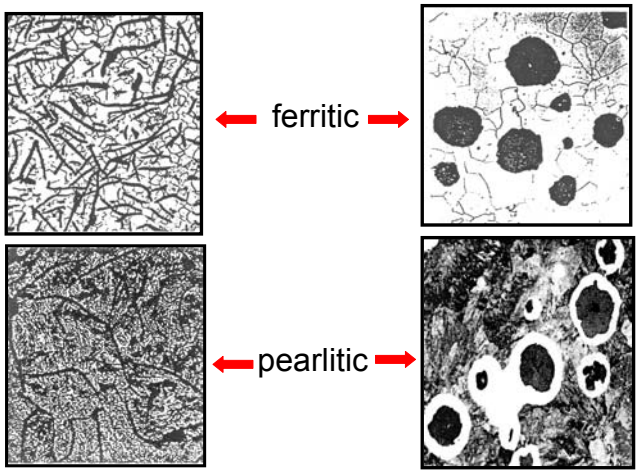
# Cast iron: factors affecting graphitization

Cast iron Carbon Equivalent

- C.E. = %C + 1/3%Si
- Gray and nodular cast iron:
  - higher %C and %Si vs. white and malleable



# Grey vs nodular cast iron (x250)




Gray – graphite as flakes

Brittle

Nodular – graphite as nodules

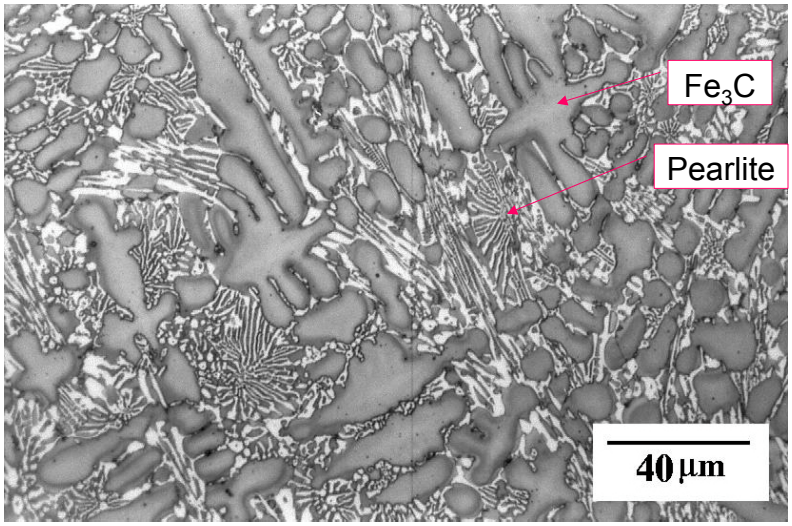
Ductile

## White cast iron

- $Fe_3C$ + pearlite
- Hard, brittle
- Shows a “white” crystalline fractured surface
- Excellent wear resistance
- High compressive stress



## White Cast Iron



## Malleable cast iron

- White cast iron + annealing treatment
- During annealing treatment graphite nucleates and grows from the $Fe_3C$ to form nodules



## Gray cast iron

- During slow solidification carbon in Fe separates or graphitizes to form separate graphite flakes

## Ductile/nodular cast iron

- Mg added to molten iron
- Helps to spherodize graphite
- Low levels of minor elements such as S and P



## General characteristics/advantages of gray cast iron

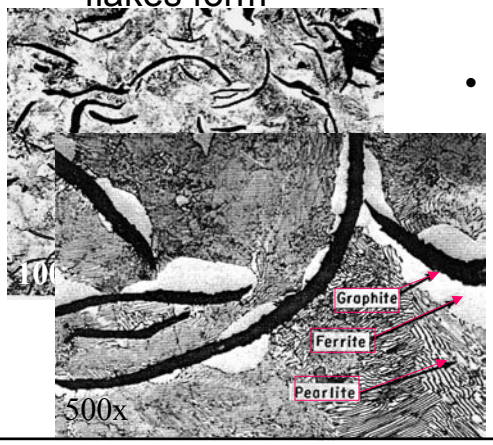
- Cheap
- Low melting point
- Fluid – easy to cast, especially advantageous into large complex shapes
- Excellent machinability
- Excellent bearing properties
- Excellent damping properties
- Excellent wear resistance (hi C)
- Can be heat treated (surface hardened etc.)
- Can be alloyed etc.



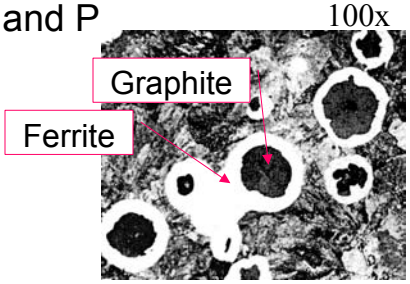
Essentially steel + graphite

# Contrasting gray and nodular/ductile cast iron

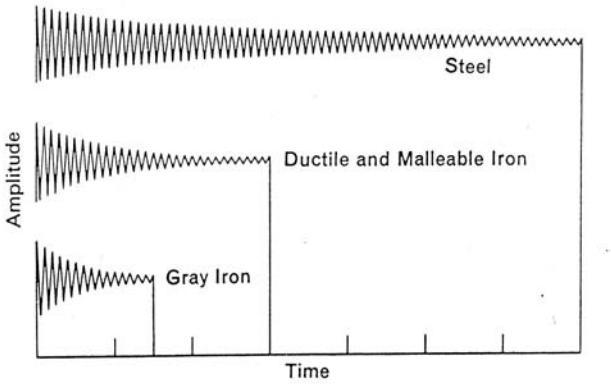
- Separate graphite flakes form




- Mg added to molten iron – helps spherodise graphite
- Low levels of minor elements such as S and P




# Great at dampening!




Relative ability of ferrous metals to dampen vibrations. The energy absorbed per cycle, or specific damping capacity of these can differ by more than 10 times.

## Gray cast iron (example)

- 3.0 %C
- graphite forms as flakes during solidification
- Have $\gamma$ dendrites + eutectic $\gamma$ + graphite flakes at T < 1153°C
- 99% $\gamma$ + 1 % graphite flakes



## Gray cast iron (example)

- at T> eutectoid
- 97.7% $\gamma$ of eutectoid (0.7%) composition, 2.3% graphite
- If cooling fast –pearlite (pearlitic gray cast iron)
- If cooling slow – ferritic gray cast iron

- May have a mixture of ferrite and pearlite:
  - Ferrite regions around flakes, rest pearlite
  - Class 20+60 Y.S. – 134 MPa; UTS – 402 MPa

## Gray cast iron

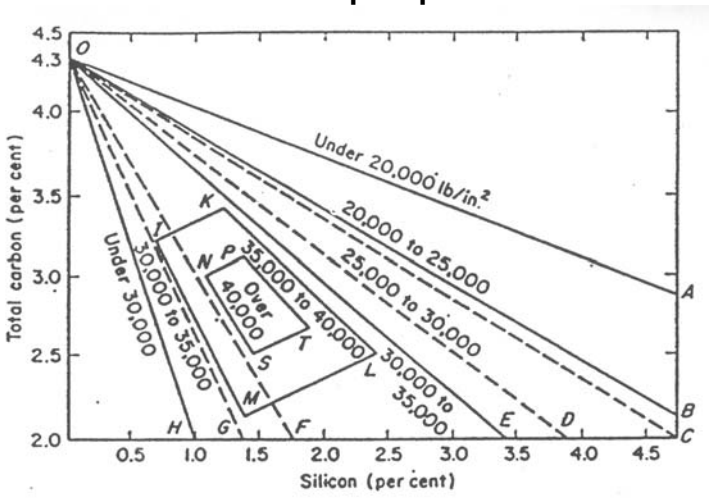
- $\gamma$ + graphite on cooling to eutectoid T (723$^{o}$C) must decide:
  - $\gamma \rightarrow \alpha$ + graphite
  - $\gamma \rightarrow \alpha$ +pearlite
- Favoured by slow cooling rates, starts as a) but as diffusion path increases, difficult to maintain, therefore reverts to $\alpha + Fe_3C$



## Comments on tensile properties

- Ferritic – softest; pearlitic – strongest
- Variation in elastic modulus
- 0 ductility – tensile strengths only quoted
  - C – 2.75-3.5%, Si 1.5-3.0%
  - Graphite flake types and size
- Fine uniform size wanted, get by:
  - increased superheat to casting
  - Inoculation with ferrosilicon or calcium silicon

# Tensile properties






# Applications of ductile cast irons

TABLE 8-3
**Common grades and typical applications of ductile cast irons**

| Type TS-YS-% elongation | Tensile strength, psi | Yield strength, psi | Typical elonga-tion, % | Hardness, Bhn | Heat treatment | Typical microstructure | Typical applications |
|---|---|---|---|---|---|---|---|
| 60-40-18 | 60,000 | 40,000 | 18 | 137–170 | Annealed | All ferritic | Pressure castings such as valve and pump bodies. |
| 65-45-12 | 65,000 | 45,000 | 12 | 149–229 | — | Ferritic | Machinery castings subject to shock and fatigue loading |
| 80-55-06 | 80,000 | 55,000 | 6 | 179–255 | — | Ferritic and pearlitic | Crankshaft gears and rollers |
| 100-70-03 | 100,000 | 70,000 | 3 | 229–302 | Normalized | All Pearlitic | High strength gears, automotive and machine components |
| 120-90-02 | 120,000 | 90,000 | 2 | 250–350+ | Quench and temper | Tempered martensitic | Pinions, gears, rollers and slides |

## Ductile/nodular cast iron

- Gray iron composition for C and Si
- Impurity level control important as it will affect nodule formation
- Have nodule instead of flake if we add in 0.05% Mg and/or Ce
- As cast structure: graphite forms as nodules instead of flakes



## Nodular cast iron

- $\gamma$ + graphite on cooling below $A_1$ must decide:
  - $\gamma \rightarrow \alpha$ + graphite
  - $\gamma \rightarrow \alpha + Fe_3C$
- Favoured by slow cooling rates, short diffusion paths etc.

$\gamma$ first follows a) in regions surrounding nodules.
Carbon diffuses to existing nodules.
As T decreases and diffusion path increases remaining
$\gamma \rightarrow \alpha + Fe_3C$(pearlite)

# Heat treatment control

- If we want more ductility (less strength) heat treat to convert pearlitic areas to $\alpha$ + graphite
  - Heat to 900°C
  - Cool at 20˚C/hr from 790° to 650°CF
  - Normal furnace cooling
  - Could be done as one step with slower original cooling