

# Mat E 272

## Lecture 19: Cast Irons

November 8, 2001

### Introduction:

One reason steels and cast iron alloys find such wide-ranging applications and dominate industrial metal production is because of how they respond to thermal processing, or heat treatment. For a given alloy composition, one can obtain a rich and diverse range of microstructures simply by applying different combinations of time and temperature. We have seen how cooling rates affect microstructure; slowly cooled steels develop a coarse pearlitic microstructure while quenched steels undergo a martensitic (diffusionless) transformation. Intermediate cooling rates also produce varying amounts of bainite, in addition to pearlite or martensite. Austenite, the high temperature FCC polymorph of steel, can also be retained at room temperature by rapid cooling, albeit metastable. Spherodite is produced by heating pearlitic or bainitic microstructures at a temperature just below the eutectoid, or  $A_1$ . All of these microstructures give rise to different mechanical properties, and it is incumbent on us to understand the relationships between composition, thermal history, and mechanical behavior. In addition, the characteristics of high-carbon Fe-C alloys, or cast irons, will be discussed.

# Cast Irons

## Definition:

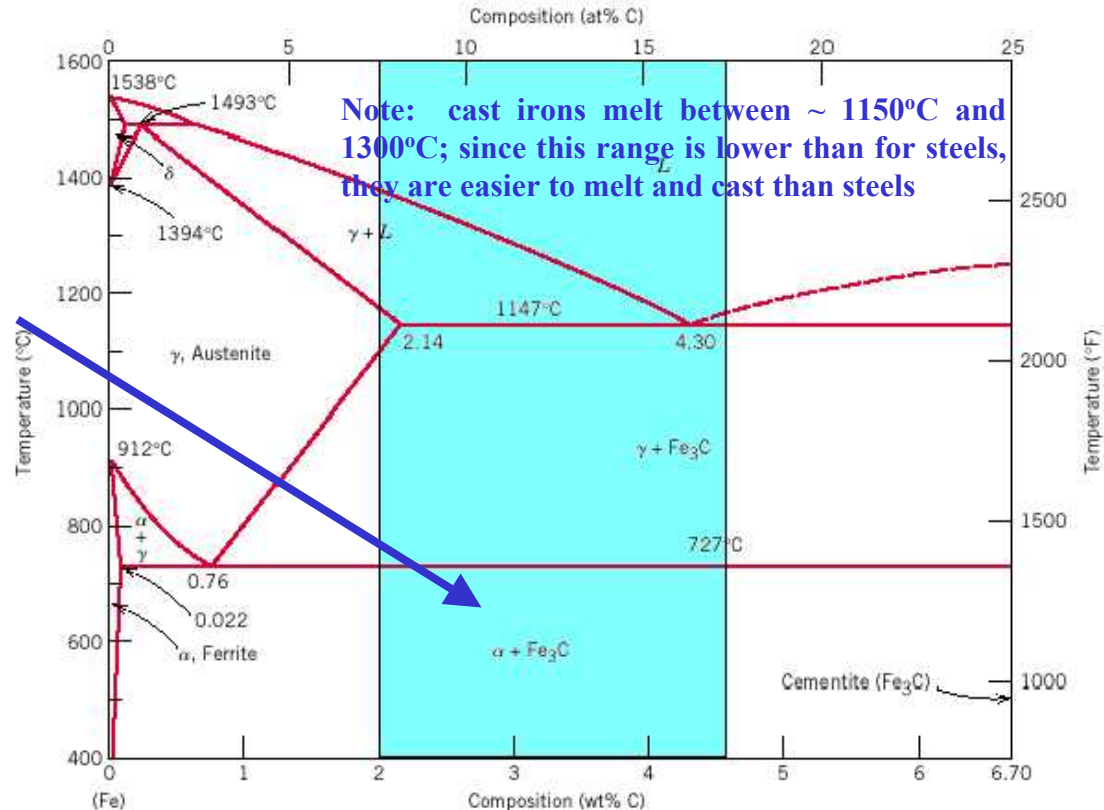
*Cast iron* is the name applied to a family of high-carbon content Fe-C alloys, specifically, those containing more than 2.14 wt. % C. Generally, most cast irons fall within the 3.0 to 4.2 wt. % range. Many contain silicon.

## Applications:

Many cast irons are strong, but also brittle. As such, they find uses as small cylinder blocks, cylinder heads, pistons, clutch plates, transmission cases, diesel engine casting.. There are four types of cast irons: gray, nodular, white, and malleable.

## Constituents:

Cast irons consists of varying amounts of ferrite, cementite ( $\text{Fe}_3\text{C}$ ), and graphite (C). Note that for most cast irons, the carbon-rich phase is graphite, not cementite.



Note: cast irons melt between ~ 1150°C and 1300°C; since this range is lower than for steels, they are easier to melt and cast than steels

Fun fact: Did you know that iron is obtained by processing iron ore? Iron ore typically contains the following components:

- Hematite -  $\text{Fe}_2\text{O}_3$  - 70% iron
- Magnetite -  $\text{Fe}_3\text{O}_4$  - 72% iron
- Limonite -  $\text{Fe}_2\text{O}_3 + \text{H}_2\text{O}$  - 50% to 66% iron
- Siderite -  $\text{FeCO}_3$  - 48% iron

# Gray Cast Iron

## Components:

Gray iron contains 2.5 to 4.0 wt. % C and also 1.0 to 3.0 wt. % silicon. The Si promotes formation of graphite instead of cementite.

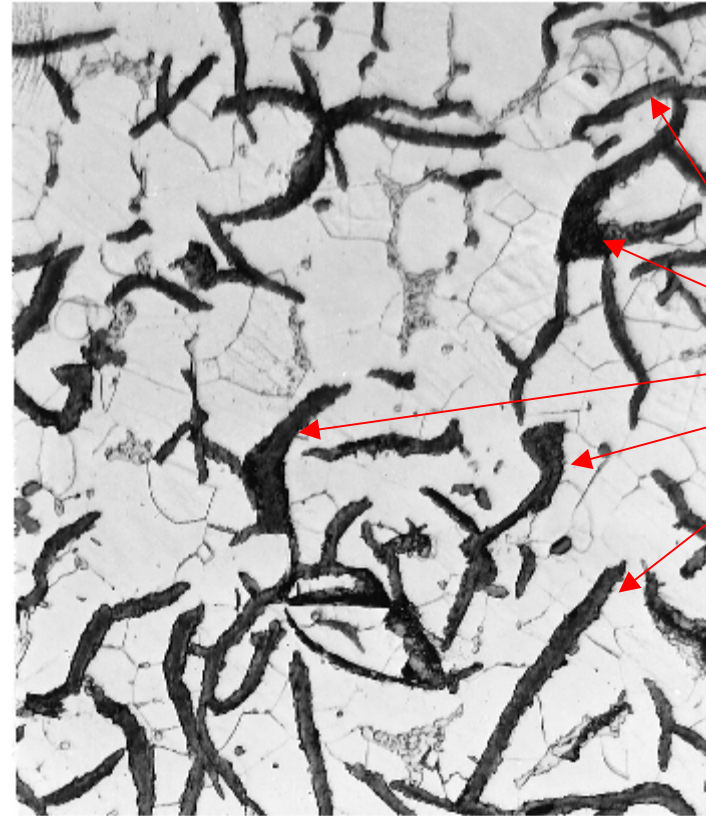
In contrast, sulfur promotes formation of carbide over graphite

## Microstructure:

Graphite is dispersed throughout a ferrite or pearlite matrix in the form of *flakes*.

## Characteristics:

The graphite flakes have sharp edges and tips. Consequently, the flakes act as *stress raisers* which can induce fracture near their tips. For this reason, gray iron is brittle in tension. It is also good at damping vibrations. Gray iron is inexpensive and relatively easy to cast with minimal shrinkage.



Graphite flakes --

makes a fracture surface appear gray in color

Gray iron is used in support structures for large, heavy machines that generate significant vibration.

# Nodular (Ductile) Iron

## Components:

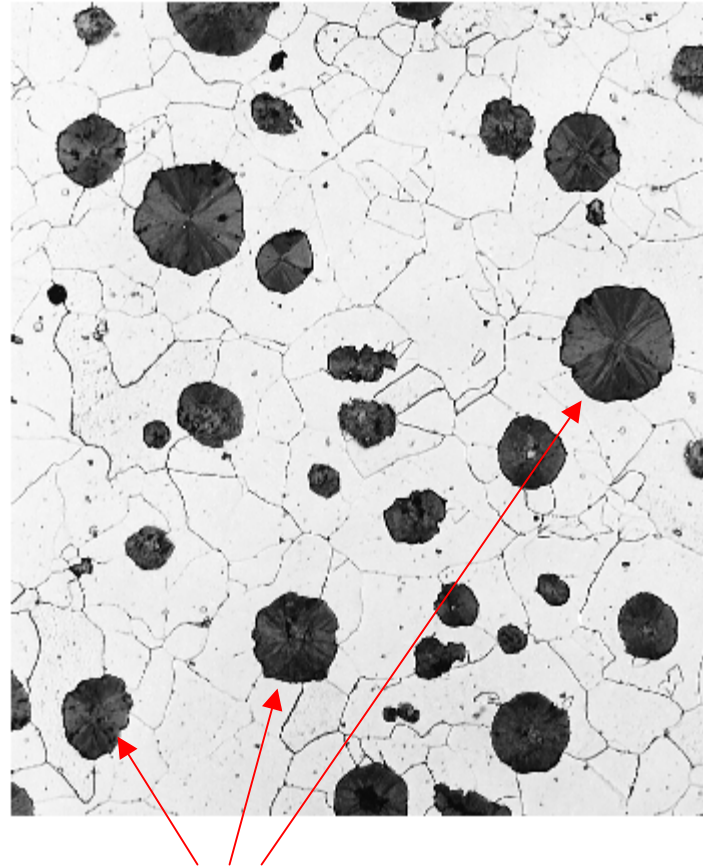
Nodular iron contains 2.5 to 4.0 wt. % C, 1.0 to 3.0 wt. % Si, plus Mg &/or Ce. The Mg &/or Ce cause the flakes to spherodize (hence nodular)

## Microstructure:

Graphite is dispersed throughout a ferrite or pearlite matrix in the form of *spheres* or *nodules*.

## Characteristics:

The graphite nodules have no sharp features; therefore, the resulting material is much more ductile than gray iron. The mechanical properties of nodular iron are similar to steel. Nodular iron is frequently used in valves, crankshafts, gears, and other automotive components.



Note the nodules of pure carbon (graphite)  
The lighter matrix is ferrite.

# White Iron

## Components:

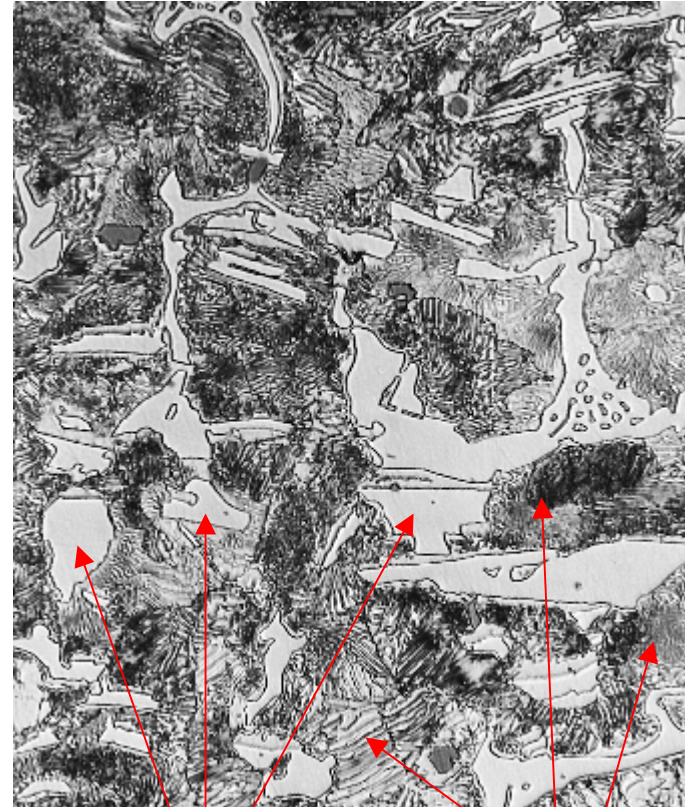
White iron contains 2.5 to 4.0 wt. % C and *less than 1.0 wt. % Si*. Because of the low Si content, the carbon forms  $Fe_3C$  instead of graphite.

## Microstructure:

Cementite is dispersed throughout pearlite (ferrite + cementite) matrix.

## Characteristics:

White iron contains a considerable volume fraction of cementite ( $Fe_3C$ ), a hard and brittle compound. Because of the amount of cementite, white iron is extremely hard and extremely brittle. Limited usage - mainly applications requiring hardness and wear resistance (such a rollers in rolling mills). Also used as a precursor to *malleable iron*.



Cementite is silvery - white in color; hence a fracture surface appears white

Lighter regions =  $Fe_3C$ ; darker matrix = pearlite (ferrite +  $Fe_3C$ )

# Malleable Iron

## Components:

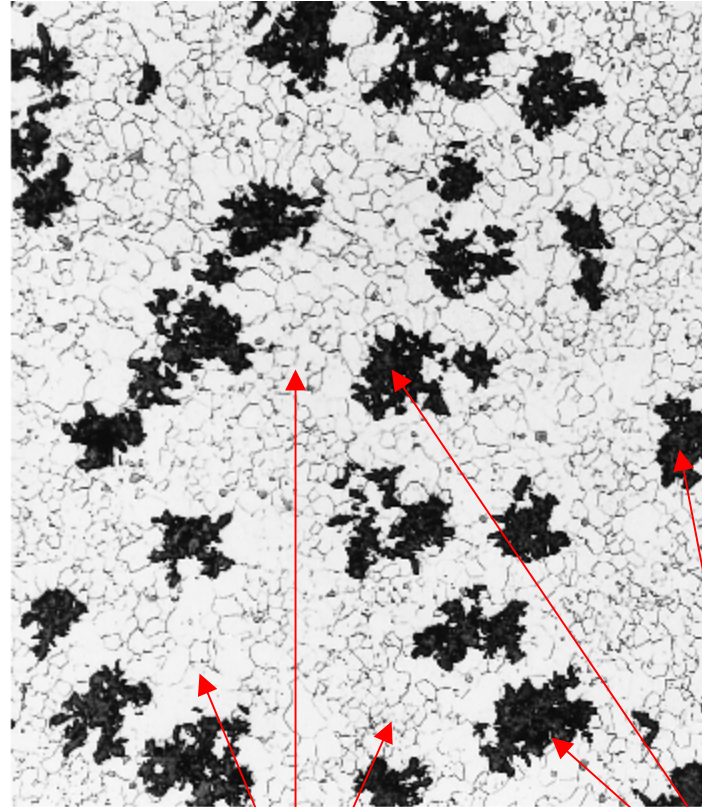
Malleable iron (just like white iron) contains 2.5 to 4.0 wt. % C and *less than 1.0 wt. % Si*. Unlike white iron, the C exists in the form of *graphite* instead of cementite.

## Microstructure:

Graphite rosettes are dispersed throughout a *ferrite (or pearlite)* matrix.

## Characteristics:

Malleable iron is produced by *heating white iron in order to decompose the cementite into graphite*. The graphite forms clusters, similar to nodular iron. Reduction in the amount of cementite causes the material to become relatively ductile (or malleable). Used in connecting rods, transmission gears, differential cases, flanges, pipe fittings.



Lighter regions = ferrite matrix; dark clusters = graphite

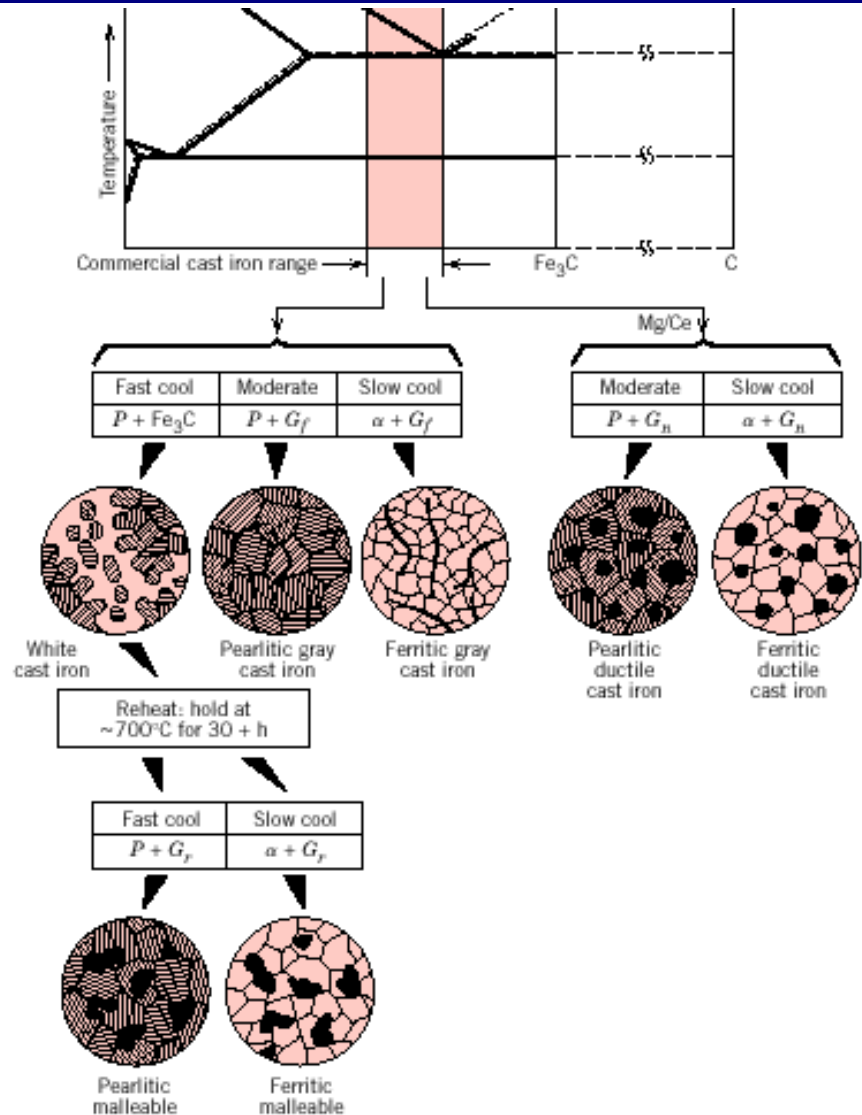
# Cast Iron microstructures

An amazing diversity of microstructures can be obtained in cast iron simply by modifying the composition and adjusting the cooling rate.

In the schematic at right,

- Gf = flake graphite,
- Gr = graphite rosettes,
- Gn = graphite nodules,
- P = pearlite (which is  $\alpha + \text{Fe}_3\text{C}$ ), and
- $\alpha$  = ferrite.

Note that, in general, slow cooling tends to produce large microstructural features whereas rapid cooling results in fine (or small) features. Fine microstructures tend to be stronger but more brittle.



# Cast Irons - Summary of Mechanical Properties

**Table 12.5** Designations, Minimum Mechanical Properties, Approximate Compositions, and Typical Applications for Various Gray, Nodular, and Malleable Cast Irons

| Grade                  | UNS Number | Composition (wt%) <sup>a</sup>                     | Matrix Structure    | Mechanical Properties        |                            |                                  | Typical Applications                                                              |
|------------------------|------------|----------------------------------------------------|---------------------|------------------------------|----------------------------|----------------------------------|-----------------------------------------------------------------------------------|
|                        |            |                                                    |                     | Tensile Strength [MPa (ksi)] | Yield Strength [MPa (ksi)] | Ductility [%EL in 50 mm (2 in.)] |                                                                                   |
| 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                                |                                                                                   |

# Gray vs. Nodular Irons - a comparison

## Gray irons --

a composite of graphite + high carbon iron

extremely brittle

stress concentration at the tips of graphite flakes

## Nodular irons --

amazing change in mechanical properties accompanies a change in microstructure

graphite spheres (nodules) replace flakes

tensile strength can be as high as 100,000 psi with favorable ductility

Typical properties:

ductility: 2 - 30% elongation in 2 inches

tensile: 55,000 to 120,000 psi (375 - 818 MPa)

yield: 30,000 to 90,000 psi (205 - 614 MPa)