Austempered Ductile Iron

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Austempered Ducile Iron (ADI)

- Self-healing
- Stronger/weight than Aluminum
- Tougher than “steel”!
- Cheap(ish)

- But we need some background to understand it . . .
Topics

• Part I: Introduction
  – Iron
  – Steel

• Part II: Steels (Steel Microstructures)
  – Thermal treatments

• Part III: Cast Iron

• Part IV: Austempered Ductile Iron
Part I: Introduction
Iron vs. Steel

The phase diagram illustrates the differences and transitions between iron and steel.

- **Austenite** (γ) is the high-temperature phase.
- **Ferrite** (α) is the low-temperature phase.
- **Delta iron** (δ) is another phase at intermediate conditions.

Key points include:
- **Austenite in liquid**
- **Primary austenite begins to solidify**
- **CM begins to solidify**

The regions highlight:
- **Austenite solid solution of carbon in gamma iron**
- **Pearlite and ferrite**
- **Pearlite and Cementite**
- **Cementite, pearlite and transformed ledeburite**

**Temperature** scale is in °F and °C.

Iron vs. Steel transitions through various phases, with different compositions and properties.
Iron vs. Steel (Simpler)
Iron vs. Steel (Simpler)
Iron vs. Steel (Simpler)

Iron \( + \) Carbon \( \approx \) Steel

Fe \( \text{Iron} \) 26 55.845

C \( \text{Carbon} \) 6 12.011

Steel
Part II: Steels (Steel Microstructure)
Why Does Carbon Make Steel Strong?

- “Metallurgical grit”
- Prevents Iron atoms from moving past each other
- Makes steel harder but more brittle than pure Iron.

Diagram:
- STEEL
- $\bullet = \text{carbon atom}$
- $\bigcirc = \text{iron atom}$
Iron/Steel Microstructures

- Austenite (A, γ, γ-Fe) (FCC)
- Allotriomorph Ferrite (F, α, δ-Fe) (BCC)
- Idiomorph Ferrite (F, α_I) (BCC)
- Pearlite (P)
- Widmanstätten Ferrite (α_w)
- Bainite (B)
  - Upper Bainite (α_b)
  - Lower Bainite (α_{lb})
- Acicular Ferrite (α_a)
- Martensite (M, α') (BCT) (tetragonal)
- Cementite (θ)
- Ledeburite
- Sphereoidite
- Ausferrite
- ...
Iron/Steel Microstructures

- Different iron/carbon microstructures have different properties

- One object can have many different microstructures!

- The game is: choose nice combinations of them
Iron/Steel Microstructures

- Thermal treatments change microstructures
Part III: Cast Iron
Cast Iron

- Cast iron: steel with too much Carbon
Cast Iron

• (Some of the) Carbon comes out of solution.
• Forms graphite “inclusions” of pure weakness surrounded by steel “matrix”.

[Image of cast iron microstructure with labeled steel matrix and graphite inclusions]
Cast Iron

- Graphite makes cast iron machinable and tough, but softer and weaker.

- Pure steels are (sometimes) considered “better”, but they're also more expensive
Cast Iron

- Gray iron
- White iron
- Malleable iron
  - Black-heart malleable iron
  - White-heat malleable iron
  - Pearlitic malleable iron
- Ductile iron
- Compacted graphite iron
- ...
Cast Iron

- Gray iron
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- ...
Part IV: Austempered Ductile Iron
Austempered Ductile Iron Algorithm

Temperature (°C)

900

Austenitizing
90 min

380

Austempering
90 min

Time (min)
Step 0

- Make casting from ductile iron
  (== cast iron + a pinch of Mg and Si)
Step 1

- Immerse casting in liquid salt (basically corrosive lava)
Step 2

- The steel matrix changes to Austenite
Step 3

- Quench (rapidly cool) (avoids pearlite)
- Can use lower-temperature salt, hot oil, or molten Pb or Sn.
Step 4

- Leave it there to austemper (an isothermal transition)
- Matrix becomes ausferrite — acicular ferrite and austenite stabilized with about 2% carbon
Step 5

- Let it cool off
Step 6: Done!

- Hooray!
- Enjoy your new superalloyed part!
Questions
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... (continued)
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# Iron vs. Steel

- Toughness: Ability to absorb energy
- Hardness: Resistance to deformation
- Strength: Resistance to force

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<tr>
<td>Hardness</td>
<td>C+</td>
<td>A+</td>
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<tr>
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