Metallurgy of Steel

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Course Topics

1. Steel grades and alloy designation system
2. Metallurgical phases that form in steel
3. Iron-carbon phase diagram
4. Phase transformations in steel during heat treating

Course learning objectives

After completing this course, students will be able to:

1. Explain the designation systems used for different steels.
2. Identify the alloying elements and carbon content in carbon and low-alloy steels based on their alloy designations.
3. Describe the common metallurgical phases and microstructures found in steels.
4. Explain the effects of the different microstructures that form in steel on steel strength and hardness
5. Explain how the iron-carbon phase diagram and time-temperature-transformation diagrams are used to predict the phases present in a steel based on a heat treating thermal cycle.
6. Explain the effects of heat treatment temperature and time on steel microstructure
7. Relate the effects of cooling rate to the microstructure formed in a steel.

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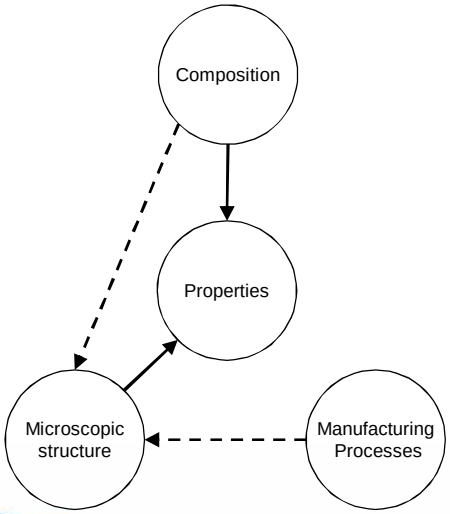
Course prerequisites

Assumed that student has taken our Principles of Metallurgy course or is familiar with the concepts and terminology covered in that course

- Crystal lattice structure
- Diffusion
- Grains
- Dislocations and dislocation motion
- Phases and phase transformations
- Microstructure

Material properties

Understand relationship → Understand how to control properties of materials



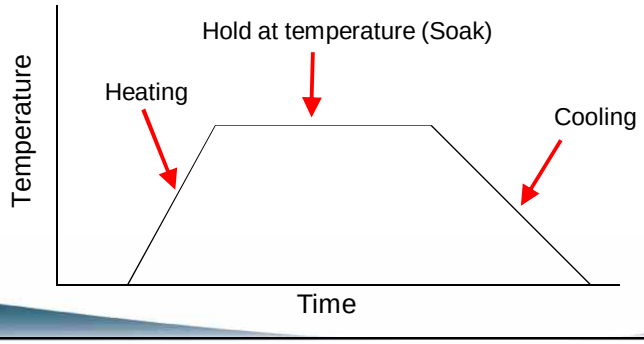
Heat Treating

Heat treating processes used to modify steel microstructure

- Obtain specific properties
- For example, improved strength and hardness, toughness, or ductility

Specific heat treatment used depends on

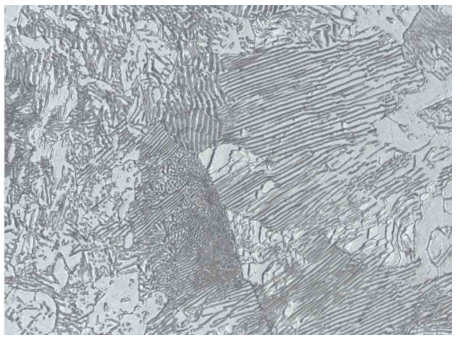
- Alloy composition
- Desired microstructure
- Desired properties



Can process a steel different ways

→ Obtain different microstructures

→ Obtain different properties



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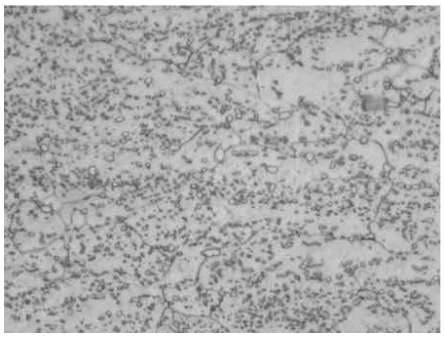

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Critical concept

- Steel alloy and heat treat process selection
- Control variation

Module learning objectives

At the end of this module students will be able to:

1. Describe the relationship between metal composition and microstructure and properties of the metal
2. List 5 categories of steel alloys
3. Explain the AISI/SAE designation system for carbon steels and low alloy steels

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Categories of steel

- Plain carbon
- Low alloy
- Tool
- High-strength low alloy
- Stainless

Course concepts apply to

- Carbon steel
- Low alloy steel
- Tool steel

High strength low alloy (HSLA) steels usually not heat treated

Stainless steels that can be strengthened by heat treatment not covered

Carbon steel

Carbon steel requirements

- Manganese < 1.65%
- Silicon < 0.60%
- Copper < 0.60%

A few classes of carbon steel

- SAE designations 10xx, 11xx, 12xx, and 15xx
- SAE = Society of Automotive Engineers

Alloy designation indicates chemical composition

Most plain carbon alloys have a four digit designation

First two digits indicate type of steel

- 10xx - plain carbon steel, ≤ 1.00% manganese
- 11xx – resulfurized steel
- 12xx – resulfurized and rephosphorized steel
- 15xx - higher manganese carbon steel

Last two digits indicate average carbon content (hundredths percent)

- 1040 steel contains, on average, 0.40% carbon

Element composition specification

- Range
- Maximum

1040

- 0.37 to 0.44 % carbon
- 0.60 to 0.90 % manganese
- < 0.040 % phosphorous
- < 0.050 % sulfur

Low-Alloy Steel

Low-alloy steels exhibit mechanical properties superior to plain carbon steels

Alloying elements such as nickel, chromium, molybedenum, and vanadium

- Total content: 2.07% up to amounts for stainless steel

> 1.65% manganese, > 0.60% silicon, and/or > 0.60% copper

Other elements added to obtain desired properties

- Aluminum, boron, cobalt, titanium

Low-alloy steel designations use same rules as for carbon steels

- First two digits indicate alloy grade
- Last two digits indicate carbon content in hundredths percent

SAE designation	Major alloy elements
13xx	Manganese steel
23xx, 25xx	Nickel steel
31xx, 32xx, 33xx, 34xx	Nickel-Chromium steel
40xx, 44xx	Molybdenum steel
41xx	Chromium-molybdenum steel
43xx, 47xx, 81xx, 86xx, 87xx, 88xx, 93xx, 94xx, 97xx, 98xx	Nickel-chromium-molybdenum steel
46xx, 48xx	Nickel-molybdenum steel
50xx, 51xx	Chromium steel
50xxx, 51xxx, 52xxx	Chromium (bearing) steel
61xx	Chromium-vanadium steel

High strength low alloy (HSLA) steel

Low-carbon steels

- 0.05 ï 0.25 % carbon

Up to 2.0% manganese

Small quantities of chromium, nickel, molybdenum, copper, nitrogen, vanadium, niobium, titanium, and zirconium in various combinations.

Better mechanical properties than conventional carbon steels

- Yield strengths of 290 to 550 MPa (42 to 80 ksi)

Many standard and proprietary grades

Not considered alloy steels

Tool Steel

Description	SAE designation
High speed tool steels	M1-M62 (molybdenum types) T1-T15 (tungsten types)
Hot work tool steels	H1-H19 (chromium types) H20-H39 (tungsten types) H40-H59 (molybdenum types)
Cold work tool steels	D2-D7 (high carbon-high chromium types) A2-A10 (medium alloy air hardening types) O1-O7 (oil hardening types)
Shock resisting tool steels	S1-S7
Mold steels	P2-P6
Special purpose	L2-L6 (low alloy types)
Water hardening tool steels	W1-W5

Stainless Steel

SAE designations for stainless steels consists of three digits

- First digit designates a general grouping

2xx Chromium-manganese-nickel steels (Austenitic stainless steels)

3xx Chromium-nickel steels (Austenitic stainless steels)

4xx Chromium steels (Ferritic and martensitic stainless steels)

xx does not indicate carbon content or any other composition information

- specific designation is sequential

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End of module