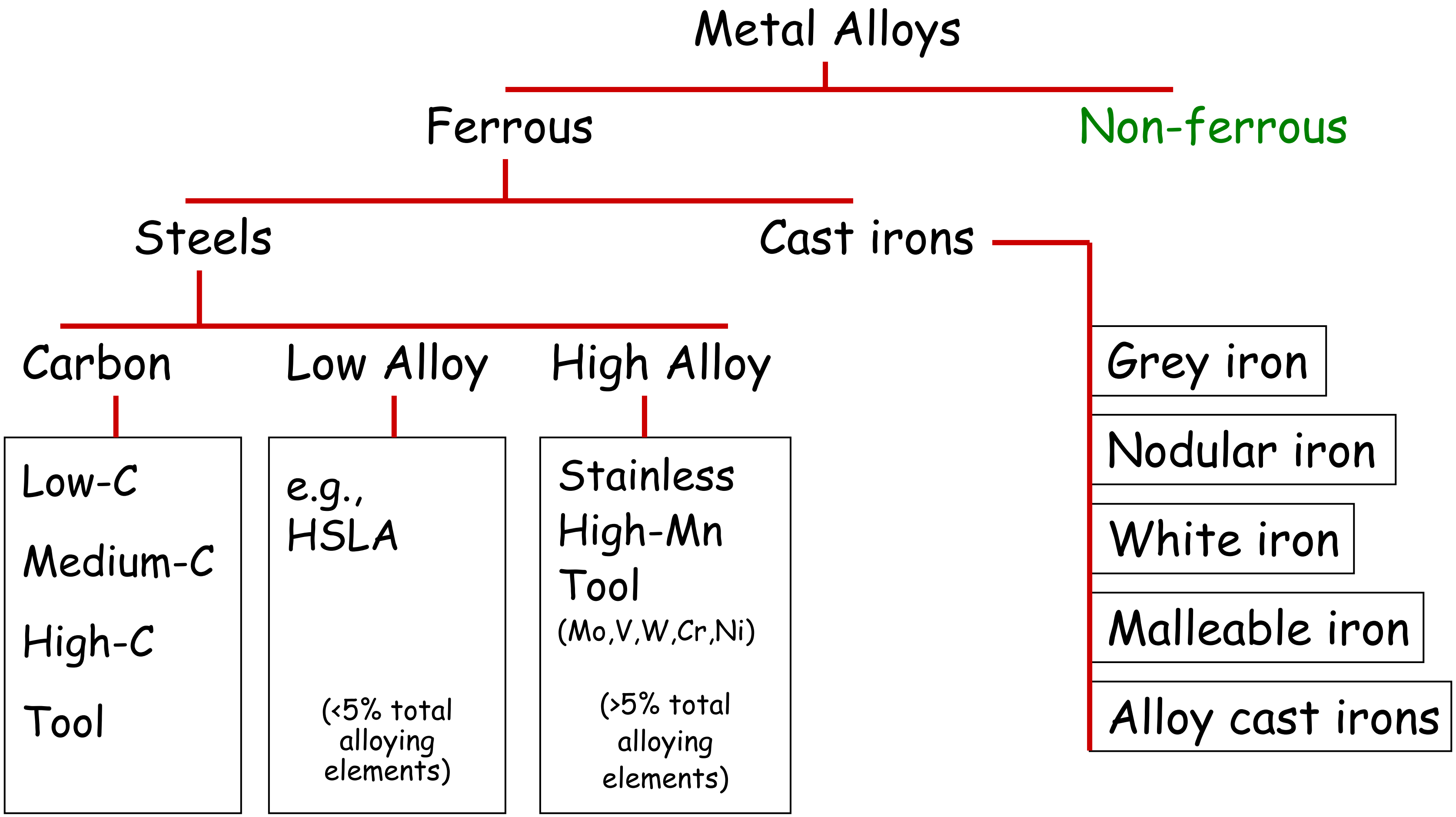
Metal Alloys

Most engineering metallic materials are alloys. Metals are alloyed to enhance their properties, such as strength, hardness or corrosion resistance, and to create new properties, such as shape memory effect.

Engineering alloys can be broadly divided into Ferrous Alloys and Non-ferrous Alloys

Metal	Global demand tonnes, x1000	Price $/tonne	Market $ billion
Steel	730,000	400	292
Aluminium	20,000	1,500	30
Stainless steel	13,000	2,000	26
Titanium	56	35,000	2
Nickel	1,000	12,000	
Copper	10,000		

1. Ferrous Alloys



Ferrous Alloys

-Alloys containing Fe as the main element.

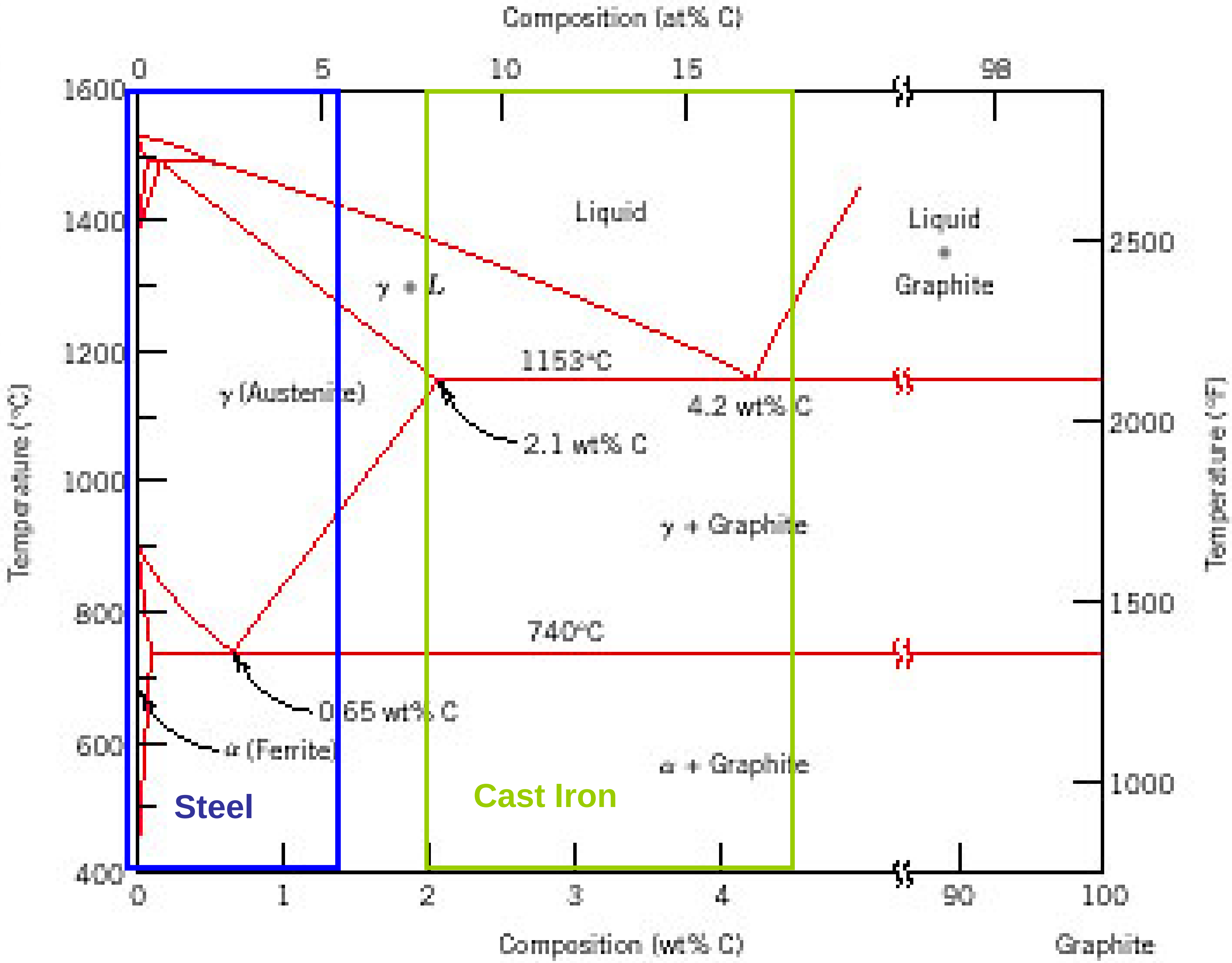
-The most important ferrous alloy system (Fe-C system)

-Alloys of this system can be further divided into steels and cast irons.

-Steels contain less C (generally <1.4wt%C) than do cast irons (generally 2.4~4.3wt%C).

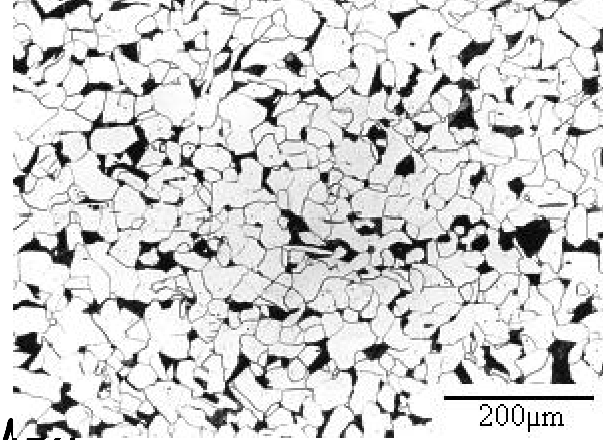
-Then, all steels solidify into a single γ-Fe structure first and then experience the complex eutectoid reaction. Therefore, heat treatment processes, which alter the eutectoid reaction, are vitally important for controlling microstructure and properties of steels.

-Cast irons experience complex eutectic reaction during solidification, due to the formation of graphite or cementite. Solidification control is the most important single factor for properties of cast irons.


Composition (at% C)
0
5
10
15
98
1600
1400
1200
1000
800
600
400
Temperature (°C)
2500
2000
1500
1000
Temperature (°F)
Liquid
Liquid + Graphite
γ + L
1153°C
γ (Austenite)
4.2 wt% C
2.1 wt% C
γ + Graphite
740°C
0.65 wt% C
α (Ferrite)
α + Graphite
Steel
Cast Iron
0
1
2
3
4
90
100
Composition (wt% C)
Graphite

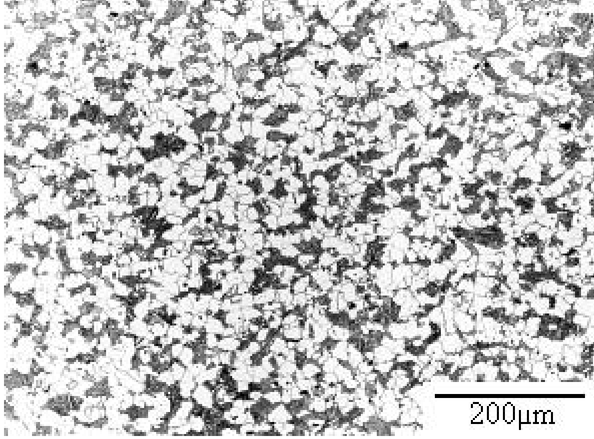
Plain Carbon Steels

Low carbon steels (mild steels): 0.1-0.25%C
proeutectoid F + small amount of P
high formability, high ductility: elongation: ~30%
relatively low strength: yield strength: 250~400MPa
excellent weldability
cannot be strengthened by heat treatment
usually strengthened by cold working
typical applications: pipes, panels, sheets, wires, I-beams etc.



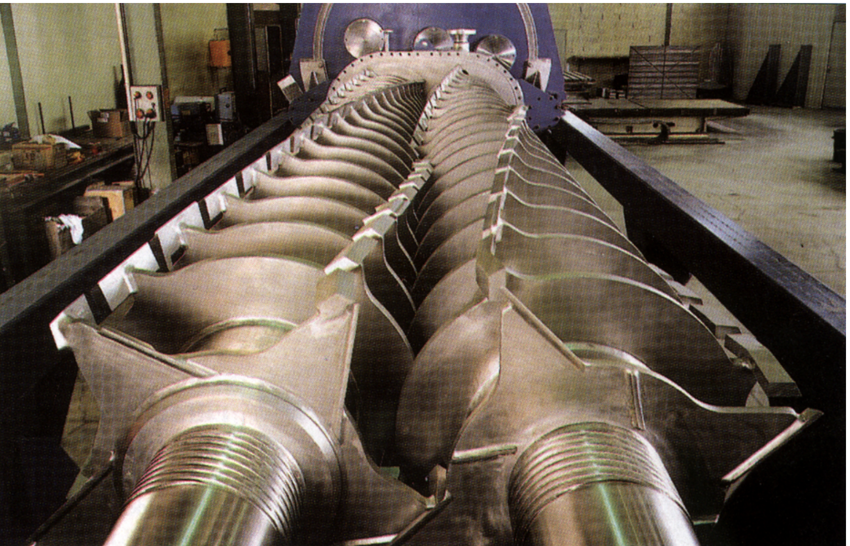
(0.15% carbon steel)

Medium-carbon steels (structural steels)
0.25-0.55%C
Good combination of strength and ductility
Yield strength: 300~600MPa
Tensile strength: 400~800MPa
Elongation: ~25%



(0.4% carbon steel)

Strengthenable by heat treatment
Weldable; weldability deteriorates with increasing C%
Used for load-bearing applications, crankshaft, bolts, gears, heavy-duty machinery, mining equipment, cranes



High strength low alloy steels (HSLA)

Medium carbon steels have desired mechanical properties for structural applications, but suffer from welding-induced embrittlement due to the formation of martensite. To overcome this problem, C content in these steels is reduced (<0.3%) and the loss of strength is compensated by increasing Mn content (>1%) and by microalloying with Nb, V, Ti, Cr and Cu. This leads to the development of HSLA steels. These steels are widely used for manufacturing large welded structures, such as Sydney harbor bridge, ocean liners and cargo ships, oil drilling rigs and platforms, large mining and earth moving equipment, and pressure vessels and storage tanks.



High carbon steels

Spring steels: 0.6~0.8%C

predominately eutectoid pearlite at room temperature

often strengthened and hardened by heat treatment

high strength and moderate toughness

spring

Tool steels: 0.8~1.2%C

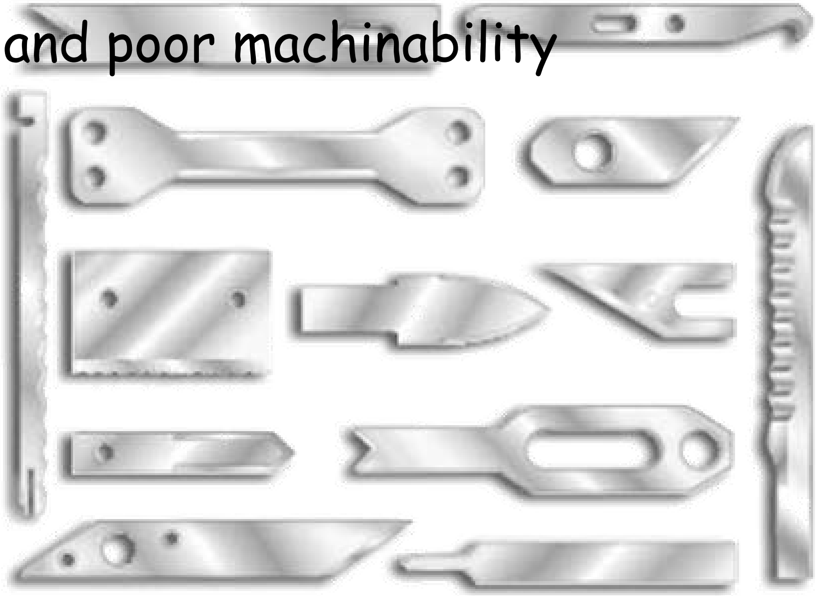
proeutectoid cementite + pearlite

very high hardness, low toughness, very difficult to machine

used for chisels, hammers, knives, saw blades, drills, dies, punches, cutlery, chine tools and wear resistant applications

High carbon steels have poor weldability and poor machinability

Extrusion dies



Cutting blades

Alloy Designation (carbon andf low-alloy steels)

AISI: American Iron and Steel Institute
SAE: Society of Automotive Engineers
ASTM: American Society for Testing and Materials
UNS: Uniform Numbering System

AISI/SAE	UNS	
carbon steels		
1040	G10400	plain carbon steel containing 0.4wt%C
1xYY	G1xYY0	modified carbon steel (S, P, Mn)
low alloy steels		
2xxx	G2xxx0	alloy steels

Tool Steels

High alloy tool steels are often alloyed with Mo, V, W, Cr and/or Ni.

UNS: Txxxxx

Normally specified by hardness and impact toughness.

Stainless Steels

Three basic classes, specified by microstructure:
Ferritics: Fe-Cr alloys (12~25%Cr), can be cheap
Martensitics: Fe-Cr alloys, low Cr, hard, cutting tools
Austenitics: Fe-Cr-Ni alloys (18Cr-8Ni), corrosion resistance
Precipitation hardened, high strength and hardness
Duplex (18Cr-5Ni)

Alloys designation

	AISI	UNS	
type	2xx	S2xx00	
	3xx	S3xx00	304, 316, 316L (austenitics)
	4xx	S4xx00	410 (martensitic), 446 (ferritic)

Typical Mechanical Properties

Yield strength: 200MPa ~ 1600MPa
Tensile strength: 300 MPa ~ 1800 MPa
Ductility: EL% 40 ~ 2
Young's modulus: ~ 170 GPa

Table 12.2a AISI/SAE and UNS Designation Systems and Composition Ranges for Plain Carbon Steel and Various Low-Alloy Steels

AISI/SAE Designation[a]	UNS Designation	Composition Ranges (wt% of Alloying Elements in Addition to C)[b]			
		Ni	*Cr*	*Mo*	*Other*
10xx, Plain carbon	G10xx0				
11xx, Free machining	G11xx0				0.08–0.33S
12xx, Free machining	G12xx0				0.10–0.35S, 0.04–0.12P
13xx	G13xx0				1.60–1.90Mn
40xx	G40xx0			0.20–0.30	
41xx	G41xx0		0.80–1.10	0.15–0.25	
43xx	G43xx0	1.65–2.00	0.40–0.90	0.20–0.30	
46xx	G46xx0	0.70–2.00		0.15–0.30	
48xx	G48xx0	3.25–3.75		0.20–0.30	
51xx	G51xx0		0.70–1.10		
61xx	G61xx0		0.50–1.10		0.10–0.15V
86xx	G86xx0	0.40–0.70	0.40–0.60	0.15–0.25	
92xx	G92xx0				1.80–2.20Si

[a] The carbon concentration, in weight percent times 100, is inserted in the place of "xx" for each specific steel.

[b] Except for 13xx alloys, manganese concentration is less than 1.00 wt%.
Except for 12xx alloys, phosphorus concentration is less than 0.35 wt%.
Except for 11xx and 12xx alloys, sulfur concentration is less than 0.04 wt%.
Except for 92xx alloys, silicon concentration varies between 0.15 and 0.35 wt%.

Table 12.2b Typical Applications and Mechanical Property Ranges for Oil-Quenched and Tempered Plain Carbon and Alloy Steels

AISI Number	*UNS Number*	*Tensile Strength [MPa (ksi)]*	*Yield Strength [MPa (ksi)]*	*Ductility [%EL in 50 mm (2 in.)]*	*Typical Applications*
		Plain Low-Carbon Steels			
1040	G10400	605–780 (88–113)	430–585 (62–85)	33–19	Crankshafts, bolts
1080[a]	G10800	800–1310 (116–190)	480–980 (70–142)	24–13	Chisels, hammers
1095[a]	G10950	760–1280 (110–186)	510–830 (74–120)	26–10	Knives, hacksaw blades
		Alloy Steels			
4063	G40630	786–2380 (114–345)	710–1770 (103–257)	24–4	Springs, hand tools
4340	G43400	980–1960 (142–284)	895–1570 (130–228)	21–11	Bushings, aircraft tubing
6150	G61500	815–2170 (118–315)	745–1860 (108–270)	22–7	Shafts, pistons, gears

[a] Classified as high-carbon steels.

Table 12.4 Designations, Compositions, Mechanical Properties, and Typical Applications for Austenitic, Ferritic, Martensitic, and Precipitation-Hardenable Stainless Steels

				Mechanical Properties			
AISI Number	*UNS Number*	*Composition (wt%)*[a]	*Condition*[b]	*Tensile Strength [MPa (ksi)]*	*Yield Strength [MPa (ksi)]*	*Ductility [%EL in 50 mm (2 in.)]*	*Typical Applications*
			Ferritic				
409	S40900	0.08 C, 11.0 Cr, 1.0 Mn, 0.50 Ni, 0.75 Ti	Annealed	380 (55)	205 (30)	20	Automotive exhaust components, tanks for agricultural sprays
446	S44600	0.20 C, 25 Cr, 1.5 Mn	Annealed	515 (75)	275 (40)	20	Valves (high temperature), glass molds, combustion chambers
			Austenitic				
304	S30400	0.08 C, 19 Cr, 9 Ni, 2.0 Mn	Annealed	515 (75)	205 (30)	40	Chemical and food processing equipment, cryogenic vessels
316L	S31603	0.03 C, 17 Cr, 12 Ni, 2.5 Mo, 2.0 Mn	Annealed	485 (70)	170 (25)	40	Welding construction
			Martensitic				
410	S41000	0.15 C, 12.5 Cr, 1.0 Mn	Annealed Q & T	485 (70) 825 (120)	275 (40) 620 (90)	20 12	Rifle barrels, cutlery, jet engine parts
440A	S44002	0.70 C, 17 Cr, 0.75 Mo, 1.0 Mn	Annealed Q & T	725 (105) 1790 (260)	415 (60) 1650 (240)	20 5	Cutlery, bearings, surgical tools
			Precipitation Hardenable				
17-7PH	S17700	0.09 C, 17 Cr, 7 Ni, 1.0 Al, 1.0 Mn	Precipitation hardened	1450 (210)	1310 (190)	1–6	Springs, knives, pressure vessels

Cast Irons

$$Fe_3C \rightarrow 3Fe(\alpha) + C(graphite)$$

>2.14wt% Carbon

- On the Fe-C system, these are to the right of steels,
- with carbon between 2 & 5.3 %,
- but more usual 2.5 to 4%.
- Really is tertiary alloy system,
- with the third element silicon.
- The microstructures present depend strongly on the chemical composition (%Si) and the cooling rate of the cast.

BASIS

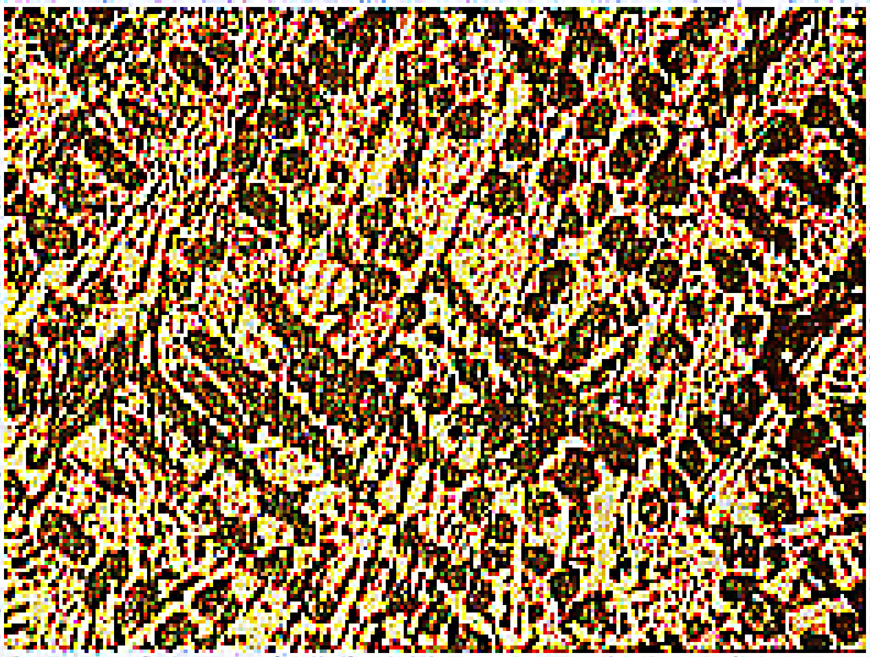
- Cast irons have carbon beyond the limit of solubility of C in γ,
- The different types of cast iron are merely the different forms the carbon takes.
- The carbon can be in the form of cementite, or “white” cast iron.
- If some silicon is added (1 to 2%, maybe 3 %) the carbon will tend to graphitize,
- and there are various forms the graphite can have.
- Then, the carbon can also be in the form of graphite (“gray”, “malleable” and “nodular” cast iron)

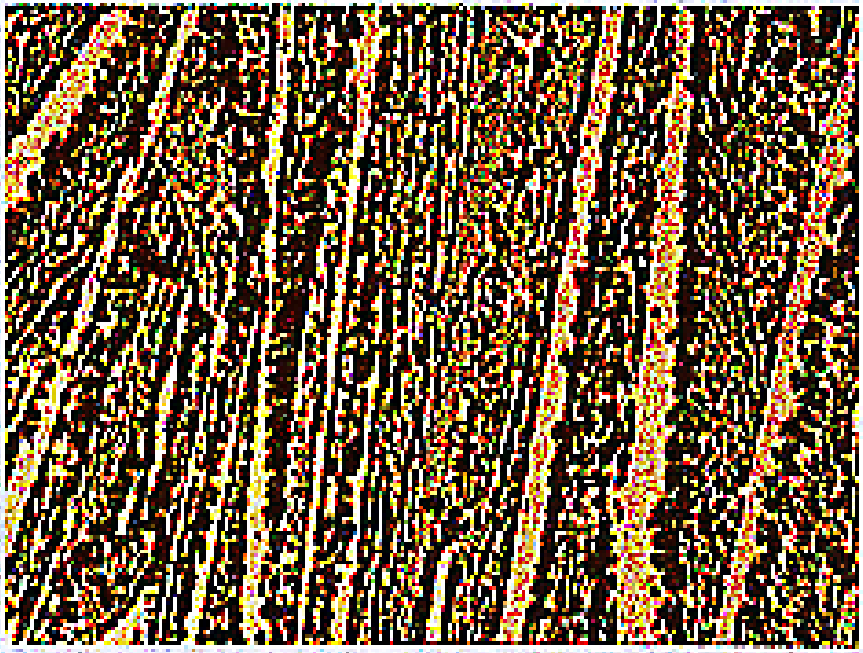
Meanwhile—

- the austenite is still there.
- What can austenite do?
- It changes to ferrite and graphite if cooled very slow (if enough silicon is added).
- It changes to pearlite if cooled slowly,
- and forms martensite if quenched, and
- bainite if cooled in between.
- In other words, we can do anything to the austenite we did with a steel,
- its just that with cast irons we'll also have excess carbon in some form.

White Cast Iron

- It contains relatively less C and Si.
- If we cooled rapidly and we do not add enough Si, the cast iron solidifies as “White” in the $Fe-Fe_3C$ System.
- We can have hypoeutectic and hypereutectic white cast irons.
- Cementite makes the alloy hard and brittle and it is practically useless as structural material.
- The high hardness renders them high resistant to abrasive wear.
- White irons are produced mainly for two purposes: (a) Intermediate product for producing malleable irons and (b) As abrasive wear resistant components, such as ball mill lining tiles, slurry pipe elbows, slurry pump bodies.





Gray Cast Iron

•If we put in 2 to 3 % Silicon,

•and cool the iron reasonably slowly (don’t quench it) the Si will cause the carbon to form as graphite flakes – Gray Cast Iron.

•If we put in more Silicon and cool slowly we can get virtually all the carbon out of the austenite

• and into the flakes, so the matrix is ferrite, or we have a ferritic gray CI.

•If we don’t cool as slowly, or we add less silicon,

•we’d have some carbon left in γ.

•When the austenite hits the eutectoid temperature it would form pearlite,

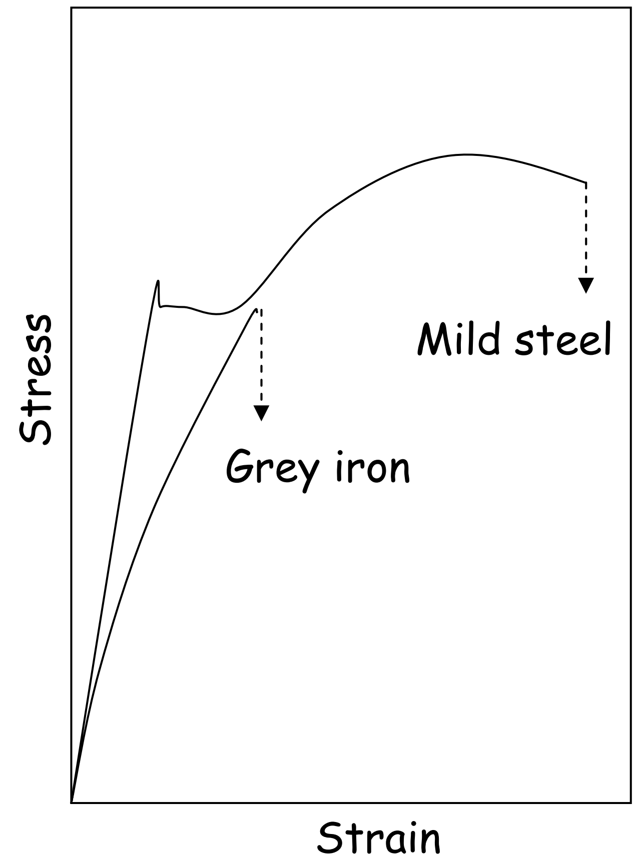
•just like it did when we talked about steels – pearlitic gray CI.


Grey Irons - Application

Grey irons are by far the most produced among all cast irons. Grey irons are used primarily for their low cost and excellent castability. Typical applications include:

engine cylinders, pistons, gear box casing, transmission casing, machine tool bases, balance weight of large cranes, large diameter underground pipework.

They are used always under compressive loading conditions. They are unsuitable for taking tensile loads or bending loads.



Tensile stress-strain behavior of grey cast iron

GRAY IRON PRODUCTS SAMPLES

Grey Irons

SAE	UNS	Tensile Strength	yield	ductility
G1800	F10004	18 (ksi) (140MPa)	-	-
G2500	F10005			
G3000	F10006			
……				
G6000	F10012	60 (ksi) (400MPa)		

Cheap to produce, excellent castability, high damping capacity, good metal-metal wear resistance when lubricated, strength much higher in compression than in tension, brittle in tension.

Malleable Cast Iron

•If we heat white CI above its critical line, normally between 900 to 1000^{o}C for 20 hours we'll make the carbide convert to graphite,

•and it will produce a rough clump of graphite, kind of between a flake and a nodule (agglomerate), - malleable CI

•These cast irons are stronger, tougher and much more ductile than grey irons, compatible to nodular irons.

•They have certain capacity to take shock loading, bending and tension. They are suitable for castings of thin thickness.

•They are expensive to produce, largely due to the heat treatment.

•Typical applications include gear box casing, transmission casing, differential casing.

ASTM	UNS	Yield strength	Ductility
32510	F32510	32.5 (ksi)	10
……			
35018	F36200	35	18

Nodular or Ductile Cast Irons

•we add some magnesium or rare elements to the molten liquid just before casting (inoculation)

•and do things as we did with the gray CI

•we can produce nodular or ductile CI.

•We will produce nodules of graphite instead of flakes,

•but as before we can end up with a matrix of either ferrite or pearlite.

•These irons are much stronger and tougher than grey irons.

•They are produced and used for high specification applications.

•They are more expensive than grey irons. Typical applications include: gears, crankshafts, pump bodies, pressure valves, rollers.

•we had austenite, just like we had in steels,

• so if we quench it we get martensite, as long as we have enough hardenability.

•We can do the same thing with any of the CI types.

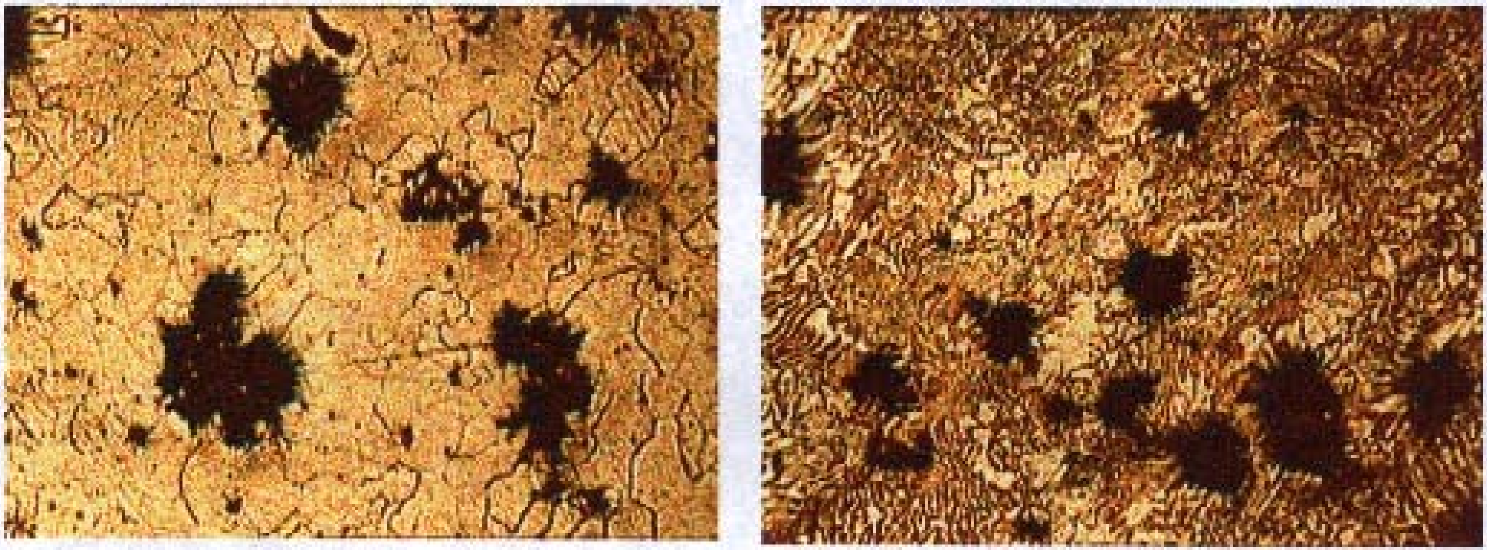
•In fact, austempered ductile iron (ADI) is very popular for many applications.

•That would have a bainitic microstructure.

Nodular Irons (ductile irons)

ASTM	UNS	Tensile	Yield	Ductility
60-40-18	F32800	60 (ksi)	40	18
……				
120-90-02	F36200	120	90	2

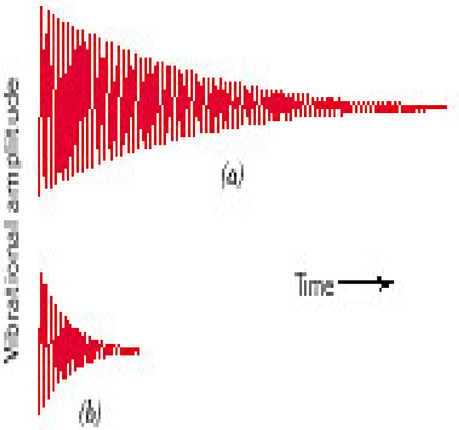
SPHEROIDAL IRON PRODUCTS SAMPLES



Hierro Fundido Maleable – Ferrítico y Perlítico

Hierro Fundido Nodular

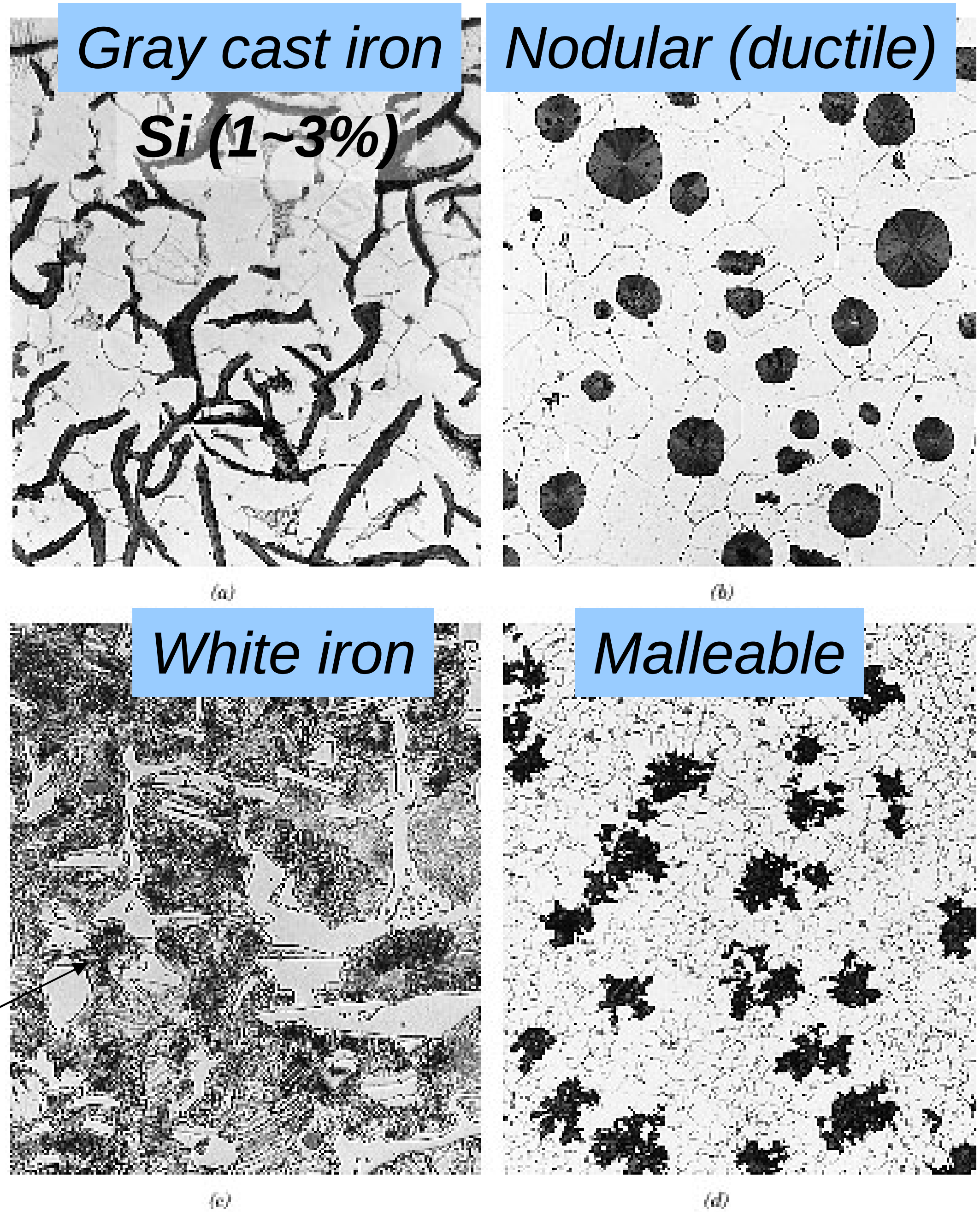
Graphite flakes in an α -ferrite matrix



Damping vibration energy

Pearlite

White cementite



Graphite in an α -ferrite matrix

Graphite in an α -ferrite matrix

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

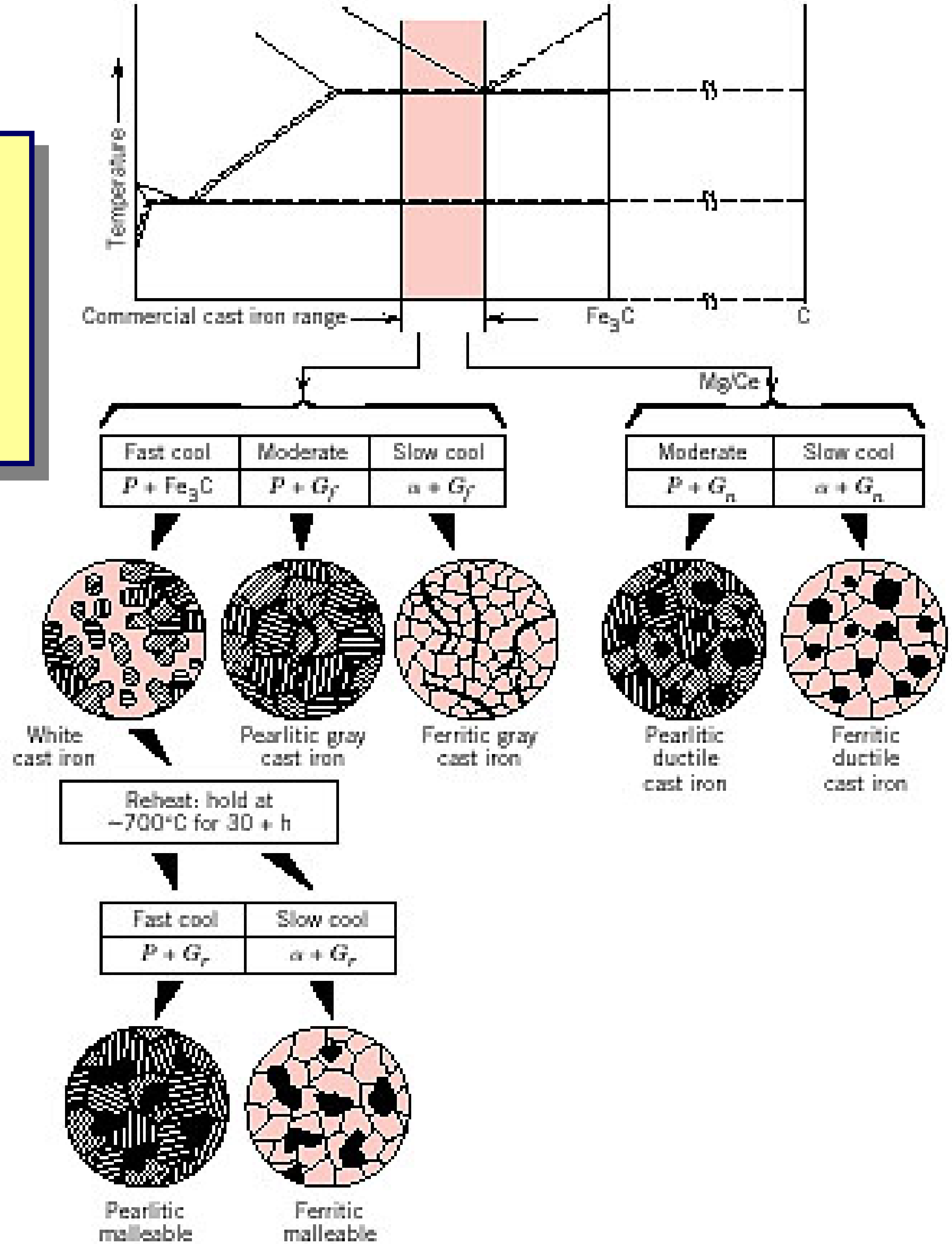
Grade	*UNS Number*	*Composition (wt%)*[a]	*Matrix Structure*	*Mechanical Properties* — *Tensile Strength [MPa (ksi)]*	*Yield Strength [MPa (ksi)]*	*Ductility [%EL in 50 mm (2 in.)]*	*Typical Applications*
				Gray Iron			
SAE G1800	F10004	3.40–3.7 C, 2.55 Si, 0.7 Mn	Ferrite + Pearlite	124 (18)	—	—	Miscellaneous 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	3.5–3.8 C, 2.0–2.8 Si, 0.05 Mg, <0.20 Ni, <0.10 Mo	Pearlite	689 (100)	483 (70)	3	High-strength gears and machine components
120-90-02	F36200	3.5–3.8 C, 2.0–2.8 Si, 0.05 Mg, <0.20 Ni, <0.10 Mo	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	General engineering service at normal and elevated temperatures

[a] The balance of the composition is iron.

Source: Adapted from *ASM Handbook*, Vol. 1, *Properties and Selection: Irons, Steels, and High-Performance Alloys*, 1990. Reprinted by permission of ASM International, Materials Park, OH.

Fabrication of Commercial Cast irons

Heat treatment to control the carbon morphology



Nonferrous Metals

- **NOT iron (Fe) based**
- **Increasing importance in modern technology**
- **Typically more costly per pound than iron or steel**
- **Inferior strength to that of steel**
- **Key properties: Examples**
  - Al and its alloys - lighter, thermal conductor
  - Mg and its alloys – the lightest metal
  - Cu and its alloys – electric conductor
  - Ni and its alloys – High temperature alloys
  - Ti and its alloys – light metal
  - Zn and its alloys – low melting point, easily injected
  - Lead and Tin – lower low melting points
  - Refractory metals
  - Precious metals

Copper

- Backbone of the electrical industry
- Major metal in a number of engineering alloys
- High conductivity and ductility
- Pure copper $\Rightarrow$ tensile strength 30 ksi
- Easily casted, machined and welded
- ETP and OFHC $\Rightarrow$ base for alloys & electrical applications

Classification of Copper

- Copper Development Association (CDA)
  - numbers 100 to 190 are copper with < 2% alloy addition
  - numbers 200 to 799 are wrought copper alloys
  - numbers 800 to 900 are copper casting alloys
- Hardness: as rolled, 1/4 hard, 1/2 hard, full hard, spring

Copper

- *Copper:* tough pitch copper, deoxidized low-phosphorous copper,oxygen-free high-conductivity copper
- *Copper alloys:* soft and ductile, easy cold work.

Brasses (Cu, Zn): $\alpha + \beta$' *(BCC)*

CDA260 … Cartridge Brass, best combination of strength and ductility, deep drawing is a popular use

Poor cold working properties

Good hot working properties

Radiators, jewelry, musical instruments, etc..

Bronzes (Cu, Sn, Al, Si, Ni)

CDA521 … Phosphorus Bronze - Good strength, toughness and wear resistance.

Ex. pump parts, bearings and gears are a popular use

Solubility of Sn: 15.8% @520^{o}C, ~0 at room temp.

Large atom, slow diffusion, easier ppt hardening

Monel (65%Ni), Corson (Cu-Si-Si)

Copper-Nickel

- **High Thermal conductivity, high-temp strength**
- **Applications: heat exchangers, cookware, coins**

Copper-Aluminum

- **“Aluminum-Bronze” - high strength and corrosion resistance**
- **application: marine hardware**

Copper-Silicon

- **“Silicon-Bronze”**
- **good strength, formability, machinability, corrosion resistance**
- **applications: boiler tank and stove application**

Copper-Beryllium

- **highest strengths of Cu based alloys -** Beryllium coppers: precipitation hardenable, Tensile strength: 1400MPa
- **applications: non-spark and plastic injection molds**
- **toxic at elevated temperatures**

Aluminum

- Aluminum 2nd to steel in quantity and usage
- Most important of the non-ferrous metals
- Good thermal and electrical conductivity
- Lightweight and low stiffness
- Good corrosion resistance
- Pure aluminum
  - soft, ductile, and not strong
- Easily casted, machined and formed
- Not easily welded

- **Mechanical Applications of Al**
  - **alloying can increase strength by a factor of 30**
  - **increasing automotive applications**
- **Corrosion Resistance of Al and Al Alloys**
  - **pure Al readily oxidizes forming an oxide coating resistant to many corrosive enviroments**
  - **alloying *decreases* corrosion resistance**
  - **corrosion resistance is a property of the surface oxide**
  - **special preparation prior to welding**

Classification of Al

- **2 Major Groups**
  - **Wrought Alloys**
  - **Casting Alloys**
- **4 digit designation system**
  - **1st digit $\Rightarrow$ major alloy element**
  - **2nd digit $\Rightarrow$ special control of impurities**
  - **3rd & 4th digits**
    - **1xxx series $\Rightarrow$ nearest 1/100th % of aluminum**
    - **2xxx to 8xxx series $\Rightarrow$ alloy number**

Aluminum alloys:

soft and ductile, easy cold work.

1xxx…8xxx

Last two digits: purity

F: as fabricated

H: strain hardened

O: annealed

T: heat treated

T3: solution heat treated

Table 12.7 Compositions, Mechanical Properties, and Typical Applications for Several Common Aluminum Alloys

Aluminum Association Number	*UNS Number*	*Composition (wt%)*[a]	*Condition (Temper Designation)*	*Mechanical Properties: Tensile Strength [MPa (ksi)]*	*Mechanical Properties: Yield Strength [MPa (ksi)]*	*Mechanical Properties: Ductility [%EL in 50 mm (2 in.)]*	*Typical Applications/ Characteristics*
			Wrought, Nonheat-Treatable Alloys				
1100	A91100	0.12 Cu	Annealed (O)	90 (13)	35 (5)	35–45	Food/chemical handling & storage equipment, heat exchangers, light reflectors
3003	A93003	0.12 Cu, 1.2 Mn, 0.1 Zn	Annealed (O)	110 (16)	40 (6)	30–40	Cooking utensils, pressure vessels and piping
5052	A95052	2.5 Mg, 0.25 Cr	Strain hardened (H32)	230 (33)	195 (28)	12–18	Aircraft fuel & oil lines, fuel tanks, appliances, rivets, and wire
			Wrought, Heat-Treatable Alloys				
2024	A92024	4.4 Cu, 1.5 Mg, 0.6 Mn	Heat treated (T4)	470 (68)	325 (47)	20	Aircraft structures, rivets, truck wheels, screw machine products
6061	A96061	1.0 Mg, 0.6 Si, 0.30 Cu, 0.20 Cr	Heat treated (T4)	240 (35)	145 (21)	22–25	Trucks, canoes, railroad cars, furniture, pipelines
7075	A97075	5.6 Zn, 2.5 Mg, 1.6 Cu, 0.23 Cr	Heat treated (T6)	570 (83)	505 (73)	11	Aircraft structural parts and other highly stressed applications
			Cast, Heat-Treatable Alloys				
295.0	A02950	4.5 Cu, 1.1 Si	Heat treated (T4)	221 (32)	110 (16)	8.5	Flywheel and rear-axle housings, bus and aircraft wheels, crankcases
356.0	A03560	7.0 Si, 0.3 Mg	Heat treated (T6)	228 (33)	164 (24)	3.5	Aircraft pump parts, automotive transmission cases, water-cooled cylinder blocks
			Aluminum–Lithium Alloys				
2090	—	2.7 Cu, 0.25 Mg, 2.25 Li, 0.12 Zr	Heat treated, cold worked (T83)	455 (66)	455 (66)	5	Aircraft structures and cryogenic tankage structures
8090	—	1.3 Cu, 0.95 Mg, 2.0 Li, 0.1 Zr	Heat treated, cold worked (T651)	465 (67)	360 (52)	—	Aircraft structures that must be highly damage tolerant

Cu

Mg

[a] The balance of the composition is aluminum.

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Wrought Alloys

- Temper Designations (p. 176)
- 2 Basic Types
  - Non-heat-treatable
  - Heat-treatable
- Cladding

Casting Alloys

- Low melting temp
- Aluminum Association designation system
  - 1st digit $\Rightarrow$ alloy group
  - 2nd & 3rd digits $\Rightarrow$ particular alloy or aluminum purity
  - decimal place $\Rightarrow$ indicates product form (casting or ingot)

Aluminum-Lithium

- Emerging as an attractive Al alloy
- Attractive aerospace material
- Available in both wrought and cast forms
- Easily machined, formed, and welded

Magnesium (Mg)

- ***Lightest*** **of the commercially important metals**
- **Weak in the pure state**
- **Density is .0628 lbs/in^3 compared to steel .283 lbs/in^3**
- **Weak at temps above 200º F**
- **Cost per unit volume is low**
- **high strength to weight ratio**

Classification system

- 1 or 2 prefix letters
  - **Largest alloying metals**
- 2 or 3 numbers
  - **Percentages of the two alloy elements in whole numbers**
- Suffix letter denotes variations in base alloy

Magnesium alloys: $T_m = 651^oC$. Used at lower temperature only

sp. Weight = 1.7

HCP, soft, low modulus,
stiff at room temp.

In atmosphere, good resistance to oxidation and corrosion !

(Due to impurities)

Good specific tensile strength

Case of laptop computers

Table 12.8 Compositions, Mechanical Properties, and Typical Applications for Six Common Magnesium Alloys

				Mechanical Properties			
ASTM Number	*UNS Number*	*Composition (wt%)*[a]	*Condition*	*Tensile Strength [MPa (ksi)]*	*Yield Strength [MPa (ksi)]*	*Ductility [%EL in 50 mm (2 in.)]*	*Typical Applications*
			Wrought Alloys				
AZ31B	M11311	3.0 Al, 1.0 Zn, 0.2 Mn	As extruded	262 (38)	200 (29)	15	Structures and tubing, cathodic protection
HK31A	M13310	3.0 Th, 0.6 Zr	Strain hardened, partially annealed	255 (37)	200 (29)	9	High strength to 315°C (600°F)
ZK60A	M16600	5.5 Zn, 0.45 Zr	Artificially aged	350 (51)	285 (41)	11	Forgings of maximum strength for aircraft
			Cast Alloys				
AZ91D	M11916	9.0 Al, 0.15 Mn, 0.7 Zn	As cast	230 (33)	150 (22)	3	Die-cast parts for automobiles, luggage, and electronic devices
AM60A	M10600	6.0 Al, 0.13 Mn	As cast	220 (32)	130 (19)	6	Automotive wheels
AS41A	M10410	4.3 Al, 1.0 Si, 0.35 Mn	As cast	210 (31)	140 (20)	6	Die castings requiring good creep resistance

[a] The balance of the composition is magnesium.

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Titanium alloys: T_m = 1668°C. (Expensive)

sp. Weight = 4.5

But, high chemical reactivity with other materials

Extreme strong, 1400Mpa, high specific tensile strength

Very good corrosion resistance at r.t.

Good ductility, easily forged and machined

Table 12.9 Compositions, Mechanical Properties, and Typical Applications for Several Common Titanium Alloys

Alloy Type	Common Name (UNS Number)	Composition (wt%)	Condition	Average Mechanical Properties: Tensile Strength [MPa (ksi)]	Yield Strength [MPa (ksi)]	Ductility [%EL in 50 mm (2 in.)]	Typical Applications
Commercially pure	Unalloyed (R50500)	99.1 Ti	Annealed	484 (70)	414 (60)	25	Jet engine shrouds, cases and airframe skins, corrosion-resistant equipment for marine and chemical processing industries
α	Ti-5Al-2.5Sn (R54520)	5 Al, 2.5 Sn, balance Ti	Annealed	826 (120)	784 (114)	16	Gas turbine engine casings and rings; chemical processing equipment requiring strength to temperatures of 480°C (900°F)
Near α	Ti-8Al-1Mo-1V (R54810)	8 Al, 1 Mo, 1 V, balance Ti	Annealed (duplex)	950 (138)	890 (129)	15	Forgings for jet engine components (compressor disks, plates, and hubs)
α-β	Ti-6Al-4V (R56400)	6 Al, 4 V, balance Ti	Annealed	947 (137)	877 (127)	14	High-strength prosthetic implants, chemical-processing equipment, airframe structural components
α-β	Ti-6Al-6V-2Sn (R56620)	6 Al, 2 Sn, 6 V, 0.75 Cu, balance Ti	Annealed	1050 (153)	985 (143)	14	Rocket engine case airframe applications and high-strength airframe structures
β	Ti-10V-2Fe-3Al	10 V, 2 Fe, 3 Al, balance Ti	Solution + aging	1223 (178)	1150 (167)	10	Best combination of high strength and toughness of any commercial titanium alloy; used for applications requiring uniformity of tensile properties at surface and center locations; high-strength airframe components

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