Outline

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  - *High Carbon Steel*
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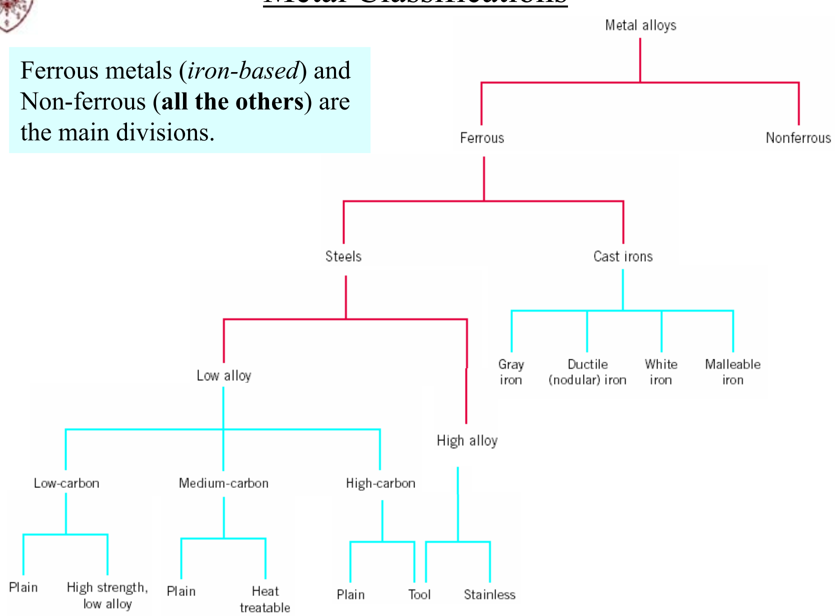
- Designations and Compositions of Steels
- Summery of Effects of Alloying Elements

Why Metals Are Important

- They have properties that satisfy a wide variety of design requirements
- The manufacturing processes by which they are shaped into products have been developed and refined over many years
- Engineers understand metals
- Also have:
  - ✓ *High stiffness and strength* - can be alloyed for high rigidity, strength, and hardness
  - ✓ *Toughness* - capacity to absorb energy better than other classes of materials
  - ✓ *Good electrical conductivity* - Metals are conductors
  - ✓ *Good thermal conductivity* - conduct heat better than ceramics or polymers
  - ✓ *Cost* – the price of steel is very ………….. with other engineering materials

Metal Classifications

Ferrous metals (*iron-based*) and Non-ferrous (**all the others**) are the main divisions.



Types of Ferrous Alloys

Ferrous Alloys.

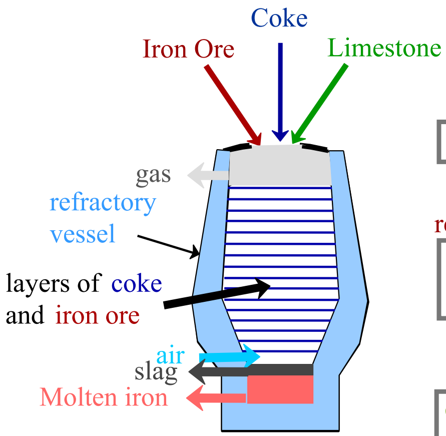
Most common engineering metal:

- Iron ores are relatively abundant
- relatively economical extraction and fabrication
- versatile material and alloys of wide range of properties can be made.

Steels

- Iron - carbon alloys with usually < 1%wt carbon.
- Plain carbon steels - Fe + C + Mn (*no other ………….. additions*)
- Alloy steels - Fe + C + Mn + other additions depending on specific alloy

Refinement of Steel from Ore



BLAST FURNACE

heat generation

$C + O_2 \rightarrow CO_2$

reduction of iron ore to metal

$CO_2 + C \rightarrow 2CO$

$3CO + Fe_2O_3 \rightarrow 2Fe + 3CO_2$

purification

$CaCO_3 \rightarrow CaO + CO_2$

$CaO + SiO_2 + Al_2O_3 \rightarrow$ slag

Iron and Steel Production

➢ Liquid Pig Iron → STEEL MAKING
→ CAST IRONS

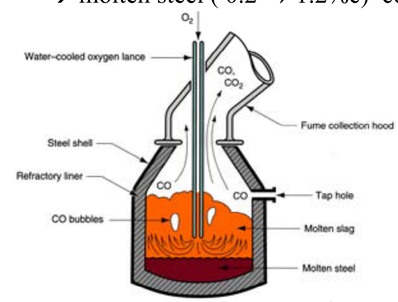
- PIG IRON FROM BLAST FURNACE ~ 4%C (***very high carbon content***)
- Steel → 0 - 1.2%C , Most Steels < 0.5% carbon
- OXIDIZE CARBON (*removed as gas + slag*)

BASIC OXYGEN SYSTEM (*BOS*) - Blow pure oxygen into molten iron

$2\,Fe + O_2 \rightarrow FeO$ then $FeO + C \rightarrow Fe + CO$

✓ Lime added to form slag on surface traps impurities - sulphur, phosphorous

→ molten steel (0.2 → 1.2%c) continuously cast & hot worked.

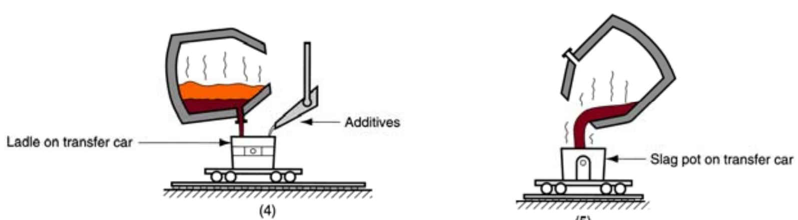


BOF vessel during processing of a heat

Steel Production

BOF sequence :

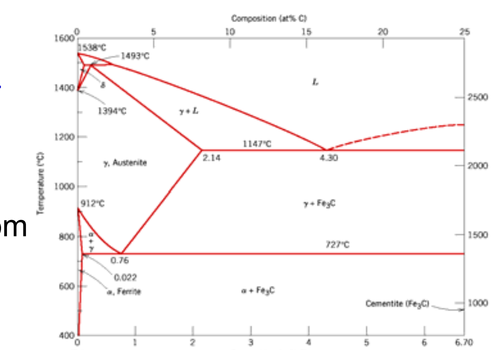
Charging of scrap — Charging pig iron — blowing



tapping the molten steel — pouring off the slag

Classifications of Fe-C alloys

- < 0.008 wt% Carbon → …….
  - α−ferrite at room T
- 0.008 – 2.14 wt% C → ……..
  - usually < 1 wt %
  - α -ferrite + Fe_3C at room
- 2.14 – 6.7 wt% C → ……….
  - usually < 4.5 wt %

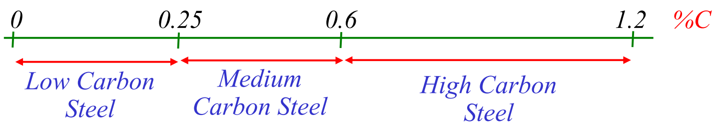


➢ Magnetic properties: α -ferrite is magnetic (below 768°C), austenite is non-magnetic.

➢ Mechanical properties: Cementite is very hard and brittle thus it can strengthen steels.

➢ Mechanical properties also depend on ……………………….. , that is, how ferrite and cementite are mixed.

Plain Carbon Steels:- 0.03 - 1.2% Carbon



eg AISI-SAE classification xxxx

1020 "Mild Steel" (low carbon steel)

- "10xx" Refers to plain carbon; i.e.. ***No extra alloying***
- "xx20" Refers to 20/100's of carbon, i.e. 0.2%C
- (1040) 0.4%C Steel
- (1080) 0.8%C Steel

Plain carbon steels good for "everyday" applications but **not** for high strength or severe requirements. CHEAP!

Plain Carbon Steels:- 0.03 - 1.2% Carbon

Low carbon steels

- Largest volume produced.
- As < 0.25%C, these steels are not hardenable by Quenching & Tempering.
- Cold working is principle hardening mechanism.
- Yield strength ≈ 275 MPa, tensile strength 415 - 550 MPa and 25%El.
- Pearlite & ferrite microstructures, relatively soft & weak but tough & ductile.

- Machinable
- Weldable
- Cheap

Car body components, structural shapes, sheets, pipelines, I-beams, girders, bridges, tin cans….. etc.

High Strength Low Alloy Steels - *HSLA steels*

- Additional alloying elements; e.g. Cu, V, Ni, Mo, ….etc. up to 10wt% total.
- Higher strengths, but still ductile, formable and machinable. And generally more corrosion resistant.

Towers, bridges, columns, pressure vessels - *more ……… applications*

Plain Carbon Steels:- 0.03 - 1.2% Carbon

Designation[a] AISI/SAE or ASTM Number	UNS Number	*Composition (wt%)*[b] C	Mn	Other
		Plain Low-Carbon Steels		
1010	G10100	0.10	0.45	
1020	G10200	0.20	0.45	
A36	K02600	0.29	1.00	0.20 Cu (min)
A516 Grade 70	K02700	0.31	1.00	0.25 Si
		High-Strength, Low-Alloy Steels		
A440	K12810	0.28	1.35	0.30 Si (max), 0.20 Cu (min)
A633 Grade E	K12002	0.22	1.35	0.30 Si, 0.08 V, 0.02 N, 0.03 Nb
A656 Grade 1	K11804	0.18	1.60	0.60 Si, 0.1 V, 0.20 Al, 0.015 N

[a] The codes used by the American Iron and Steel Institute (AISI), the Society of Automotive Engineers (SAE), and the American Society for Testing and Materials (ASTM), and in the Uniform Numbering System (UNS) are explained in the text.

[b] Also a maximum of 0.04 wt% P, 0.05 wt% S, and 0.30 wt% Si (unless indicated otherwise).

Plain Carbon Steels:- 0.03 - 1.2% Carbon

AISI/SAE or ASTM Number	*Tensile Strength [MPa (ksi)]*	*Yield Strength [MPa (ksi)]*	*Ductility [%EL in 50 mm (2 in.)]*	*Typical Applications*
		Plain Low-Carbon Steels		
1010	325 (47)	180 (26)	28	Automobile panels, nails, and wire
1020	380 (55)	205 (30)	25	Pipe; structural and sheet steel
A36	400 (58)	220 (32)	23	Structural (bridges and buildings)
A516 Grade 70	485 (70)	260 (38)	21	Low-temperature pressure vessels
		High-Strength, Low-Alloy Steels		
A440	435 (63)	290 (42)	21	Structures that are bolted or riveted
A633 Grade E	520 (75)	380 (55)	23	Structures used at low ambient temperatures
A656 Grade 1	655 (95)	552 (80)	15	Truck frames and railway cars

Medium Carbon Steels 0.25 - 0.6%C

• Can be heat treated by austenitizing, quenching & tempering to increase mechanical properties (*usually used as ………………………….*).

• *Plain carbon steels* can only be hardened in thin sections with rapid quenching. Often distort & crack on quenching. (hardening). Poor impact resistance at low temperatures.

• To Improve heat treating capabilities add alloying elements: Cr, Ni, Mo,
eg. 4340
8650

• Can be much stronger than low-C steels but usually ductility & toughness reduced.

Medium Carbon steels used for machine components, crankshafts etc.

High Carbon Steels 0.6 - 1.2%C

• Hardest, strongest, least ductile.
• Used in hardened & tempered state for wear resistance & cutting edges.
• Tool steels have alloying elements to form hard carbides; Cr, V, W, Mo, ($Cr_{23}C_6$, V_4C_3, WC).

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.

Tool Steel

AISI Number	UNS Number	Composition (wt%)[a] C	Cr	Ni	Mo	W	V	Typical Applications
M1	T11301	0.85	3.75	0.30 max	8.70	1.75	1.20	Drills, saws; lathe and planer tools
A2	T30102	1.00	5.15	0.30 max	1.15	—	0.35	Punches, embossing dies
D2	T30402	1.50	12	0.30 max	0.95	—	1.10 max	Cutlery, drawing dies
O1	T31501	0.95	0.50	0.30 max	—	0.50	0.30 max	Shear blades, cutting tools
S1	T41901	0.50	1.40	0.30 max	0.50 max	2.25	0.25	Pipe cutters, concrete drills
W1	T72301	1.10	0.15 max	0.20 max	0.10 max	0.15 max	0.10 max	Blacksmith tools, wood-working tools

[a] The balance of the composition is iron. Manganese concentrations range between 0.10 and 1.4 wt%, depending on alloy; silicon concentrations between 0.20 and 1.2 wt% depending on alloy.

T, M *High-speed tool steels* - cutting tools in machining
H *Hot-working tool steels* - hot-working dies for forging, extrusion, and die-casting
D *Cold-work tool steels* - cold working dies for sheetmetal pressworking, cold extrusion, and forging
W *Water-hardening tool steels* - high carbon but little else
S *Shock-resistant tool steels* - tools needing high toughness, as in sheetmetal punching and bending
P *Mold steels* - molds for molding plastics and rubber

Steel Numbering Systems

- ASTM (Testing and Materials), AISI (Iron and Steel Institute), SAE devised codes to define the various steels
- 1st 2 digits: main alloying ingredients
- Last 2 digits: carbon content in hundredths of a percent
- Alloy steel – use various elements and combinations to change material properties, e.g. strength, corrosion resistance, hardenability, etc.

General Effects of Alloying Elements in Steel

1. To improve mechanical properties by **increasing the depth to which a steel can be hardened**
   - *Allows advantage of tempered martensite throughout*
   - *Allows slower quench*
2. To allow higher tempering temperatures while maintaining high strength and good ductility.
3. To improve mechanical properties at high and low temperatures
4. To improve corrosion resistance and elevated temperature oxidation
5. To improve special properties such as **abrasion resistance** and **fatigue behaviour**.

Designation Systems and Composition Ranges for Steels

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%.

Designations and Compositions of Steel Alloys

Carbon steels	10XX	Plain carbon, Mn 1.00% max
	11XX	Resulfurized free machining
	12XX	Resulfurized/rephosphorized free machining
	15XX	Plain carbon, Mn 1.00-1.65%

Last two digits indicate amount of C in *hundredth*

Manganese: Improves hardenability, strength, abrasion resistance and machinability*; deoxidizes the molten steel and reduces hot shortness; decreases weldability.*

Manganese steel	13XX	Mn 1.75%

Nickel – improve strength without loss of ductility
Enhances case hardenability

Nickel steels	23XX	Ni 3.50%
	25XX	Ni 5.00%

Designations and Compositions of Steel Alloys

Nickel-chromium steels	31XX	Ni 1.25%, Cr 0.65-0.80%
	32XX	Ni 1.75%, Cr 1.07%
	33XX	Ni 3.50%, Cr 1.50-1.57%
	34XX	Ni 3.00%, Cr .77%

Nickel with Chromium: improved elastic limit, hardenability, impact resistance and fatigue resistance

Molybdenum steels	40XX	Mo 0.20-0.25%
	44XX	Mo 0.40-0.52%

Molybdenum: Improves hardenability, wear resistance, toughness, elevated temperature strength, creep resistance and hardness*; minimizes temper embrittlement.*

Chromium-molybdenum steels	41XX	Cr .50-.95%, Mo .12-.30%

Nickel-chromium-molybdenum steels	43XX	Ni 1.82%, Cr 0.50-0.80%, Mo 0.25%
	47XX	Ni 1.05%, Cr 0.45%, Mo 0.20-0.35%

Molybdenum with nickel and/or chromium – adds hardness, reduces brittleness, increase toughness

Designations and Compositions of Steel Alloys

Nickel-molybdenum steels	46XX	Ni 0.85-1.82%, Mo 0.20-0.25%
	48XX	Ni 3.50%, Mo 0.25%

Chromium – improves strength, ductility, toughness, wear resistance, hardenabilty and high temp. mech. properties.

Chromium steels	50XX	Cr 0.27-0.65%
	51XX	Cr 0.80-1.05%
	50XXX	Cr 0.50%, C 1.00% min
	51XXX	Cr 1.02%, C 1.00% min
	52XXX	Cr 1.45%, C 1.00% min

Vanadium: Improves strength, toughness, abrasion resistance and hardness at elevated temp.*; inhibits grain growth during heat treatment.*

Chromium-vanadium steels	61XX	Cr 0.60-0.95%, V 0.10-0.15%

Tungsten = Cobalt: Improve strength and hardness at elevated temperatures

Tungsten-chromium steels	72XX	W 1.75%, Cr 0.75%

Designations and Compositions of Steel Alloys

Nickel-chromium-molybdenum steels	81XX	Ni 0.30%, Cr 0.40%, Mo 0.12%
	86XX	Ni 0.55%, Cr 0.50%, Mo 0.20%
	87XX	Ni 0.55%, Cr 0.50%, Mo 0.25%
	88XX	Ni 0.55%, Cr 0.50%, Mo 0.35%

Silicon: Improves strength, hardness, corrosion resistance and electrical conductivity*; decreases magnetic hysteresis loss, machinability and cold formability.*

Silicon-manganese steels	92XX	Si 1.40-2.00%, Mn 0.65-0.85%, Cr 0-0.65%

Nickel-chromium-molybdenum steels	93XX	Ni 3.25%, Cr 1.20%, Mo 0.12%
	94XX	Ni 0.45%, Cr 0.40%, Mo 0.12%
	97XX	Ni 0.55%, Cr 0.20%, Mo 0.20%
	98XX	Ni 1.00%, Cr 0.80%, Mo 0.25%

Alloys Favorably Affecting Properties

Hardenability	Strength	Toughness	Machinability
Boron	**Carbon**	Calcium	Lead
Carbon	Cobalt	Cerium	Manganese
Chromium	Chromium	Chromium	Phosphorus
Manganese	Copper	Magnesium	Selenium
Molybdenum	Manganese	Molybdenum	**Sulfur**
Phosphorus	Molybdenum	**Nickel**	Tellurium
Titanium	Nickel	Niobium	
	Niobium	Tantalum	
	Phosphorus	Tellurium	
	Silicon	Vanadium	
	Tantalum	Zirconium	
	Tungsten		
	Vanadium		

--- Element with most influence

Next time:

Continue Types of Metal Alloys