Metals

Part 2

Manufacturing Materials IE251

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METALS

1. Alloys and Phase Diagrams
2. Ferrous Metals
3. Nonferrous Metals
4. Superalloys
5. Guide to the Processing of Metals

Non Ferrous Metals

Nonferrous Metals

Metal elements and alloys not based on iron

- Most important nonferrous metals are aluminum, copper, magnesium, nickel, titanium, and zinc, and their alloys
- Although not as strong as steels, certain nonferrous alloys have corrosion resistance and/or strength-to-weight ratios that make them competitive with steels in moderate to high stress applications
- Many nonferrous metals have properties other than mechanical that make them ideal for applications in which steel would not be suitable

Aluminum and Magnesium

- Aluminum (Al) and magnesium (Mg) are light metals
  - They are often specified in engineering applications for this feature
- Both elements are abundant on earth, aluminum on land and magnesium in the sea
  - Neither is easily extracted from their natural states
- Principal ore is *bauxite* - mostly hydrated aluminum oxide (Al_2O_3-H_2O) + other oxides

Aluminum

- Properties
  - 1/3 the weight of steel
  - Corrosion resistant
  - Easy to fabricate

Aluminum

– Good electrical conductor

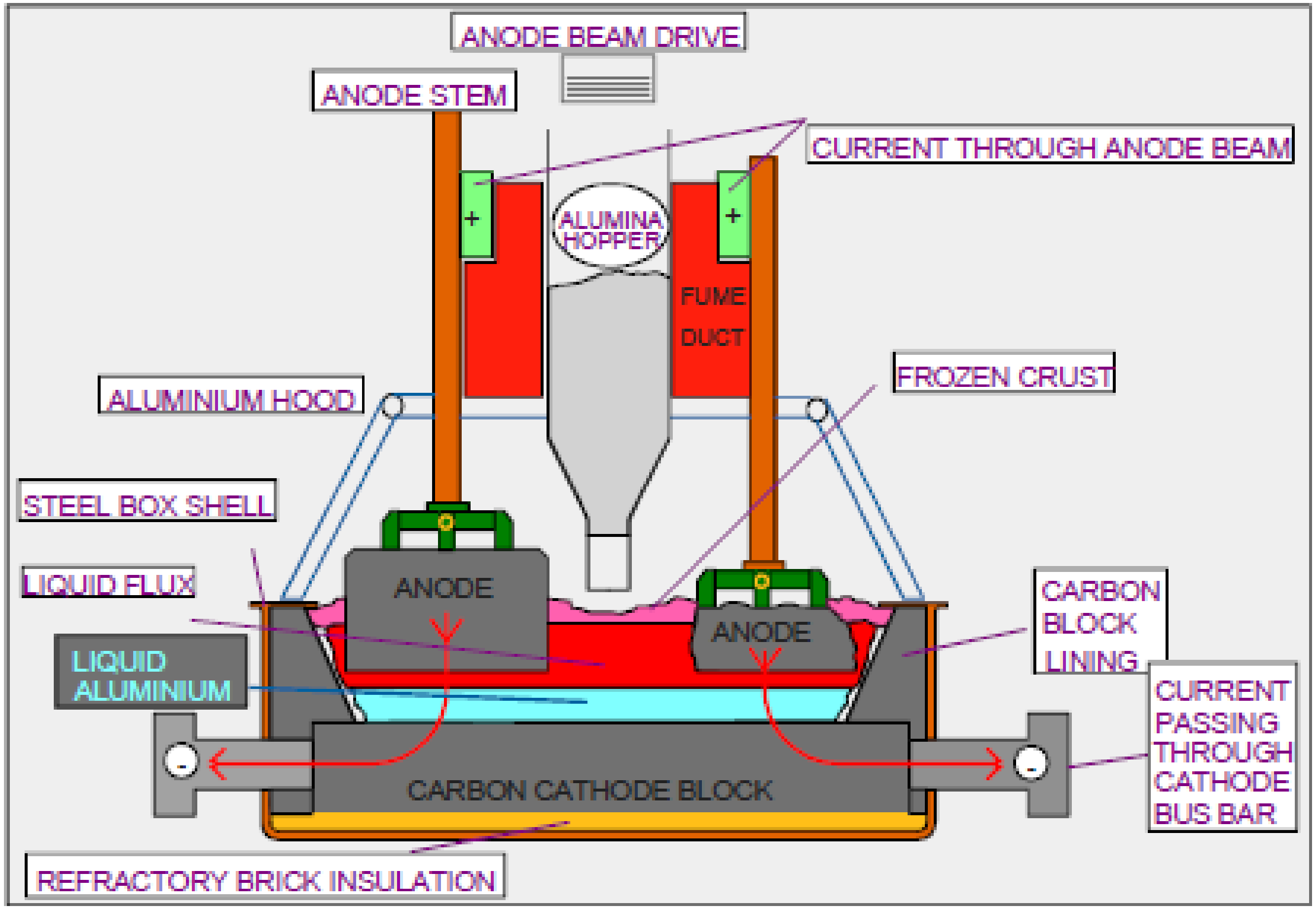
– Many alloy combinations

– High heat and light reflectivity

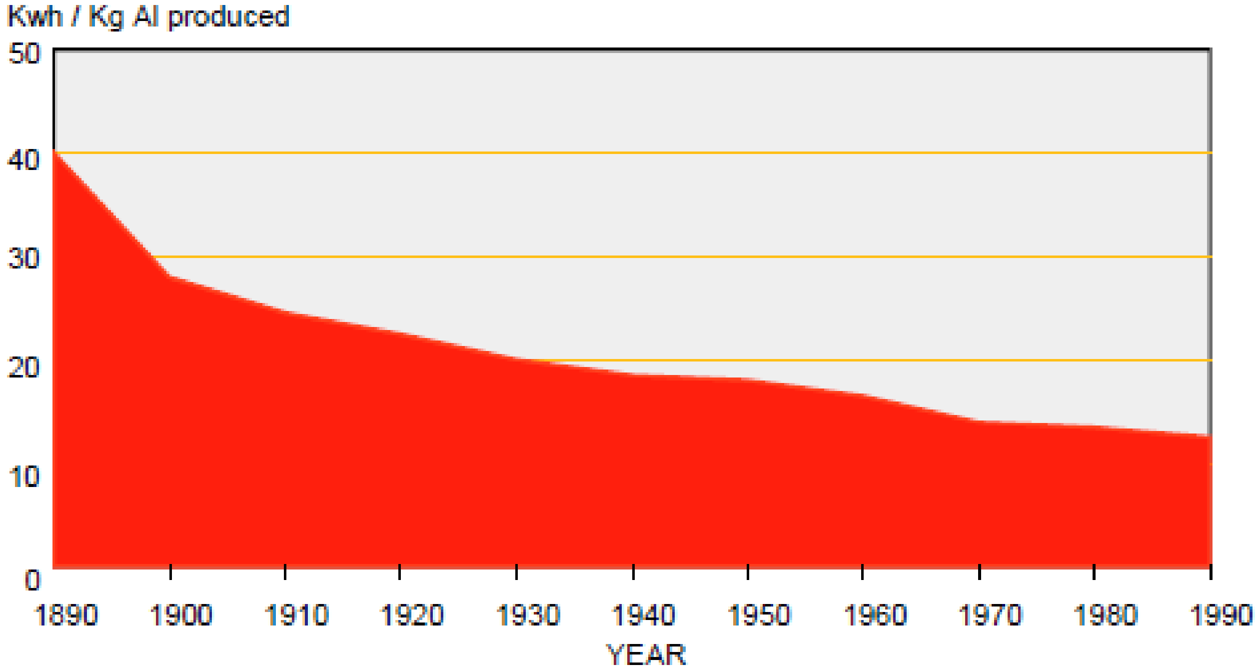
– Takes a good natural finish

Aluminum

- Forms of aluminum products
  - Cast
    - Accurate to within ±0.001”
  - Wrought
    - This means the aluminum has been rolled or worked after casting

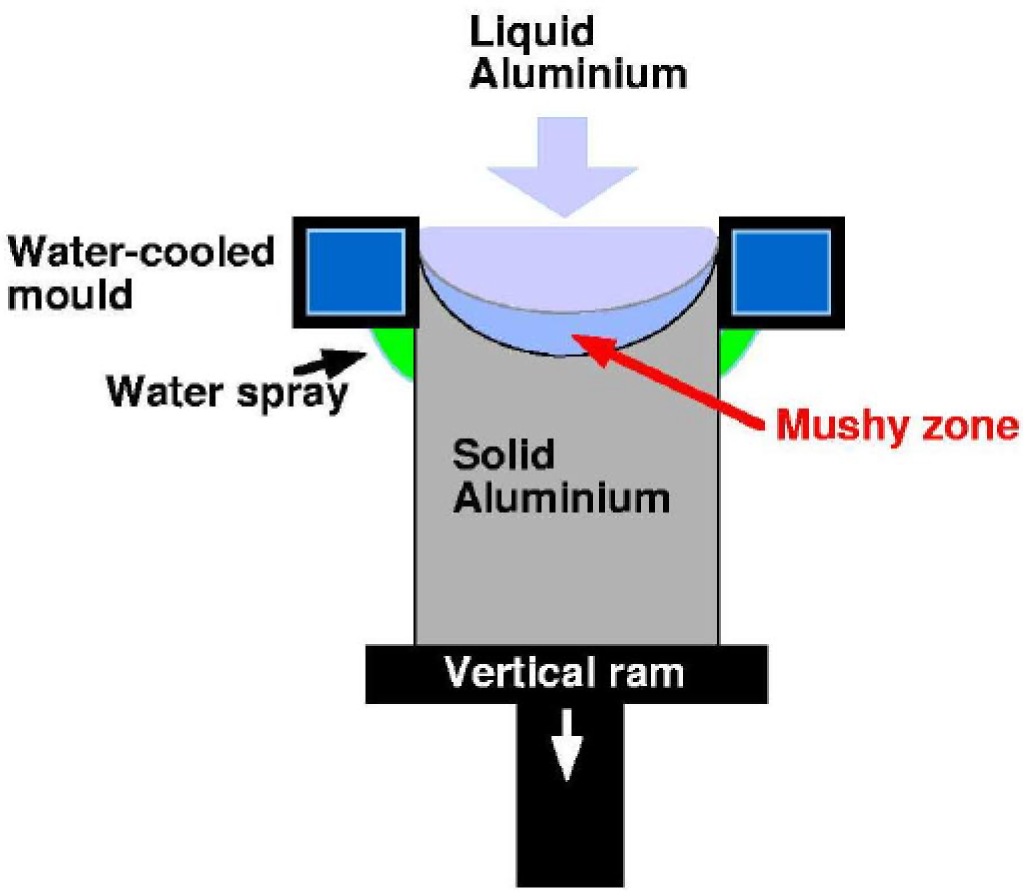


TALAT Training in Aluminium Application Technologies	Cross Section of an Electrolytic Cell	1101.04.02

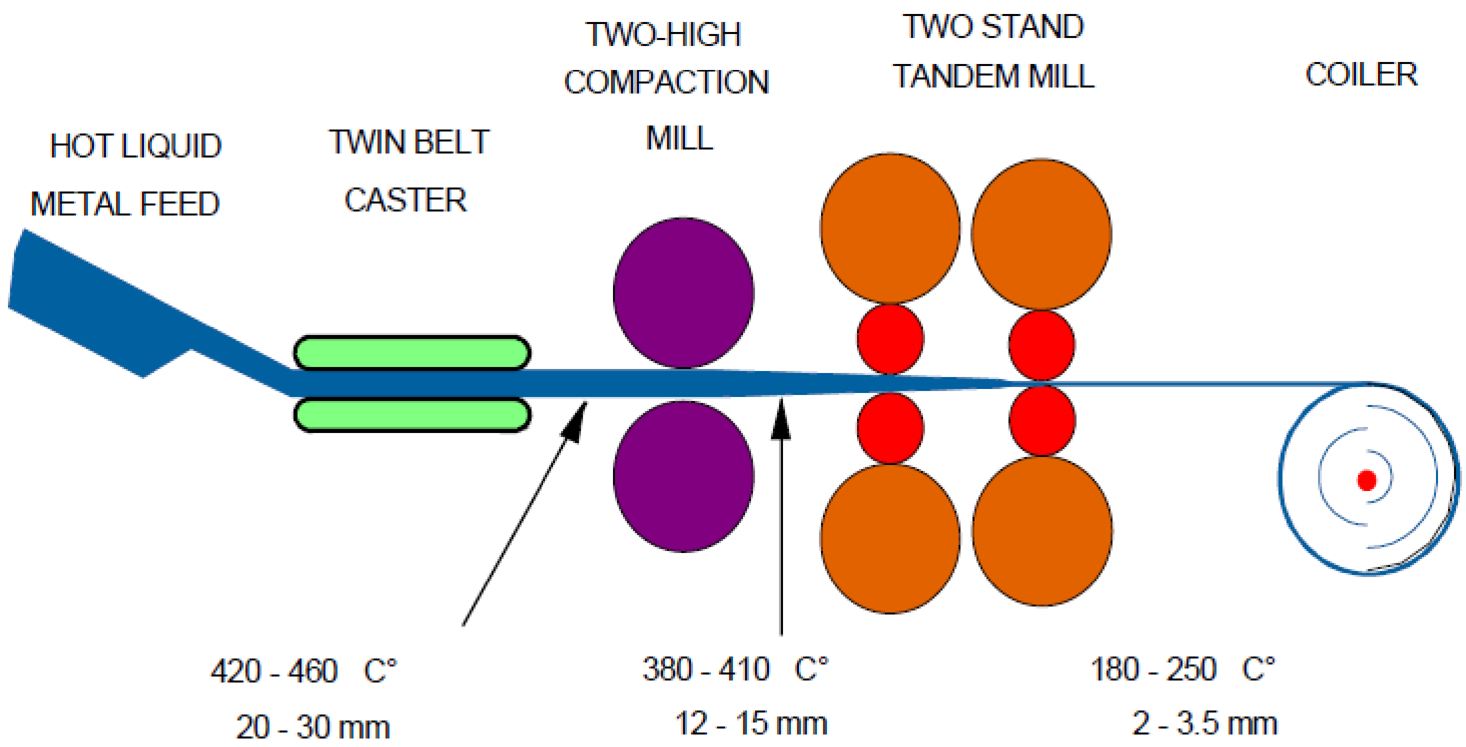


Source: Aluminiumteknik 1991

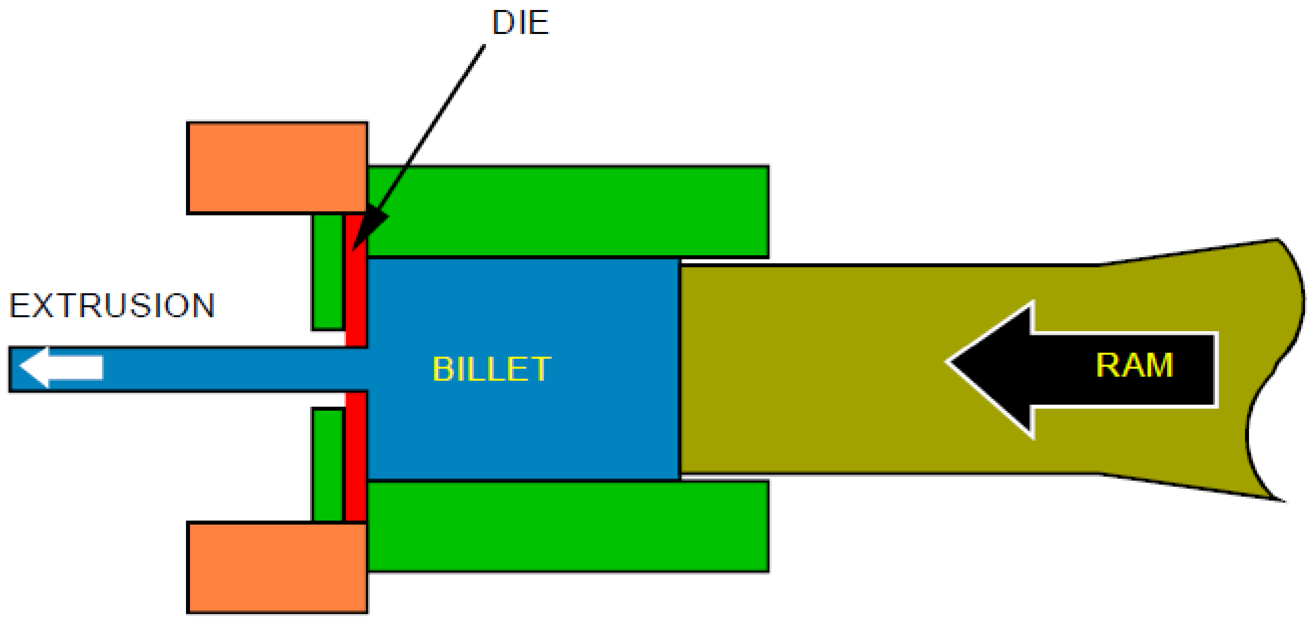
TALAT	Development of Electricity Consumption in the Electrolytic Process	1101.04.03



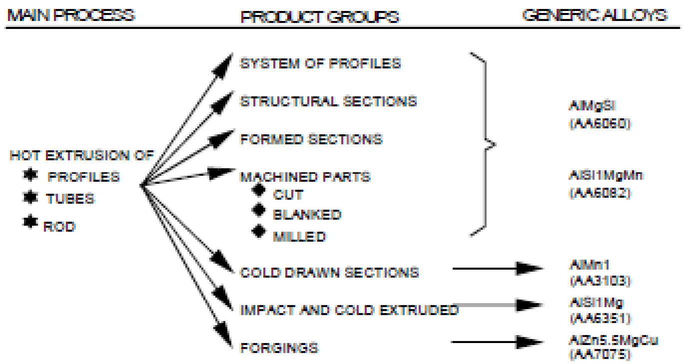
Direct Chill (DC) casting



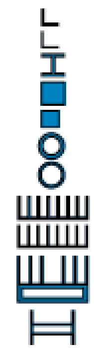
TALAT Training in Aluminium Application Technologies	Continuous Strip Casting Line	1301.02.05



Forward or Direct Extrusion



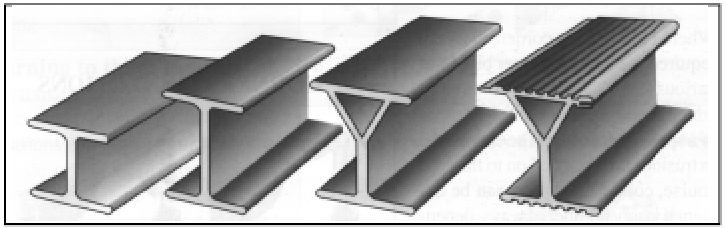
TALAT | Extrusions | 1302.00.02



SECTION TYPE	CCD mm	THICKNESS mm	SHAPE FACTOR
	142	2.5	300
	70	1.5	500
	112	5.0	152
	142	SOLID	15
	70	SOLID	30
	50	3.0	247
	50	1.5	494
	210	3.0	190
	210	2.0	285
	140	2.0/6.0	183
	40	2.0/1.5	430

TALAT | Shape Factor Values $\text{SHAPE FACTOR} = \frac{\text{PERIPHERY}}{\text{CROSS SECTION AREA}}$ | 1302.01.07

Steel- and Aluminium Girders with the same Bending Stiffness



Steel	Aluminium appro. 50% lower weight vs. steel	Aluminium increased torsional stiffness	Aluminium increased torsional stiffness and integrated functions

TALAT | Designing Extrusions with Improved Stiffness | 1302.01.11

PURE ALUMINIUM

Annealed pure aluminium is:

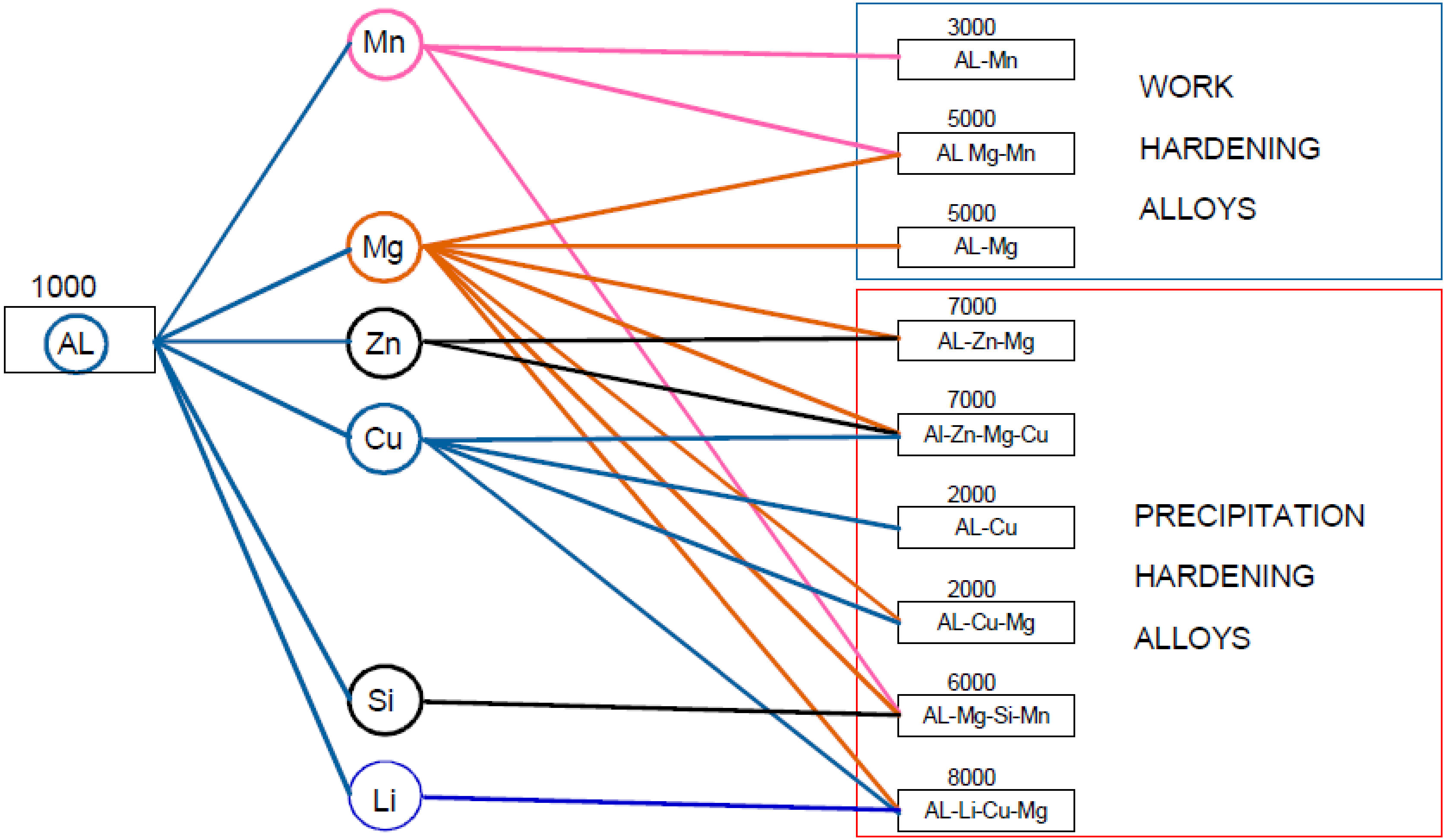
- not very strong
- soft and ductile
- light in weight
- corrosion resistant
- of high thermal and electrical conductivities

Typical mechanical properties are:

	Annealed	Moderate cold work
0.2% Yield Strength	15 MPa	50 MPa
UTS	50 MPa	100 MPa
Elongation †	50%	50%
Hardness	130 Hv	230 Hv

† maximum elongation before breaking

REQUIRED CHARACTERISTIC	ALLOYING ELEMENT	PRODUCT
LOWER MELTING POINT	Si	BRAZING SHEET, FOIL
INCREASED CONDUCTIVITY	B	CONDUCTOR STRIP
INCREASED ELASTIC MODULUS	Li	AEROSPACE SHEET
DECREASED DENSITY	Li	AEROSPACE SHEET
STRESS CORROSION RESISTANCE	Cr, Zr, Ag	AIRCRAFT SHEET
SACRIFICIAL CORROSION	Zn	HEAT EXCHANGERS CLAD PRODUCTS
VACUUM BRAZING RESPONSE	Mg	HEAT EXCHANGERS
RESPONSE TO CHEMICAL or ELECTROCHEMICAL TREATMENT	Si, Cu, Cr	DECORATIVE APPLICATIONS



TALAT
Training in Aluminium Application Technologies

Main Alloy Types Available as Sheet and Plate

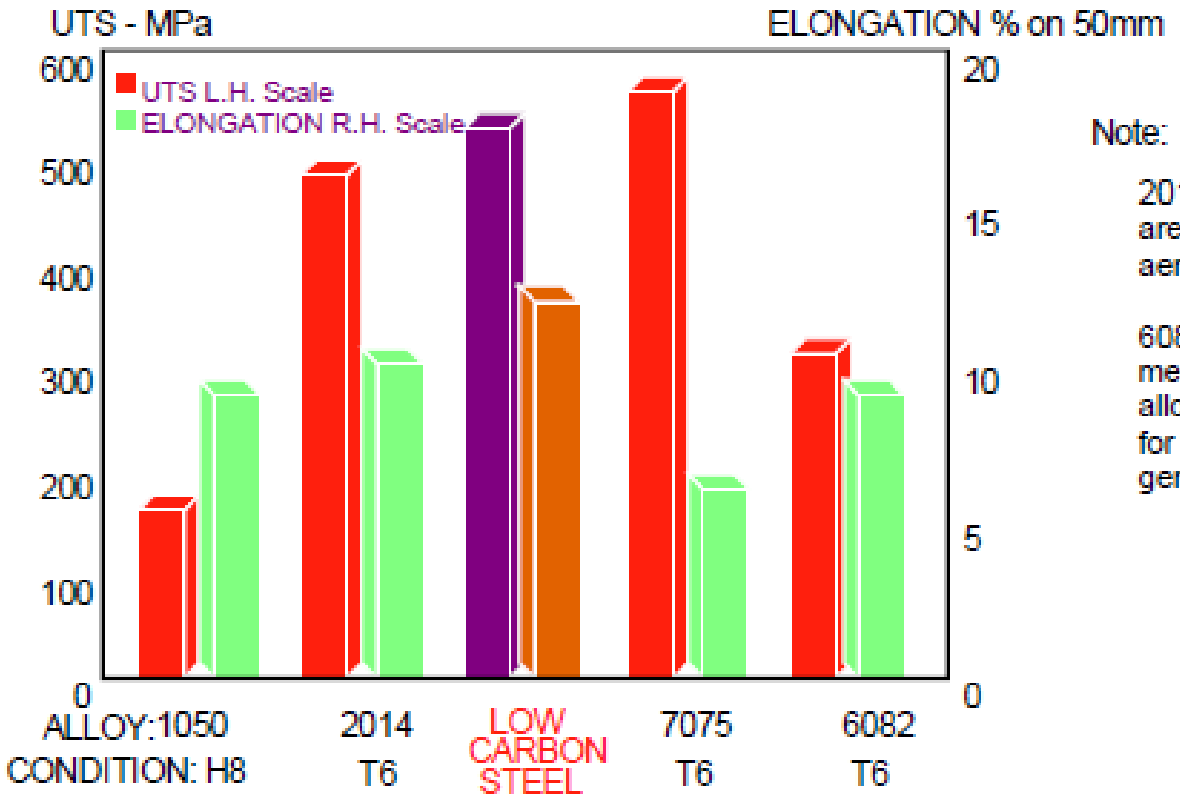
1301.01.05

1XXX	Aluminium of 99% minimum purity
2XXX	Aluminium and copper alloys
3XXX	Aluminium and manganese alloys
4XXX	Aluminium and silicon alloys
5XXX	Aluminium and magnesium alloys
6XXX	Aluminium, Mg and Si alloys
7XXX	Aluminium, Zn and Mg alloys
8XXX	other alloys (eg. aluminium lithium).

Each alloy is described by a four digit number plus a further letter and number indicating the temper or condition.

WORK HARDENING		HEAT TREATABLE	
1XXX	(Al)		
		2XXX	(Al/Cu)
3XXX	(Al/Mn)		
5XXX	(Al/Mg)		
		6XXX	(Al/Mg/Si)
		7XXX	(Al/Zn/Mg)
8XXX	(Al/Other)	8XXX	(Al/Other)

The 4xxx series in wrought form is almost exclusively used for welding rod and wire as well as for braze cladding.



Note:

2014 and 7075 are typical aerospace alloys.

6082 is a medium strength alloy widely used for transport and general structures.

TALAT	1050-H8 (99.5% Al) Compared with Heat Treatable Alloys and Work Hardening Alloys	1101.02.05

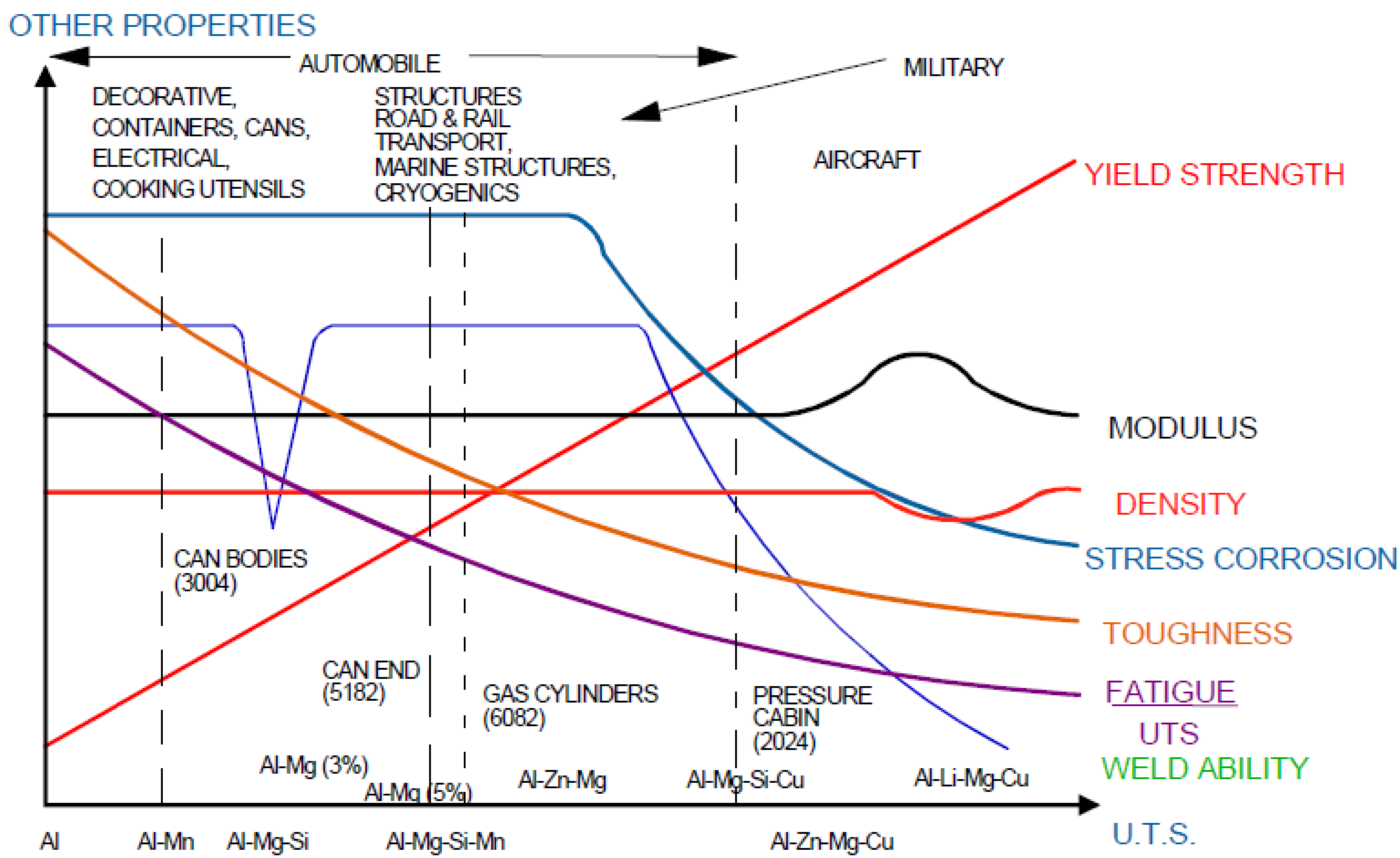
	K TONNES
CANS	2,013
OTHER PACKAGING	361
ROAD VEHICLES	298
RESIDENTIAL SIDING	190
OTHER BUILDING	155
AIR CONDITIONERS / APPLIANCES	140
HOUSEHOLD & FOIL	133
AIRCRAFT PLATE	110
AIRCRAFT SHEET	96
COOKING UTENSILS	50
LITHOGRAPHIC SHEET	50
MOBILE HOMES	35

Source: Aluminum Association

TALAT Training in Aluminium Application Technologies

1990 Sheet, Plate & Foil Markets by Product Type (N. America)

1301.01.02



TALAT Training in Aluminium Application Technologies | Range of Properties and Uses of Aluminium Alloys | 1301.01.03

ALLOY	APPLICATION
WORK-HARDENING ALLOYS	
1060	CHEMICAL EQUIPMENT, TANKERS.
1100	COOKING UTENSILS, DECORATIVE PANELS.
3003, 3004	CHEMICAL EQUIPMENT, STORAGE TANKS, BEVERAGE CAN BODIES.
5005, 5050 5052, 5657	AUTOMOTIVE TRIM, ARCHITECTURAL APPLICATIONS.
5085, 5086	MARINE STRUCTURES, STORAGE TANKS, RAIL CARS.
5454, 5456	PRESSURE VESSELS, ARMOUR PLATE.
5182, 5356	CYROGENIC TANKS, BEVERAGE CAN ENDS.
HEAT TREATABLE ALLOYS	
2219	HIGH TEMPERATURE (eg high speed aircraft).
2014, 2024	AIRFRAMES, AUTOBODY SHEET.
6061, 6063 6082, 6351 6009, 6010	MARINE STRUCTURES, HEAVY ROAD TRANSPORT, RAIL CARS, AUTOBODY SHEET.
7004, 7005 7019, 7039	MISSILES, ARMOUR PLATE, MILITARY BRIDGES.
7075, 7079, 7050, 7010, 7150	AIRFRAMES, TOOLING PLATE.

Typical Applications of some Aluminium Sheet & Plate Alloys

Magnesium and Its Alloys

- Lightest of the structural metals
- Available in both wrought and cast forms
- Relatively easy to machine
- In all processing of magnesium, small particles of the metal (such as small metal cutting chips) oxidize rapidly, and care must be taken to avoid fire hazards

Ipod case

Properties of Magnesium

- As a pure metal, magnesium is relatively soft and lacks sufficient strength for most engineering applications
- However, it can be alloyed and heat treated to achieve strengths comparable to aluminum alloys
- In particular, its strength-to-weight ratio is an advantage in *aircraft* and *missile* components

Copper

- One of the oldest metals known to mankind

- Good electrical conductor - commercially pure copper is widely used as an electrical conductor

- Also an excellent thermal conductor

- One of the *noble metals* (gold and silver are also noble metals), so it is corrosion resistant

Copper Alloys

- Strength and hardness of copper is <u>relatively low</u>; to improve strength, copper is frequently alloyed
- Bronze - alloy of copper and tin (typical ~ 90% Cu, 10% Sn), widely used today and in ancient times (i.e., the *Bronze Age*)
- Brass - alloy of copper and zinc (typical ~ 65% Cu, 35% Zn).
- <u>Highest strength alloy</u> is beryllium-copper (only about 2% Be), which can be heat treated to high strengths and used for springs

Coins?!

What are the coins made of?

The Australian 10 cent coin is roughly the same size as a US Quarter.

And an Australian 5 cent coin is roughly the size of a US Dime.

Dimes are made out of an alloy of 91.67 percent copper and 8.33 percent nickel (before 1965, the dime was made out of silver).

Nickel and Its Alloys

- Similar to iron in some respects:
  - Magnetic
  - Modulus of elasticity $\cong E$ for iron and steel
- Differences with iron:
  - Much more corrosion resistant - widely used as
    1. an alloying element in steel, e.g., *stainless steel*,
    2. as a plating metal on metals such as plain *carbon steel*
  - High temperature properties of Ni alloys are superior

Nickel Alloys

Alloys of nickel are commercially important and are noted for corrosion resistance and high temperature performance

- In addition, a number of superalloys are based on nickel
- Applications: stainless steel alloying ingredient, plating metal for steel, applications requiring high temperature and corrosion resistance

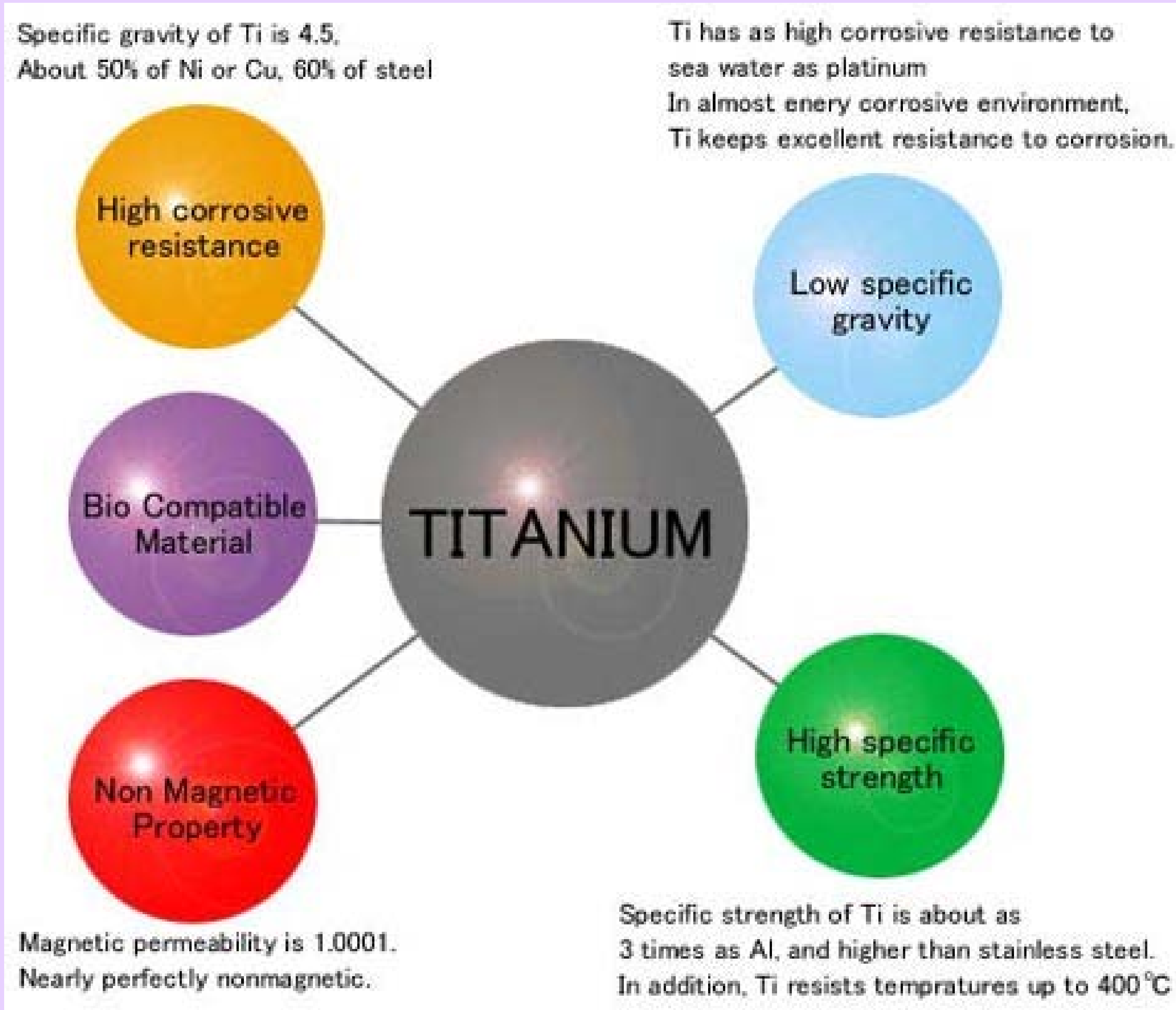
Titanium and Its Alloys

- Abundant in nature, constituting ~ 1% of earth's crust (aluminum is ~ 8%)
- Density of Ti is between aluminum and iron
- Importance has grown in recent decades due to its aerospace applications where its light weight and good strength-to-weight ratio are exploited

Properties of Titanium

- Coefficient of thermal expansion is relatively low among metals
- Stiffer and stronger than Al
- Retains good strength at elevated temperatures
- Pure Ti is reactive, which presents problems in processing, especially in molten state
- At room temperature Ti forms a thin adherent oxide coating (TiO_2) that provides excellent corrosion resistance

Properties of Titanium



Applications of Titanium

- In the commercially pure state, Ti is used for corrosion resistant components, such as marine components and prosthetic implants

- Titanium alloys are used as <u>high strength components at temperatures</u> ranging up to above <u>550°C</u> (<u>1000°F</u>), especially where its excellent <u>strength-to-weight ratio</u> is exploited

Examples: aircraft and missile components

Alloying elements used with titanium include aluminum, manganese, tin, and vanadium

Summary

Nonferrous Metals

- Aluminum
- Copper
- Magnesium
- Nickel
- Titanium
- Zinc

Aluminum Alloys

- Abundantly Available on Land (Bauxite)
  - ~ 8% of earth's crust
- Light Weight
- More complex ore extraction than steel
- Excellent Thermal & Electrical Conductor
- Great Corrosive Resistance
- Easily Formed

Aluminum Designations

Major Alloy	Wrought Code	Cast Code
99%+ Pure	1XXX	1XX.X
Copper	2XXX	2XX.X
Manganese	3XXX	
Si + Cu +/- Mg		3XX.X
Silicon	4XXX	4XX.X
Magnesium	5XXX	5XX.X
Magnesium & Si	6XXX	
Zinc	7XXX	7XX.X
Tin		8XX.X
Other	8XXX	9XX.X

Magnesium Alloys

- Mined from sea-water
- Lightest of the structural alloys
- Easy to machine
- Small Mg particles easily oxidize
  - Fire hazard
- 3 to 5 alpha code alloy designation

Copper Alloys

- One of the Oldest Metals Known
  - ~ 6000 B.C.
- Found in naturally & extracted from ore
  - Chalcopyrite ($CuFeS_2$)
- One of the lowest electrical resistivities
- Noble metal (corrosive resistant)
- Low strength & hardness
- Bronze – when alloyed with Tin
- Brass – when alloyed with Zinc

Nickel Alloys

- Similar strength to iron
- More corrosive resistant than iron
- Commonly used as an alloying element with iron
- Extracted from pentlandite ($(NiFe)_9S_8$)

Titanium Alloys

- Fairly abundant in nature
  - ~ 1% of earth's crust
- Principle ores:
  - Rutile - TiO_2
  - Ilmenite - FeO & TiO_2
- Good strength to weight ratio
- Relatively low thermal expansion
- Stiffer & stronger than aluminum
- Good hot hardness
- Excellent corrosion resistance

Superalloys

Superalloys

High-performance alloys designed to meet demanding requirements for strength and resistance to surface degradation at high service temperatures

- Many superalloys contain substantial amounts of three or more metals, rather than consisting of one base metal plus alloying elements
- Commercially important because they are very expensive
- Technologically important because of their unique properties

Why Superalloys are Important

- Room temperature strength properties are good but not outstanding
- High temperature performance is excellent - tensile strength, creep resistance, and corrosion resistance at very elevated temperatures
- Operating temperatures often around 1100°C (2000°F)
- Applications: gas turbines - jet and rocket engines, steam turbines, and nuclear power plants (all are systems in which operating efficiency increases with higher temperatures)

Three Groups of Superalloys

1. Iron-based alloys - in some cases iron is less than 50% of total composition
   - Alloyed with Ni, Cr, Co
2. Nickel-based alloys - better high temperature strength than alloy steels
   - Alloyed with Cr, Co, Fe, Mo, Ti
3. Cobalt-based alloys - ~ <u>40% Co and ~ 20% chromium</u>
   - Alloyed with Ni, Mo, and W

- In virtually all superalloys, including iron based, strengthening is by precipitation hardening

Manufacturing Processes for Metals

Manufacturing Processes for Metals

- Metals are shaped by all of the basic shaping processes: casting, powder metallurgy, deformation, and material removal
- In addition, metal parts are joined to form assemblies by welding, brazing, soldering, and mechanical fastening
- Heat treating is used to enhance properties
- Finishing processes (e.g., electroplating and painting) are commonly used to improve appearance of metal parts and/or to provide corrosion protection

How to Enhance Mechanical Properties

- Alloying - to increase strength of metals
- Cold working - strain hardening during deformation to increase strength (also reduces ductility)
  - Strengthening of the metal occurs as a byproduct of the forming operation
- Heat treatment - heating and cooling cycles performed on a metal to beneficially change its mechanical properties
  - Operate by altering the microstructure of the metal, which in turn determines properties