روشهاي توليد و كارگاه

PRODUCTION TECHNIQUES

NONFERROUS METALS AND ALLOYS:

PRODUCTION, GENERAL PROPERTIES, AND APPLICATIONS

DEPARTMENT OF MECHANICAL ENGINEERING
ISFAHAN UNIVERSITY OF TECHNOLOGY

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Introduction

- ✓ **Nonferrous metals and alloys**
  - ✓ From more common metals such as aluminium, copper and magnesium to high-strength high-temperature alloys such as those tungsten, tantalum, and molybdenum
  - ✓ Generally more expensive than ferrous metals
  - ✓ Main properties: corrosion resistance, high thermal and electrical conductivity, low density, and ease of fabrication
  - ✓ **Typical examples of the applications:**
    - ✓ Aluminium for cooking utensils and aircraft body
    - ✓ Copper wire for electricity
    - ✓ Zinc for galvanized sheet metal for car bodies
    - ✓ Titanium for jet-engine turbine blades and for orthopedic implants
    - ✓ Tantalum for rocket engine

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Cost of Wrought Metals and Plastics vs. Carbon Steel

TABLE 6.1

Approximate Cost-per-unit-volume for Wrought Metals and Plastics Relative to the Cost of Carbon Steel

Gold	60,000	Magnesium alloys	2-4
Silver	600	Aluminum alloys	2-3
Molybdenum alloys	200-250	High-strength low-alloy steels	1.4
Nickel	35	Gray cast iron	1.2
Titanium alloys	20-40	Carbon steel	1
Copper alloys	5-6	Nylons, acetals, and silicon rubber*	1.1-2
Zinc alloys	1.5-3.5	Other plastics and elastomers*	0.2-1
Stainless steels	2-9		

*As molding compounds.
Note: Costs vary significantly with quantity of purchase, supply and demand, size and shape, and various other factors.

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Nonferrous Metals and Alloys

TABLE 6.2

General Characteristics of Nonferrous Metals and Alloys

Material	Characteristics
Nonferrous alloys	More expensive than steels and plastics; wide range of mechanical, physical, and electrical properties; good corrosion resistance; high-temperature applications
Aluminum	High strength-to-weight ratio; high thermal and electrical conductivity; good corrosion resistance; good manufacturing properties
Magnesium	Lightest metal; good strength-to-weight ratio
Copper	High electrical and thermal conductivity; good corrosion resistance; good manufacturing properties
Superalloys	Good strength and resistance to corrosion at elevated temperatures; can be iron-, cobalt-, and nickel-based alloys
Titanium	Highest strength-to-weight ratio of all metals; good strength and corrosion resistance at high temperatures
Refractory metals	Molybdenum, niobium (columbium), tungsten, and tantalum; high strength at elevated temperatures
Precious metals	Gold, silver, and platinum; generally good corrosion resistance

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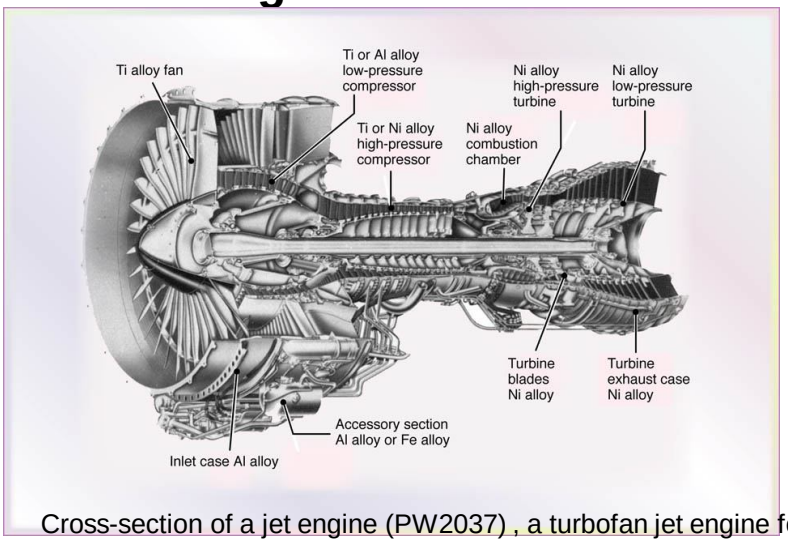
Jet Engine Cross-Section



Cross-section of a jet engine (PW2037) , a turbofan jet engine for the Boeing 757 aircraft typically contains 38% Ti, 37% Ni, 12% Cr, 6 % Co, 5% Al, 1% Nb, and 0.02% Ta Source: Courtesy of United Aircraft Pratt & Whitney.

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Aluminium and Aluminium alloys

- ✓ **Important factors in selecting:**
  - ✓ High strength-to-weight ratio
  - ✓ Resistance to corrosion by many chemicals
  - ✓ high thermal and electrical conductivity
  - ✓ Nontoxicity
  - ✓ Reflectivity
  - ✓ Appearance
  - ✓ Ease of formability and machining
  - ✓ Nonmagnetic

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Aluminum Alloy Properties

TABLE 6.3

Properties of Selected Aluminum Alloys at Room Temperature

Alloy (UNS)	Temper	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation in 50mm (%)
1100 (A91100)	O	90	35	35–45
1100	H14	125	120	9–20
2024 (A92024)	O	190	75	20–22
2024	T4	470	325	19–20
3003 (A93003)	O	110	40	30–40
3003	H14	150	145	8–16
5052 (A95052)	O	190	90	25–30
5052	H34	260	215	10–14
6061 (A96061)	O	125	55	25–30
6061	T6	310	275	12–17
7075 (A97075)	O	230	105	16–17
7075	T6	570	500	11

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Aluminum Alloy Properties and Applications

TABLE 6.4

Manufacturing Properties and Typical Applications of Selected Wrought Aluminum Alloys

Alloy	Characteristics*			Typical applications
	Corrosion resistance	Machinability	Weldability	
1100	A	C–D	A	Sheet metal work, spun hollowware, tin stock
2024	C	B–C	B–C	Truck wheels, screw machine products, aircraft structures
3003	A	C–D	A	Cooking utensils, chemical equipment, pressure vessels, sheet metal work, builders' hardware, storage tanks
5052	A	C–D	A	Sheet metal work, hydraulic tubes, and appliances; bus, truck and marine uses
6061	B	C–D	A	Heavy-duty structures where corrosion resistance is needed; truck and marine structures, railroad cars, furniture, pipelines, bridge railings, hydraulic tubing
7075	C	B–D	D	Aircraft and other structures, keys, hydraulic fittings

*A, excellent; D, poor.

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Aluminium and Aluminium alloys (con't)

- ✓ **Availability**
  - ✓ As mill products, that is, as wrought products made into shapes by rolling, extrusion, drawing, and forging
  - ✓ As ingot for casting
  - ✓ As in powder for powder-metallurgy applications

- ✓ **Types of wrought alloys of aluminium:**
  - ✓ Not heat treatable, but can be hardened by cold working
  - ✓ Can be hardened by heat treatment

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Designation of wrought aluminium alloys

- ✓ 1xxx– Commercially pure aluminium: Excellent corrosion resistance, high thermal and electrical conductivity, good workability, low strength, not heat-treatable
- ✓ 2xxx– Copper: High strength-to-weight ratio, low resistance to corrosion, heat treatable
- ✓ 3xxx–Manganese: Good workability, moderate strength, generally not heat-treatable
- ✓ 4xxx–Silicon: lower melting point, forms an oxide film of a dark-gray to charcoal strength, generally not heat-treatable
- ✓ 5xxx—magnesium: Good corrosion resistance and weldability, moderate to high strength, not heat-treatable
- ✓ 6xxx—Magnesium and Silicon: medium strength, good formability, machinability, weladability, heat treatable
- ✓ 7xxx—Zinc: moderate to very high strength, heat treatable

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Designation of cast aluminium alloys

- ✓ 1xx.x–Aluminium (99.00% minimum)
- ✓ 2xx.x–Aluminium-Copper
- ✓ 3xx.x--Aluminium-Silicon (with copper and/or magnesium)
- ✓ 4xx.x--Aluminium-Silicon
- ✓ 5xx.x--Aluminium-Magnesium
- ✓ 6xx.x—Unused series
- ✓ 7xx.x--Aluminium-Zinc
- ✓ 8xx.x--Aluminium-Tin

Temper designations:

- ✓ F–- As fabricated (by cold or hot working or by casting)
- ✓ O—Annealed (from the cold worked or the cast state)
- ✓ H—Strain hardened by cold working (for wrought products only)
- ✓ T---Heat treated
- ✓ W—Solution treated only (unstable temper)

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Aluminium Production

- ✓ The principle ore: *bauxite* (hydrous aluminium oxide)
  - ✓ Washing off the clay and dirt
    - ✓ Crushing into powder
      - ✓ Treating with hot sodium hydroxide to remove impurity
        - ✓ Extracting aluminium oxide (Alumina) from this solution
      - ✓ Dissolving in a molten sodium-fluoride and aluminium-fluoride at 940 to 980 °C
    - ✓ Subjecting to direct-current electrolysis
  - ✓ Forming aluminium metal at the cathode, while realising oxygen at the anode

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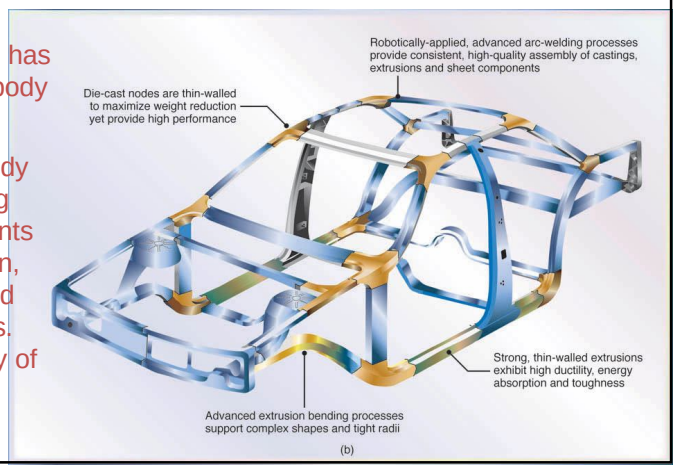
The All Aluminum Audi A8

(a) The Audi A8 automobile which has an all-aluminum body structure.

(b) The aluminum body structure, showing various components made by extrusion, sheet forming, and casting processes. *Source*: Courtesy of ALCOA, Inc.



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Magnesium and Magnesium alloys

- ✓ The lightest engineering metal available
- ✓ Good vibration damping
- ✓ Suitable wherever weight is of primary importance
- ✓ Alloying element in various nonferrous metals

Typical usages:

- ✓ In aircraft and missile components
- ✓ Handling equipments
- ✓ Luggage, bicycles and sporting goods
- ✓ Printing and textile machinery

- ✓ Not sufficiently strong in its pure form
- ✓ *Pyrophoric* (oxidization rapidly), thus existing fire hazard when machining, grinding, or sand-casting

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Wrought Magnesium Alloys: Properties and Forms

TABLE 6.5

Properties and Typical Forms of Selected Wrought Magnesium Alloys

Alloy	Composition (%)					Condition	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation in 50 mm (%)	Typical forms
	Al	Zn	Mn	Zr	Th					
AZ31B	3.0	1.0	0.2	-	-	F	260	200	15	Extrusions
						H24	290	220	15	Sheet and plates
AZ80A	8.5	0.5	0.2	-	-	T5	380	275	7	Extrusions and forgings
HK31A	-	-	-	0.7	3	H24	255	200	8	Sheet and plates
ZK60A	-	5.7	-	0.55	-	T5	365	300	11	Extrusions and forgings

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Copper and Copper alloys

- ✓ Properties somewhat similar to those of aluminium
- ✓ Among the best conductors of electricity and heat
- ✓ Good corrosion resistance
- ✓ Processing easily by various forming, machining, casting, and joining techniques

Typical usages:

- ✓ Electrical and electronic components
- ✓ Springs, plumbing, heat exchangers, marine hardware
- ✓ Dies in polymer injection

Brass: an alloy of copper and zinc

Bronze: an alloy of copper and tin

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Wrought Copper and Brasses: Properties and Applications

TABLE 6.6

Properties and Typical Applications of Selected Wrought Copper and Brasses

Type and UNS number	Nominal composition (%)	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation in 50 mm (%)	Typical applications
Electrolytic tough pitch copper (C11000)	99.90 Cu, 0.04O	220-450	70-365	55-4	Downspouts, gutters, roofing, gaskets, auto radiators, bus bars, nails, printing rolls, rivets
Reb brass, 85% (C2300)	85.0 Cu, 15.0 Zn	270-725	70-435	55-3	Weather stripping, conduits, sockets, fasteners, fire extinguishers, condeser and heat-exchanger tubing
Cartridge brass, 70% (C2600)	70.0 Cu, 30.0 Zn	300-900	75-450	66-3	Radiator cores and tanks, flashlight shells, lamp fixtures, fasteners, locks, hinges, ammunition components, plumbing accessories
Free-cutting brass (C3600)	61.5 Cu, 3.0 Pb, 35.5 Zn	340-470	125-310	53-18	Gears, pinions, automatic high-speed screw machine parts
Naval brass (C46400 to C46700)	60.0 Cu, 39.25 Zn, 0.75 Sn	380-610	170-455	50-17	Aircraft: turnbuckle barrels, balls, bolts; marine hardware: propeller shafts, rivets, valve stems, condenser plates

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Wrought Bronzes: Properties and Applications

TABLE 6.7

Properties and Typical Applications of Selected Wrought Bronzes

Type and UNS number	Nominal composition (%)	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation in 50 mm (%)	Typical applications
Architechtural bronze (C38500)	57.0 Cu, 3.0 Pb, 40.0 Zn	415 (As extruded)	140	30	Architectural extrusions, store fronts, thresholds, trim, butts, hinges
Phosphor bronze, 5% A (C51000)	95.0 Cu, 5.0 Sn, trace P	325-960	130-550	64-2	Bellows, clutch disks, cotter pins, diaphragms, fasteners, wire brishes, chemical hardware, textile machinery
Free-cutting phosphor bronze (C54400)	88.0 Cu, 4.0 Pb, 4.0 Zn, 4.0 Sn	300-520	130-435	50-15	Bearings, bushings, gears, pinions, shafts, thrust washers, valve parts
Low-silicon bronze, B (C65100)	98.5 Cu, 1.5 Si	275-655	100-475	55-11	Hydraulic pressure lines, bolts, marine hardware, electrical conduits, heat-exchanger tubing
Nickel silver, 65-10 (C74500)	65.0 Cu, 25.0 Zn, 10.0 Ni	340-900	125-525	50-1	Rivets, screws, slide fasteners, hollowware, nameplates

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Nickel and Nickel Alloys

- ✓ Nickel (Ni) is a silver-white metal
- ✓ Major alloying element that imparts strength, toughness, and corrosion resistance
- ✓ High strength and corrosion resistance at elevated temperatures
- ✓ Alloying elements are chromium, cobalt, and molybdenum
- ✓ Forming, machining, casting, and welding can be modified by various other alloying elements

Typical usages:

- ✓ High-temperature applications such as jet engine components, rockets, and nuclear power plants
- ✓ Electromagnetic applications such as solenoids
- ✓ Electroplating of parts for their appearance and for the improvement of wear resistance

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Nickel Alloy Properties and Applications

TABLE 6.8

Properties and Typical Applications of Selected Nickel Alloys (All are Trade Names)

Type and UNS number	Nominal composition (%)	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation in 50 mm (%)	Typical applications
Nickel 200 (annealed)	None	380-550	100-275	60-40	Chemical and food processing industry, aerospace equipment, electronic parts
Duranickel 301 (age hardened)	4.4 Al, 0.6 Ti	1300	900	28	Springs, plastic extrusion equipment, molds for glass, diaphragms
Monel R-405 (hot rolled)	30 Cu	525	230	35	Screw-machine products, water meter parts
Monel K-500 (age hardened)	29 Cu, 3 Al	1050	750	30	Pump shafts, valve stems, springs
Inconel 600 (annealed)	15 Cr, 8 Fe	640	210	48	Gas turbine parts, heat-treating equipment, electronic parts, nuclear reactors
Hastelloy C-4 (solution-treated and quenched)	16 Cr, 15 Mo	785	400	54	Parts requiring high-temperature stability and resistance to stress-corrosion cracking

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Superalloys

- ✓ Heat-resistant or high-temperature applications
- ✓ Good resistance to corrosion, mechanical and thermal fatigue, mechanical and thermal shock, creep, and erosion at elevated temperatures
- ✓ Identification by trade names (such as *Inconel* & *Hastelloy*) or by special numbering systems
- ✓ Maximum service temperature of about 1000°C in structural applications and 1200°C for non-load bearing

Typical usages:

- ✓ Jet engines and gas turbines
- ✓ Reciprocating engines, rocket engines, tools and dies for hot working of metals
- ✓ Nuclear, chemical, and petrochemical industries

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Types of Superalloys

- ✓ **Iron-based superalloys**:
- ✓ Contain from 32 to 67% Fe, from 15 to 22% Cr, and from 9 to 38% Ni.
- ✓ Incoloy series
- ✓ **Cobalt-based superalloys**:
- ✓ Contain from 35 to 65% Co, from 19 to 30% Cr, and up to 35% Ni
- ✓ Not as strong as nickel-based, but retain strength at higher temperatures
- ✓ **Nickel-based superalloys**:
- ✓ Contain from 38 to 76% Ni, up to 27% Cr and 20% Co
- ✓ *Hastelloy, Inconel, Nimonic, Rene, Udimet, Astroloy, and Waspaloy*

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Nickel-Based Superalloy Properties and Applications

TABLE 6.9

Properties and Typical Applications of Selected Nickel-Based Superalloys at 870°C (1600°F) (All are Trade Names)

Alloy	Condition	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation in 50 mm (%)	Typical applications
Astroloy	Wrought	770	690	25	Forgings for high temperature use
Hastelloy X	Wrought	255	180	50	Jet engine sheet parts
IN-100	Cast	885	695	6	Jet engine blades and wheels
IN-102	Wrought	215	200	110	Superheater and jet engine parts
Inconel 625	Wrought	285	275	125	Aircraft engines and structures, chemical processing equipment
Inconel 718	Wrought	340	330	88	Jet engine and rocket parts
MAR-M 200	Cast	840	760	4	Jet engine blades
MAR-M 432	Cast	730	605	8	Integrally cast turbine wheels
Rene 41	Wrought	620	550	19	Jet engine parts
Udimet 700	Wrought	690	635	27	Jet engine parts
Waspaloy	Wrought	525	515	35	Jet engine parts

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Titanium and Titanium Alloys

- ✓ Titanium (Ti) is a silvery white metal was discovered 1791
- ✓ High strength-to-weight ratio
- ✓ Corrosion resistance at room and elevated temperatures
- ✓ Ti alloys have developed for service at 550°C
- ✓ Extremely sensitive to small variations in both alloying and residual elements
- ✓ Beta-titanium (bcc) is ductile, whereas alpha-titanium (hcp) is brittle and very sensitive to stress corrosion

Typical usages:

- ✓ Aircraft, jet engines, racing cars, golf clubs
- ✓ Chemical, petrochemical, and marine components
- ✓ Biomaterials such as orthopedic implants

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Wrought Titanium Alloy Properties and Applications

TABLE 6.10

Properties and Typical Applications of Selected Wrought Titanium Alloys at Various Temperatures

Nominal composition (%)	UNS	Condition	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Reduction of area (%)	Temp. (°C)	Ultiamte tensile strength (MPa)	Yield strength (MPa)
99.5 Ti	R50250	Annealed	330	240	30	55	300	150	95
5 Al, 2.5 Sn	R545200	Annealed	860	810	16	40	300	565	450
6 Al, 4V	R56400	Annealed	1000	925	14	30	300	725	650
		Solution + age	1175	1100	10	20	300	980	900
13 V, 11 Cr, 3 Al	R58010	Solution + age	1275	1210	8	-	425	1100	830

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Refractory metals and Alloys

- ✓ High melting point
- ✓ Maintain strength at elevated temperatures
- ✓ **Molybdenum (Mo):** high modulus of elasticity, good resistance to thermal shock, and good electrical and thermal conductivity
- ✓ Used as solid-propellant rockets, jet engines, honeycomb structures, electronic components
- ✓ Low resistance to oxidation at temperatures above 500°C
- ✓ **Niobium (Nb):** good ductility and formability, and greater oxygen resistance than other refractories
- ✓ used in rocket and missiles; nuclear, chemical, and superconductors applications

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Refractory metals and Alloys

- ✓ **Tungsten (W):** the highest melting point of any metal (3410°C); high strength at elevated temperatures; high density, brittle at low temperatures; poor resistance to oxidation
- ✓ For applications above 1650°C such as nozzle throat liners in missiles, circuit breakers, welding electrodes, tooling for EDM, and spark-plug electrodes; tungsten-carbide as tool and die materials
- ✓ **Tantalum (Ta):** high melting point (3000°C); high density, good ductility, resistance to corrosion; poor resistance to chemicals at temperatures above 150°C
- ✓ Used in electrolytic capacitors and in various components in the electrical, electronic, and chemical industries; in missiles and aircraft

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Beryllium and Zirconium

- ✓ **Beryllium (Be):** high strength-to-weight ratio
- ✓ Unalloyed Be is used in rocket nozzles, space and missile structures, aircraft disc brakes, and precision instruments and mirrors
- ✓ In nuclear and X-ray applications because of its low neutron absorption
- ✓ As alloying element (copper and nickel) and used as springs, electrical contacts, and nonsparking tools
- ✓ Be and its oxide are toxic
- ✓ **Zirconium (Zr):** silvery in appearance; good strength and ductility at elevated temperatures; good corrosion resistance because of an adherent oxide film
- ✓ Used in electronic components and nuclear-power reactor applications because of its low neutron absorption

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Low-Melting Alloys

- ✓ Include lead, zinc, tin and their alloys
- ✓ **Lead (Pb):** high density, resistance to corrosion, softness, low strength, ductility, and good workability
- ✓ Its alloys used for piping, collapsible tubing, bearing alloys, cable sheathing, and lead-acid storage batteries
- ✓ For damping sound and vibrations, radiation shielding against x-rays
- ✓ An alloying element in solders, steels, and copper as promotes corrosion resistance and machinability
- ✓ As solid lubricant for hot-metal forming operations
- ✓ Because of its toxicity, environmental contamination by lead is a major concern

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Low-Melting Alloys

- ✓ **Zinc (Zn):** a bluish-white in colour
- ✓ Major uses:
  - ✓ Used for galvanizing iron, steel sheet, and wire
  - ✓ As an alloy base for casting
- ✓ **Tin (Sn):** a silvery-white, lustrous metal
- ✓ For protective coating on steel sheet used in making containers for food
- ✓ Improving deep drawing and pressworking performance of tin coatings on steel due to low shear strength

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Other Metals

- ✓ **Precious Metals:** Gold, Silver and Platinum
- ✓ **Shape-Memory Alloys**
  - ✓ After being plastically deformed at room temperature into various shapes, they return to their original shape upon heating; a typical SMA alloy is 55% Ni-45% Ti
- ✓ **Amorphous Alloys (Metallic Glasses)**
- ✓ **Metal Foams**
  - ✓ Material structures where the metal consists of only 5 to 20% of the structure's volume. They produced either by blowing air into molten metal; chemical vapor deposition into a polymer or carbon foam lattice or doping molten or powder metals with titanium hydride
- ✓ **Nanomaterials**
  - ✓ Materials with grains, fibers, films, and composites having particles that are on the order of 1-100 nm in size

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