



PRD 508 – Pengetahuan Material
CMF– Colour Material Finish

Metal

Most of the elements in the periodic table are metals. Metals have “free” electrons that flow in an electric field, so they conduct electricity well, they reflect light and viewed with the light behind them, they are completely opaque. The metals used in product design are, almost without exception, alloys. Steels (iron with carbon and a host of other alloying elements to make them harder, tougher, or more corrosion resistant) account for more than 90% of all the metals consumed in the world; aluminum comes next, followed by copper, nickel, zinc, titanium, magnesium and tungsten.

Compared to all other classes of material, metals are stiff, strong and tough, but they are heavy. They have relatively high melting points, allowing some metal alloys to be used at temperatures as high as 2200 c. Only one metal – gold – is chemically stable as a metal; all the others will, given the chance, react with oxygen or sulfur to form compounds that are more stable than the metal itself, making them vulnerable to corrosion. There are numerous ways of preventing or slowing this to an acceptable level, but they require maintenance. Metals are ductile, allowing them to be shaped by rolling, forging, drawing and extrusion; they are easy to machine with precision; and they can be joined in many different ways. This allows a flexibility of design with metals that is only now being challenged by polymers.

The development of metals and alloys continues. Superplastic alloys have the unique property that, in sheet form, they can be vacuum or thermoformed like thermoplastics. Shape-memory alloys have the capacity to remember their initial shape even when deformed very heavily, so that they spring back like a rubber – they are used in thermostats, and as the frames for eye glasses, brassieres and small actuators. Metal matrix composites

(such as aluminum with silicon carbide) extend the property range of metals, usually to make them stiffer, lighter, and more tolerant of heat, but their cost limits their applications. Techniques for foaming metals are emerging that have the potential to capture new market. Nonetheless, the status of metals has been eroded during the past few decades by other materials: polymers in small scale structures like household appliances, polymerbased composites in cars, aircraft and boats; and ceramics in certain engine parts and cutting blades. But as Guy Nordenson, of the engineering firm Arup, observes, “Materials development and usage are historically cyclical. Work with metals is probably more out of touch than it is behind.”

Primary production of metals is energy intensive. Many, among them aluminum, magnesium and titanium, require at least twice as much energy per unit weight (or five times more per unit volume) than commodity polymers. But metals can generally be recycled, and the energy required to do so is much less than that required for primary production. Some are toxic, particularly the heavy metals – lead, cadmium, mercury. Some, however, are so inert that they can be implanted in the body: stainless steels, cobalt alloys and certain alloys of titanium, for example.

Metals

Aluminum alloys

Copper alloys

Magnesium alloys

Nickel alloys

Steels – carbon

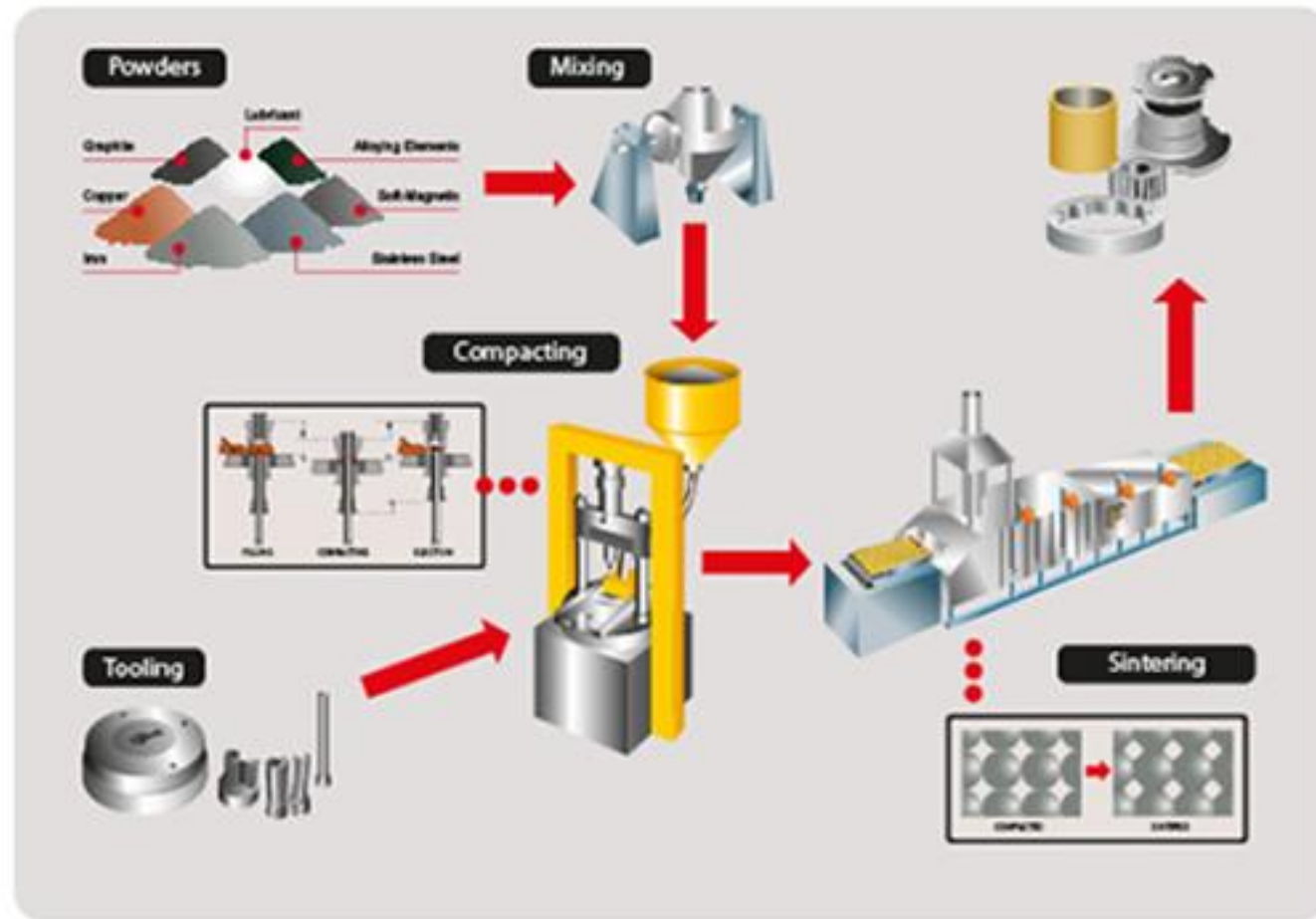
Steels – low alloy

Steels – stainless

Titanium alloys

Zinc alloys

Metal Manufacturing Process



Metal Ingots



Aluminum alloys

Attributes of Aluminum Alloys

Price, \$/kg	1.30-5.70
Density, mg/m ³	2.50-2.95

Technical Attributes

El. modulus, GPa	68-88.5
Elongation, %	1-44
Fr. toughness, MPa·m ^{1/2}	18-40
Vickers hardness, H _v	20-150
Yld. strength, MPa	30-510
Service temp., °C	-270-180
Specific heat, J/kg·K	857-990
Th. conduct., W/m·K	76-235
Th. expansion, 10 ⁻⁶ /K	16-24

Eco-Attributes

Energy content, MJ/kg	235-335
Recycle potential	High

Aesthetic Attributes

Low (o), High Pitch (10)	8-9
Muffled (o), Ringing (10)	5-8
Soft (o), Hard (10)	8-9
Warm (o), Cool (10)	9-10
Reflectivity, %	80-92

Features (Relative to Other Metals)

Lightweight
Corrosion resistant
Easy to recycle

Application : Aerospace engineering; automotive engineering; die cast chassis for household and electronic products; siding for buildings; foil for containers and packaging; beverage cans; electrical and thermal conductors.

Environment : Aluminum ore is abundant. It takes a lot of energy to extract aluminum, but it is easily recycled at low energy cost.



Carbon Steels

Attributes of Carbon Steels

Price, \$/kg	0.40-0.60
Density, mg/m ³	7.8-7.9

Technical Attributes

El. modulus, GPa	200-216
Elongation, %	4-47
Fr. toughness, MPa·m ^{1/2}	12-92
Vickers hardness, H _v	120-650
Yld. strength, MPa	250-1755
Service temp., °C	-70-360
Specific heat, J/kg·K	440-520
Th. conduct., W/m·K	45-55
Th. expansion, 10 ⁻⁶ /K	10-14

Eco-Attributes

Energy content, MJ/kg	57-72
Recycle potential	High

Aesthetic Attributes

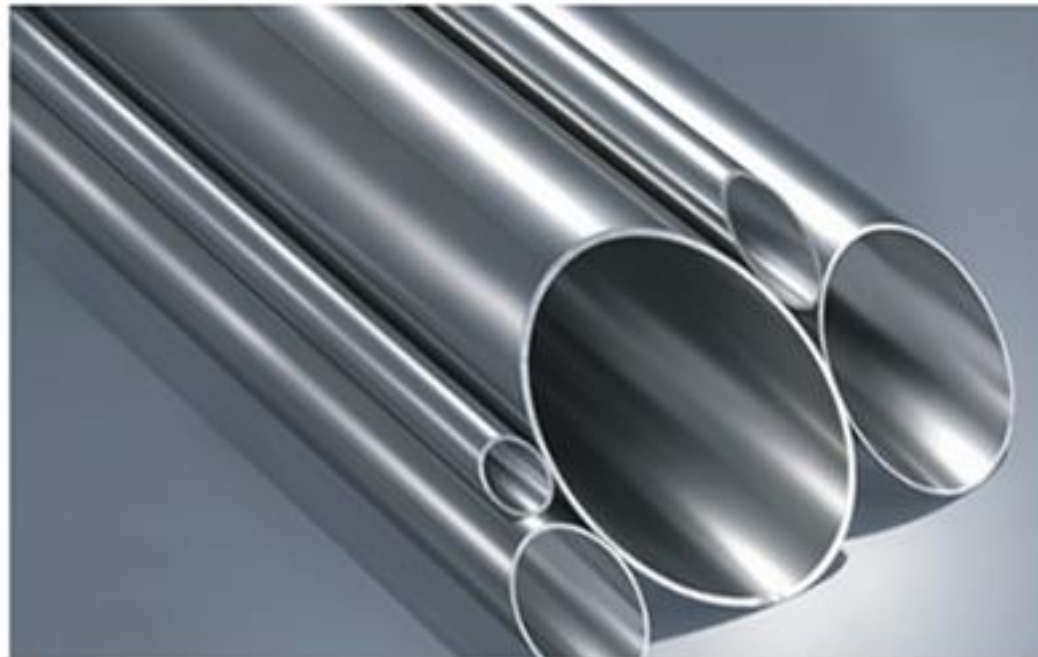
Low (o), High Pitch (10)	9
Muffled (o), Ringing (10)	6-7
Soft (o), Hard (10)	9
Warm (o), Cool (10)	9
Reflectivity, %	59

Features (Relative to Other Metals)

Stiff and strong
Tough
Cheap

Application : Reinforcement of concrete, steel sections for construction, sheet for roofing, car body panels, cans and pressed sheet products give an idea of the scope. Medium carbon steels are the materials of general construction and engineering, axles and gears, bearings, cranks and shafts. High carbon steels are used for cutting tools, high performance bearings, cranks and shafts, springs, knives, ice axes and ice skates.

Environment : The production energy of steel is comparatively low – per unit weight, about a half that of polymers; per unit volume, though, twice as much. Carbon steels are easy to recycle, and the energy to do so is small.



Low Alloy Steels

Application : Springs, tools, ball bearings, rollers; crankshafts, gears, connecting rods.

Environment : Steels are not particularly energy intensive to make, and are easily and widely recycled.



Attributes of Low Alloy Steels

Price, \$/kg	0.40-0.90
Density, mg/m ³	7.8-7.9

Technical Attributes

El. modulus, GPa	201-217
Elongation, %	3-38
Fr. toughness, MPa·m ^{1/2}	14-210
Vickers hardness, H _v	140-700
Yld. strength, MPa	245-2255
Service temp., °C	-70-660
Specific heat, J/kg·K	410-530
Th. conduct., W/m·K	34-55
Th. expansion, 10 ⁻⁶ /K	10.5-13.5

Eco-Attributes

Energy content, MJ/kg	60-83
Recycle potential	High

Aesthetic Attributes

Low (o), High Pitch (10)	9-9
Muffled (o), Ringing (10)	6-8
Soft (o), Hard (10)	9
Warm (o), Cool (10)	8-9
Reflectivity, %	40-60

Features (Relative to Other Metals)

Exceptionally strong
Stiff and strong
Relatively cheap

Stainless Steels

Application : Railway cars, trucks, trailers, food-processing equipment, sinks, stoves, cooking utensils, cutlery, flatware, architectural metalwork, laundry equipment, chemical processing equipment, jet-engine parts, surgical tools, furnace and boiler components, oil-burner parts, petroleum-processing equipment, dairy equipment, heat-treating equipment, automotive trim.

Environment : Stainless steels are FDA approved – indeed, they are so inert that they can be implanted in the body. All can be recycled.



Attributes of Stainless Steels

Price, \$/kg	1.20-8.50
Density, mg/m ³	7.4-8.1

Technical Attributes

El. modulus, GPa	189-210
Elongation, %	0.5-70
Fr. toughness, MPa·m ^{1/2}	12-280
Vickers hardness, H _v	130-600
Yld. strength, MPa	170-2090
Service temp., °C	-270-850
Specific heat, J/kg·K	400-530
Th. conduct., W/m·K	11-29
Th. expansion, 10 ⁻⁶ /K	9-20

Eco-Attributes

Energy content, MJ/kg	83-115
Recycle potential	High

Aesthetic Attributes

Low (o), High Pitch (10)	8-9
Muffled (o), Ringing (10)	6-7
Soft (o), Hard (10)	9
Warm (o), Cool (10)	7-8
Reflectivity, %	60-80

Features (Relative to Other Metals)

Durability
Extremes of temperature
Stiff and strong

Magnesium Alloys

Attributes of Magnesium Alloys

Price, \$/kg	2.60-11.40
Density, mg/m ³	1.73-1.95

Technical Attributes

El. modulus, GPa	40-47
Elongation, %	1.5-20
Fr. toughness, MPa·m ^{1/2}	12-70
Vickers hardness, H _v	35-135
Yld. strength, MPa	65-435
Service temp., °C	-40-300
Specific heat, J/kg·K	950-1060
Th. conduct., W/m·K	50-156
Th. expansion, 10 ⁻⁶ /K	24.6-30

Eco-Attributes

Energy content, MJ/kg	300-500
Recycle potential	High

Aesthetic Attributes

Low (o), High Pitch (10)	8-9
Muffled (o), Ringing (10)	3-6
Soft (o), Hard (10)	8
Warm (o), Cool (10)	8-9
Reflectivity, %	68

Features (Relative to Other Metals)

Exceptionally lightweight
Easy to die-cast
Adequate strength

Application : Aerospace; automotive; sports goods; nuclear fuel cans; vibration damping and shielding of machine tools; engine case castings; automotive wheels; ladders; housings for electronic equipment, office equipment, and lawnmowers.

Environment : Magnesium is the fifth most abundant metal in the earth's crust, and the third in its oceans – and it can be extracted economically from both (the Dead Sea, thick with dissolved salts – is the best source of all). But its extraction is very energy intensive, consuming three times more per unit weight than commodity polymers and nearly twice as much as aluminum. It can be recycled, and doing this uses barely one-fifth as much energy.



Titanium Alloys

Attributes of Titanium Alloys

Price, \$/kg	21.00-28.00
Density, mg/m^3	4.36-4.84

Technical Attributes

El. modulus, GPa	90-137
Elongation, %	1-40
Fr. toughness, $\text{MPa}\cdot\text{m}^{1/2}$	14-120
Vickers hardness, H _v	60-380
Yld. strength, MPa	172-1245
Service temp., °C	-40-500
Specific heat, J/kg·K	510-650
Th. conduct., W/m·K	3.8-20.7
Th. expansion, $10^{-4}/\text{K}$	7.9-11

Eco-Attributes

Energy content, MJ/kg	750-1250
Recycle potential	High

Aesthetic Attributes

Low (o), High Pitch (10)	8-9
Muffled (o), Ringing (10)	5-8
Soft (o), Hard (10)	8-9
Warm (o), Cool (10)	7-8
Reflectivity, %	44-53

Features (Relative to Other Metals)

Exceptionally strong
Exceptionally corrosion resistant
Tough

Application : Aircraft turbine blades; general aerospace applications; chemical engineering; heat exchangers; bioengineering; medical; missile fuel tanks; heat exchangers, compressors, valve bodies, surgical implants, marine hardware, paper-pulp equipment, casings for mobile phones and portable computers.

Environment : Extracting titanium from its ores is very energy intensive. It can be recycled provided it is not contaminated with oxygen.



Nickel Alloys

Application : blades, disks, and combustion chambers in turbines and jet engines, rocket engines, bi-metallic strips, thermocouples, springs, food equipment, heating wires, electroplating for corrosion protection, coinage, and nickel-cadmium batteries.

Environment : About 10% of the population is sensitive to nickel, causing them to react even to the nickel in stainless steel watch straps. Compounds of nickel can be more toxic; nickel carbonyl, used in the extraction of nickel, is deadly.



Attributes of Nickel Alloys

Price, \$/kg	4.30-28.60
Density, mg/m^3	7.65-9.3

Technical Attributes

El. modulus, GPa	125-245
Elongation, %	0.3-70
Fr. toughness, $\text{MPa}\cdot\text{m}^{1/2}$	65-150
Vickers hardness, H _v	75-600
Yld. strength, MPa	70-2100
Service temp., °C	-200-1200
Specific heat, J/kg·K	365-565
Th. conduct., W/m·K	8-91
Th. expansion, $10^{-4}/\text{K}$	0.5-16.5

Eco-Attributes

Energy content, MJ/kg	40-690
Recycle potential	High

Aesthetic Attributes

Low (o), High Pitch (10)	8-9
Muffled (o), Ringing (10)	3-6
Soft (o), Hard (10)	8
Warm (o), Cool (10)	8-9
Reflectivity, %	50-65

Features (Relative to Other Metals)

Exceptionally corrosion resistant
High temperatures
Stiff, strong and tough

Zinc Alloys

Application : Roofing, gutters, flashlight reflectors, fruit jar caps, radio shielding, gaskets, photoengraving plates, handles, gears, automotive components, kitchen counter-tops, protective plating.

Environment : Zinc vapor is toxic if you inhale it you get the “spelter-shakes” but adequate protection is now universal. In all other ways zinc is a star: it is non-toxic, has low energy content and – in bulk can be recycled (not, of course, as plating).



Attributes of Zinc Alloys

Price, \$/kg	0.90-2.90
Density, kg/m^3	5.5-7.2

Technical Attributes

El. modulus, GPa	60-110
Elongation, %	1-90
Fr. toughness, $\text{MPa}\cdot\text{m}^{1/2}$	10-130
Vickers hardness, HV	30-160
Yld. strength, MPa	50-450
Service temp., °C	-45-120
Specific heat, J/kg·K	380-535
Th. conduct., W/m·K	95-135
Th. expansion, $10^{-4}/\text{K}$	14-40

Eco-Attributes

Energy content, MJ/kg	50-145
Recycle potential	High

Aesthetic Attributes

Low (o), High Pitch (10)	8
Muffled (o), Ringing (10)	4-7
Soft (o), Hard (10)	8-9
Warm (o), Cool (10)	9
Reflectivity, %	74-85

Features (Relative to Other Metals)

- Easily die-cast
- Corrosion resistant
- Easily machined

Copper

Application : Electrical conductors, heat exchangers, coinage, pans, kettles and boilers, plates for etching and engraving, roofing and architecture, cast sculptures, printing wires, heat pipes, filaments and musical instruments.

Environment : Copper and its alloys are particularly easy to recycle in many countries the recycle fraction approaches 90%.



Brass



Bronze



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