Bronze

Description

Image

Caption

1. Propeller. 2. Cast bell.

The material

Bronze, the material of the Bronze age (3000 - 1000 BC) was originally an alloy of copper (Cu) and tin (Sn), but today the term is used for any alloy of copper that has a principal alloying element other than zinc or nickel. The tin bronzes contain 5 - 25% Sn; those with more than 10% Sn have high strength but little ductility, so they must be cast to shape. Aluminum bronzes (Cu with 4 - 14% Al plus a little Mn) have high strength and excellent corrosion resistance. Phosphor bronzes (Cu with 1.25 - 10% Sn and up to 0.6% P) have low friction coefficient and are widely used for bearings. Gunmetal is a tin bronze containing some zinc and lead.

Composition (summary)

Tin bronze: Cu + 5 - 25% Sn
Aluminum bronze: Cu + 4 - 14% Al
Phosphor bronze: Cu + 3 - 9% Sn + 0.1 - 0.4% P
Gunmetal: Cu + 5 % Sn + 5 % Zn + 5 % Pb

General properties

Density		531	-	562	lb/ft^3
Price	*	2.71	-	3.17	USD/lb
Date first used		-3000			

Mechanical properties

Young's modulus		10.2	-	15.2	10^6 psi
Shear modulus		3.63	-	4.79	10^6 psi
Bulk modulus	*	12.2	-	13.8	10^6 psi
Poisson's ratio		0.34	-	0.35	
Yield strength (elastic limit)		14.5	-	72.5	ksi
Tensile strength		30.5	-	106	ksi
Compressive strength		14.5	-	72.5	ksi
Elongation		2	-	40	% strain

Hardness - Vickers		60	-	240	HV
Fatigue strength at 10^7 cycles	*	14.5	-	42.1	ksi
Fracture toughness		21.8	-	54.6	ksi.in^0.5
Mechanical loss coefficient (tan delta)	*	5e-5	-	2.5e-4	

Thermal properties

Melting point	1.63e3	-	1.9e3	°F
Maximum service temperature	338	-	392	°F
Minimum service temperature	-459			°F
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	28.9	-	36.4	BTU.ft/h.ft^2.F
Specific heat capacity	0.0912	-	0.0936	BTU/lb.°F
Thermal expansion coefficient	9.44	-	10.6	µstrain/°F

Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	15	-	24	µohm.cm

Optical properties

Transparency	Opaque

Critical Materials Risk

High critical material risk?	Yes

Processability

Castability	4	-	5
Formability	3	-	5
Machinability	4	-	5
Weldability	4	-	5
Solder/brazability	4	-	5

Durability: water and aqueous solutions

Water (fresh)	Excellent
Water (salt)	Excellent
Soils, acidic (peat)	Excellent
Soils, alkaline (clay)	Excellent
Wine	Excellent

Durability: acids

Acetic acid (10%)	Limited use
Acetic acid (glacial)	Unacceptable
Citric acid (10%)	Acceptable

Hydrochloric acid (10%)	Limited use
Hydrochloric acid (36%)	Unacceptable
Hydrofluoric acid (40%)	Unacceptable
Nitric acid (10%)	Acceptable
Nitric acid (70%)	Unacceptable
Phosphoric acid (10%)	Limited use
Phosphoric acid (85%)	Unacceptable
Sulfuric acid (10%)	Limited use
Sulfuric acid (70%)	Unacceptable

Durability: alkalis

Sodium hydroxide (10%)	Excellent
Sodium hydroxide (60%)	Excellent

Durability: fuels, oils and solvents

Amyl acetate	Excellent
Benzene	Excellent
Carbon tetrachloride	Excellent
Chloroform	Excellent
Crude oil	Acceptable
Diesel oil	Excellent
Lubricating oil	Excellent
Paraffin oil (kerosene)	Excellent
Petrol (gasoline)	Excellent
Silicone fluids	Acceptable
Toluene	Excellent
Turpentine	Excellent
Vegetable oils (general)	Excellent
White spirit	Excellent

Durability: alcohols, aldehydes, ketones

Acetaldehyde	Excellent
Acetone	Excellent
Ethyl alcohol (ethanol)	Excellent
Ethylene glycol	Excellent
Formaldehyde (40%)	Excellent
Glycerol	Excellent
Methyl alcohol (methanol)	Excellent

Durability: halogens and gases

Chlorine gas (dry)	Excellent

Fluorine (gas)	Acceptable
O2 (oxygen gas)	Acceptable
Sulfur dioxide (gas)	Excellent

Durability: built environments

Industrial atmosphere	Excellent
Rural atmosphere	Excellent
Marine atmosphere	Excellent
UV radiation (sunlight)	Excellent

Durability: flammability

Flammability	Non-flammable

Durability: thermal environments

Tolerance to cryogenic temperatures	Excellent
Tolerance up to 150 C (302 F)	Excellent
Tolerance up to 250 C (482 F)	Acceptable
Tolerance up to 450 C (842 F)	Unacceptable
Tolerance up to 850 C (1562 F)	Unacceptable
Tolerance above 850 C (1562 F)	Unacceptable

Geo-economic data for principal component

Annual world production, principal component	1.56e7	ton/yr
Reserves, principal component	5.31e8	I. ton

Primary material production: energy, CO2 and water

Embodied energy, primary production	*	7.01e3	-	7.75e3	kcal/lb
CO2 footprint, primary production	*	3.97	-	4.39	lb/lb
Water usage	*	95.7	-	106	gal(US)/lb
Eco-indicator 95		1.4e3			millipoints/kg
Eco-indicator 99		3.01e3			millipoints/kg

Material processing: energy

Casting energy	*	920	-	1.02e3	kcal/lb
Extrusion, foil rolling energy	*	826	-	913	kcal/lb
Rough rolling, forging energy	*	428	-	473	kcal/lb
Wire drawing energy	*	3.01e3	-	3.33e3	kcal/lb
Metal powder forming energy	*	2.33e3	-	2.77e3	kcal/lb
Vaporization energy	*	9.93e5	-	1.09e6	kcal/lb
Coarse machining energy (per unit wt removed)	*	112	-	122	kcal/lb
Fine machining energy (per unit wt removed)	*	648	-	716	kcal/lb
Grinding energy (per unit wt removed)					

	* 1.25e3	-	1.38e3	kcal/lb
Non-conventional machining energy (per unit wt removed)	9.93e3	-	1.09e4	kcal/lb

Material processing: CO2 footprint

Casting CO2	* 0.637	-	0.704	lb/lb
Extrusion, foil rolling CO2	* 0.572	-	0.632	lb/lb
Rough rolling, forging CO2	* 0.297	-	0.328	lb/lb
Wire drawing CO2	* 2.09	-	2.31	lb/lb
Metal powder forming CO2	* 1.72	-	2.04	lb/lb
Vaporization CO2	* 688	-	760	lb/lb
Coarse machining CO2 (per unit wt removed)	* 0.0769	-	0.085	lb/lb
Fine machining CO2 (per unit wt removed)	* 0.448	-	0.496	lb/lb
Grinding CO2 (per unit wt removed)	* 0.861	-	0.952	lb/lb
Non-conventional machining CO2 (per unit wt removed	6.88	-	7.6	lb/lb

Material recycling: energy, CO2 and recycle fraction

Recycle	✔			
Embodied energy, recycling	* 1.55e3	-	1.71e3	kcal/lb
CO2 footprint, recycling	* 1.12	-	1.24	lb/lb
Recycle fraction in current supply	45	-	60	%
Downcycle	✔			
Combust for energy recovery	✖			
Landfill	✔			
Biodegrade	✖			
Toxicity rating	Non-toxic			
A renewable resource?	✖			

Environmental notes

Bronzes are readily recycled.

Supporting information

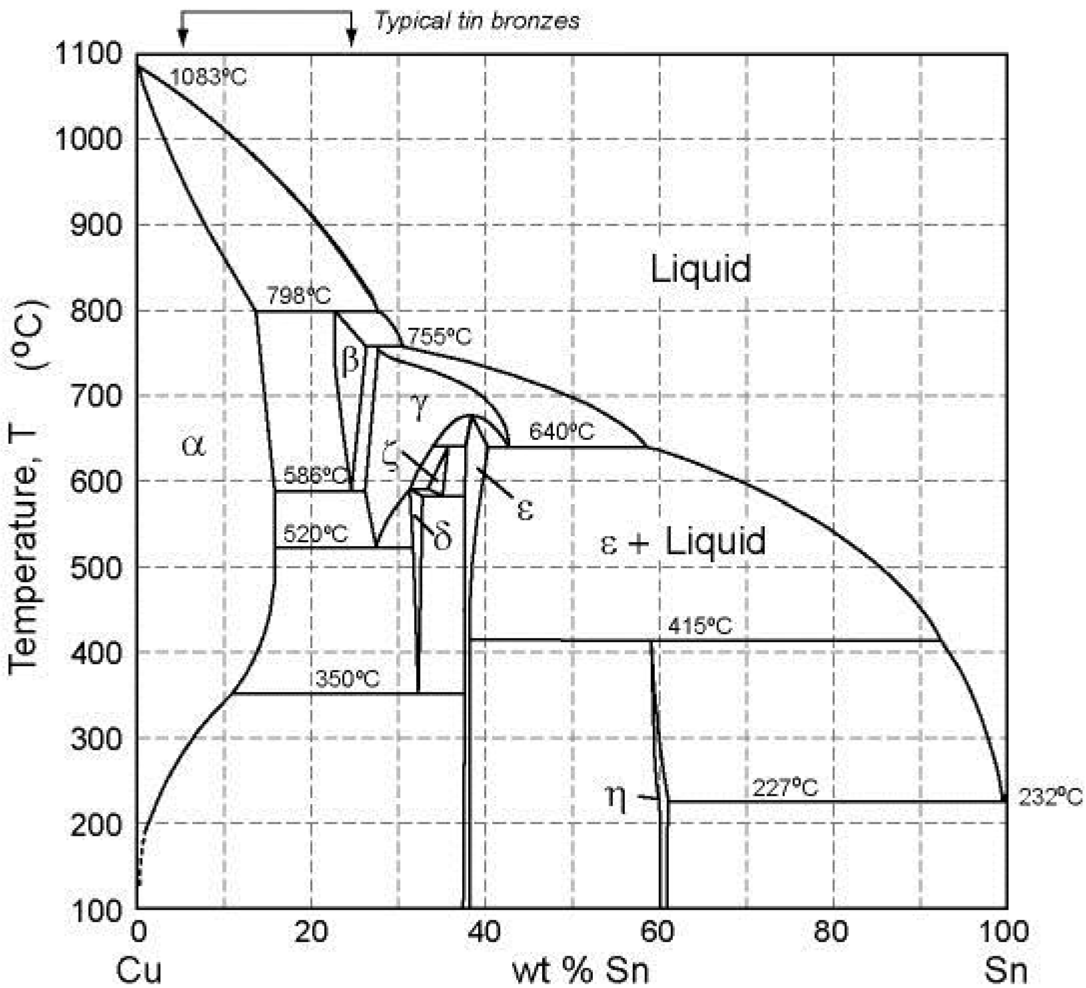
Design guidelines

Bronze, the material of the Bronze age (3000 - 1000 BC) is still the material of choice for grand statuary, bells and ornamental architectural parts. It is hard and strong (hence its use for weapons), it can be cast to intricate shapes and it resists corrosion well even in a marine environment. Low-tin and aluminum bronzes can be rolled to sheet and worked easily; those with higher alloy content must be cast.

Technical notes

There is now a UNS designation system for copper and its alloys: the letter C (for 'copper') followed by a 5-digit number. Only the first digit means anything: C1**** designates almost pure copper, the C2, C3 and C4 series are brasses with increasing zinc content, the C5s are bronzes based on copper and tin, the C6s are other bronzes containing aluminum instead of tin, and the C7s are copper-nickel alloys. More information on designations and equivalent grades can be found on the Granta Design website at www.grantadesign.com/designations

Phase diagram



Phase diagram description

Tin bronzes are alloys of copper (Cu) with 5 - 25% tin (Sn), for which this is the phase diagram.

Typical uses

Tin bronzes and gunmetals: sand casting of marine and architectural fittings, bells, pump parts, taps and valves, coinage. Aluminum bronzes: die-cast and wrought components, particularly those to resist corrosion, heat exchangers, condensers, ships propellers and marine fittings, architectural cladding, valve and pump bodies. Phosphor bronzes: bearings and gears, springs, pump parts, coinage, tubing a plate to resist corrosion and erosion.

Tradenames

Coinage bronze (Cu 3% Sn 1.5% Zn)

Links

Reference

ProcessUniverse

Producers