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	8.5e3	-	9e3	kg/m^3
Price	* 5.97	-	6.98	USD/kg
Date first used	-3000			

Mechanical properties

Young's modulus	70	-	105	GPa
Shear modulus	25	-	33	GPa
Bulk modulus	* 84	-	95	GPa
Poisson's ratio	0.34	-	0.35	
Yield strength (elastic limit)	100	-	500	MPa
Tensile strength	210	-	730	MPa
Compressive strength	100	-	500	MPa
Elongation	2	-	40	% strain

Hardness - Vickers		60	-	240	HV
Fatigue strength at 10^7 cycles	*	100	-	290	MPa
Fracture toughness		24	-	60	MPa.m^0.5
Mechanical loss coefficient (tan delta)	*	5e-5	-	2.5e-4	

Thermal properties

Melting point		887	-	1.04e3	°C
Maximum service temperature		170	-	200	°C
Minimum service temperature		-273			°C
Thermal conductor or insulator?		Good conductor			
Thermal conductivity		50	-	63	W/m.°C
Specific heat capacity		382	-	392	J/kg.°C
Thermal expansion coefficient		17	-	19	µstrain/°C

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	1.58e7	tonne/yr
Reserves, principal component	5.4e8	tonne

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 64.7	-	71.5	MJ/kg
CO2 footprint, primary production	* 3.97	-	4.39	kg/kg
Water usage	* 799	-	883	l/kg
Eco-indicator 95	1.4e3			millipoints/kg
Eco-indicator 99	3.01e3			millipoints/kg

Material processing: energy

Casting energy	* 8.49	-	9.38	MJ/kg
Extrusion, foil rolling energy	* 7.62	-	8.43	MJ/kg
Rough rolling, forging energy	* 3.95	-	4.37	MJ/kg
Wire drawing energy	* 27.8	-	30.7	MJ/kg
Metal powder forming energy	* 21.5	-	25.5	MJ/kg
Vaporization energy	* 9.17e3	-	1.01e4	MJ/kg
Coarse machining energy (per unit wt removed)	* 1.03	-	1.13	MJ/kg
Fine machining energy (per unit wt removed)	* 5.98	-	6.61	MJ/kg
Grinding energy (per unit wt removed)				

	* 11.5	-	12.7	MJ/kg
Non-conventional machining energy (per unit wt removed)	91.7	-	101	MJ/kg

Material processing: CO2 footprint

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

Material recycling: energy, CO2 and recycle fraction

Recycle	✓			
Embodied energy, recycling	* 14.3	-	15.8	MJ/kg
CO2 footprint, recycling	* 1.12	-	1.24	kg/kg
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

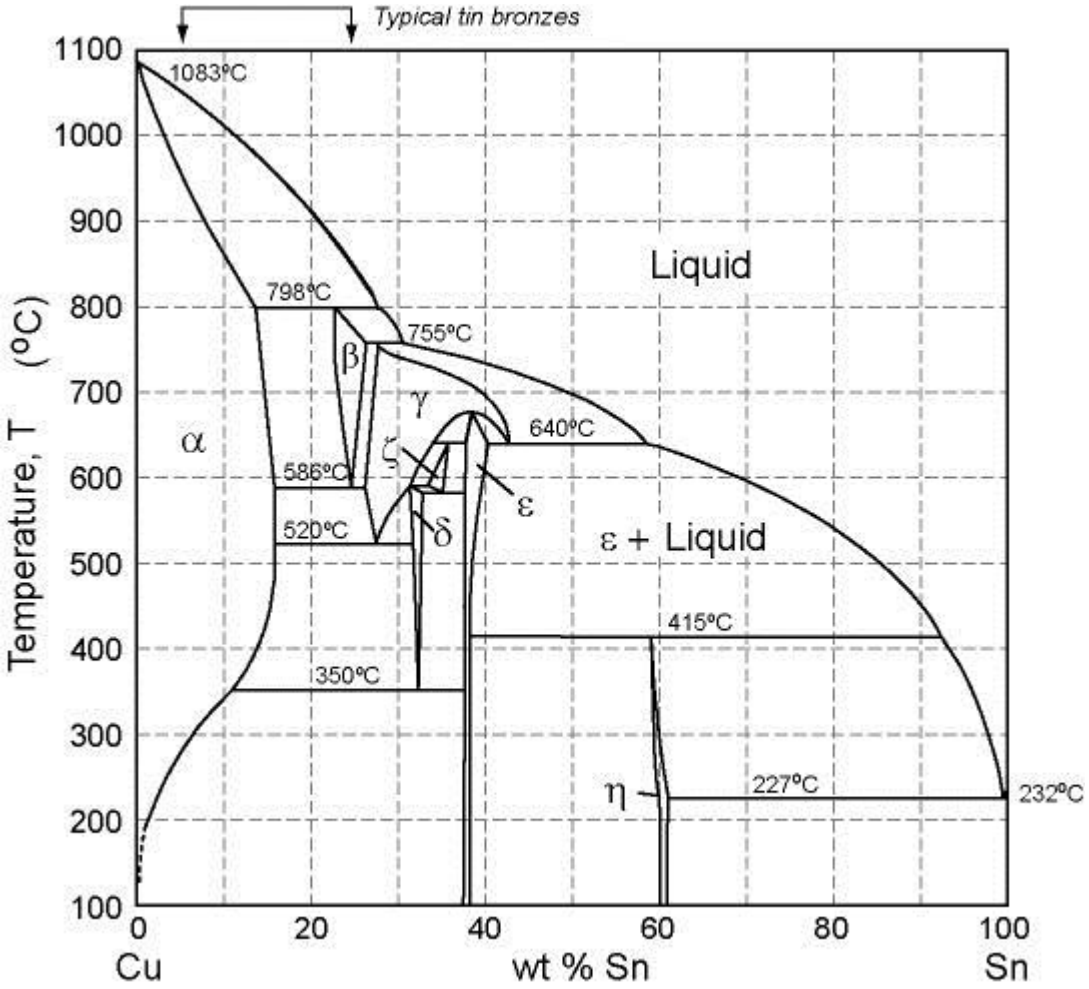
Design guidelines

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