Cast iron, ductile (nodular)

Description

Image

Caption

Ductile or malleable cast irons are used for heavily loaded parts such as gears and automotive suspension components.

The material

The foundations of modern industrial society are set, so to speak, in cast iron: it is the material that made the industrial revolution possible. Today it holds a second honor: that of being the cheapest of all engineering metals. Cast iron contains at least 2% carbon -- most have 3 to 4% -- and from 1-3% silicon. The carbon makes the iron very fluid when molten, allowing it to be cast to intricate shapes. There are five classes of cast iron: gray, white, ductile (or nodular), malleable and alloy; details are given under Design Guidelines, below. The two that are most used are gray and ductile. This record is for ductile cast iron.

Compositional summary

Fe/3.2-4.1%C/1.8-2.8%Si/<0.8%Mn/<0.1%P/<0.03%S

General properties

Density	7.05e3	-	7.25e3	kg/m^3
Price	* 0.41	-	0.44	USD/kg
Date first used	1948			

Mechanical properties

Young's modulus	165	-	180	GPa
Shear modulus	64	-	71	GPa
Bulk modulus	119	-	137	GPa
Poisson's ratio	0.26	-	0.28	
Yield strength (elastic limit)	250	-	680	MPa
Tensile strength	410	-	830	MPa
Compressive strength	250	-	790	MPa
Elongation	3	-	18	% strain

Hardness - Vickers	115	-	320	HV
Fatigue strength at 10^7 cycles	180	-	330	MPa
Fracture toughness	22	-	54	MPa.m^0.5
Mechanical loss coefficient (tan delta)	0.002	-	0.009	

Thermal properties

Melting point	1.13e3	-	1.25e3	°C
Maximum service temperature	350	-	450	°C
Minimum service temperature	-98.2	-	-38.2	°C
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	29	-	44	W/m.°C
Specific heat capacity	460	-	495	J/kg.°C
Thermal expansion coefficient	10	-	12.5	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	49	-	56	µohm.cm

Optical properties

Transparency	Opaque

Processability

Castability	5		
Formability	1	-	2
Machinability	4		
Weldability	1		
Solder/brazability	1	-	2

Durability: water and aqueous solutions

Water (fresh)	Acceptable
Water (salt)	Limited use
Soils, acidic (peat)	Acceptable
Soils, alkaline (clay)	Acceptable
Wine	Unacceptable

Durability: acids

Acetic acid (10%)	Limited use
Acetic acid (glacial)	Limited use
Citric acid (10%)	Limited use
Hydrochloric acid (10%)	Unacceptable
Hydrochloric acid (36%)	Unacceptable
Hydrofluoric acid (40%)	

	Unacceptable
Nitric acid (10%)	Unacceptable
Nitric acid (70%)	Unacceptable
Phosphoric acid (10%)	Unacceptable
Phosphoric acid (85%)	Unacceptable
Sulfuric acid (10%)	Acceptable
Sulfuric acid (70%)	Acceptable

Durability: alkalis

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

Durability: fuels, oils and solvents

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

Durability: alcohols, aldehydes, ketones

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

Durability: halogens and gases

Chlorine gas (dry)	Excellent
Fluorine (gas)	Limited use
O2 (oxygen gas)	Limited use

Sulfur dioxide (gas)	Acceptable			

Durability: built environments

Industrial atmosphere	Acceptable			
Rural atmosphere	Acceptable			
Marine atmosphere	Limited use			
UV radiation (sunlight)	Excellent			

Durability: flammability

Flammability	Non-flammable			

Durability: thermal environments

Tolerance to cryogenic temperatures	Unacceptable			
Tolerance up to 150 C (302 F)	Excellent			
Tolerance up to 250 C (482 F)	Excellent			
Tolerance up to 450 C (842 F)	Excellent			
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	2.3e9			tonne/yr
Reserves, principal component	1.6e11			tonne

Primary material production: energy, CO2 and water

Embodied energy, primary production	* 18	-	22	MJ/kg
CO2 footprint, primary production	* 1.7	-	1.8	kg/kg
Water usage	* 42.6	-	47.1	l/kg
Eco-indicator 95	40			millipoints/kg
Eco-indicator 99	112			millipoints/kg

Material processing: energy

Casting energy	* 10	-	11.1	MJ/kg
Metal powder forming energy	* 29.9	-	34.4	MJ/kg
Vaporization energy	* 1.09e4	-	1.2e4	MJ/kg
Coarse machining energy (per unit wt removed)	* 1.01	-	1.11	MJ/kg
Fine machining energy (per unit wt removed)	* 5.8	-	6.41	MJ/kg
Grinding energy (per unit wt removed)	* 11.1	-	12.3	MJ/kg
Non-conventional machining energy (per unit wt removed)	109	-	120	MJ/kg

Material processing: CO2 footprint

Casting CO2	* 0.751	-	0.83	kg/kg
Metal powder forming CO2	* 2.39	-	2.75	kg/kg

Vaporization CO2	* 815	-	901	kg/kg
Coarse machining CO2 (per unit wt removed)	* 0.0756	-	0.0835	kg/kg
Fine machining CO2 (per unit wt removed)	* 0.435	-	0.481	kg/kg
Grinding CO2 (per unit wt removed)	* 0.835	-	0.923	kg/kg
Non-conventional machining CO2 (per unit wt removed)	8.15	-	9.01	kg/kg

Material recycling: energy, CO2 and recycle fraction

Recycle	✔			
Embodied energy, recycling	* 7.84	-	8.67	MJ/kg
CO2 footprint, recycling	* 0.616	-	0.681	kg/kg
Recycle fraction in current supply	60	-	80	%
Downcycle	✔			
Combust for energy recovery	✖			
Landfill	✔			
Biodegrade	✖			
Toxicity rating	Non-toxic			
A renewable resource?	✖			

Environmental notes

As metals go, it takes relatively little energy to make cast iron; it's exceptionally durable, and easily recycled. The pollution caused by blast furnaces in which it is made was at one time a major problem; but modern technology has totally overcome this.

Supporting information

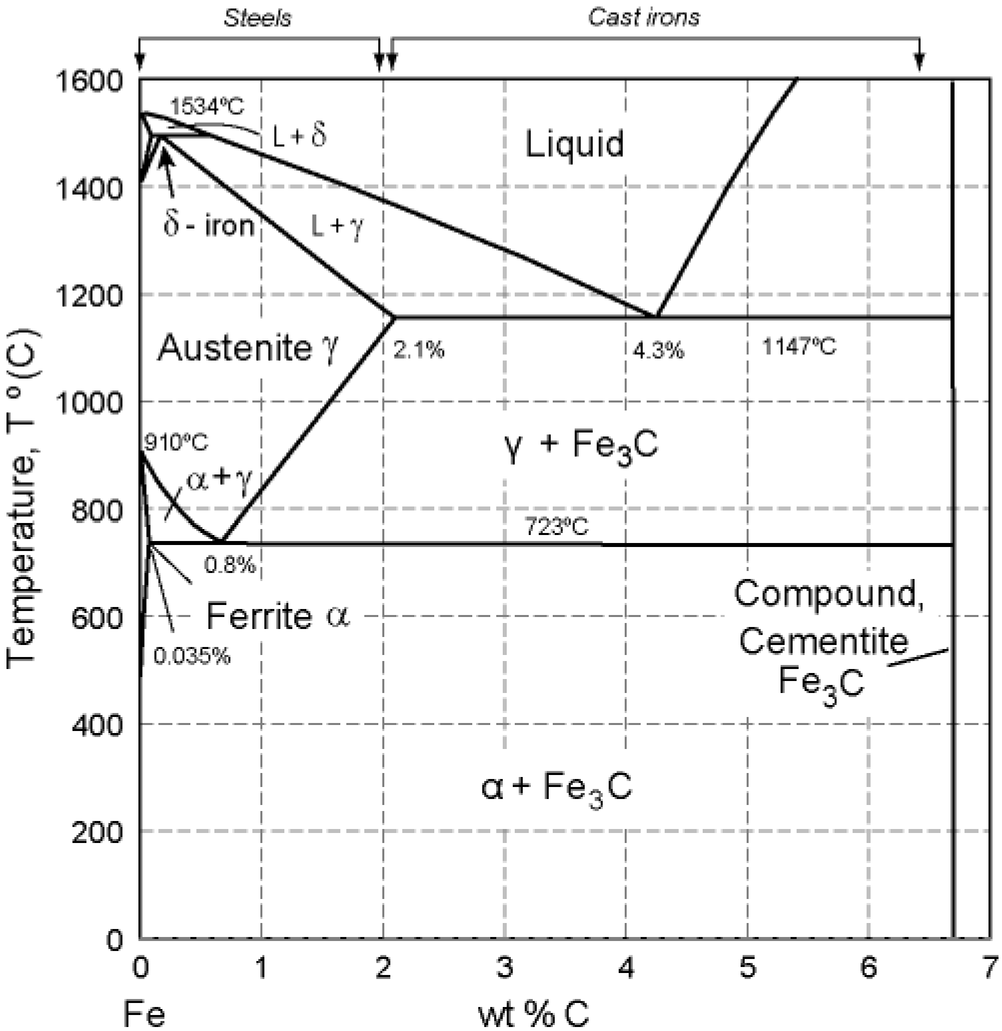
Design guidelines

There are five kinds of cast iron. Gray cast iron machines easily, damps vibration well, is relatively brittle and has low tensile strength; it is the material of automotive cylinder blocks, exhaust manifolds, break disks and drums, gears and flywheels. White cast iron, made by chill casting to give a high cooling rate at the surface, is much harder than gray; it is used when wear resistance is wanted, as in rolls for rolling mills, blades for crushers and mixers. Nodular (ductile) cast iron contains additions that cause the flakes of graphite that are present in gray iron to spherodize, giving higher toughness and strength but at the loss of damping-ability; it is used for crank shafts and heavy duty gears. Malleable cast iron, made by heat-treating white cast iron, is ductile and easily machined; it is used for heavy-duty parts of cars, trucks, and railway rolling stock. Finally, alloy cast irons contain up to 35% of chromium or nickel; they are corrosion resistant and have high strength, but are much more expensive.

Technical notes

There is no single systematic numbering system for cast irons. The UNS and the AISI systems are widely used, particularly in the US. Ductile cast irons are generally described using the ASTM system, a set of three numbers separated by colons, like this: ASTM 60:40:18. The first number is the tensile strength in ksi, the second is the yield strength in ksi and the third is the elongation in % (to convert ksi to MPa, multiply by 6.89).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

Grey cast irons are based on iron (Fe) with 3 - 4.1% carbon (C), for which this is the phase diagram. Ductile cast irons have small additions of magnesium or cerium that cause the graphite to form spherical nodules rather than flakes.

Typical uses

Brake discs and drums; bearings; camshafts; cylinder liners; piston rings; machine tool structural parts; engine blocks, gears, crankshafts; heavy-duty gear cases; pipe joints; pump casings; components in rock crushers.

Links

Reference

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