Low alloy steel

Description

Image

Caption

Low alloy steel wrench. © Granta Design

The material

Pure iron is soft stuff. Add carbon and heat-treat it right, and you can get a material that is almost as hard and brittle as glass, or as ductile and tough as boiler plate. 'Heat treat' means heating the steel to about 800 C to dissolve the carbon, then quenching (rapid cooling, often by dropping into cold water) and tempering - reheating it to a lower temperature and holding it there. Quenching turns the steel into hard, brittle 'martensite'; tempering slowly restores the toughness and brings the hardness down. Control of tempering time and temperature gives control of properties. It's wonderful what 1% of carbon can do. But (the inevitable 'but') the cooling rate in that initial quench has to be fast - more than 200 C/second for plain carbon steels. There is no difficulty in transforming the surface of a component to martensite, but the interior cools more slowly because heat has to be conducted out. If the component is more than a few millimeters thick, there is a problem - the inside doesn't cool fast enough. The problem is overcome by alloying. Add a little manganese (Mn), nickel (Ni), molybdenum (Mo), or chromium (Cr), and the critical cooling rate comes down, allowing thick sections to be hardened and then tempered. Adding some vanadium, V, as well allows a dispersion of carbides giving strength while retaining toughness and ductility. Chrome-molybdenum steels such as AIS 4140 are used for aircraft tubing and other high strength parts. Chrome-vanadium steels are used for crank and propeller shafts and high quality tools. Steels alloyed for this purpose are called low alloy steels, and the property they have is called 'hardenability'.

Compositional summary

Fe/<1.0 C/<2.5 Cr/<2.5 Ni/<2.5 Mo/<2.5 V

General properties

Density	7.8e3	-	7.9e3	kg/m^3
Price	* 0.63	-	0.66	USD/kg
Date first used	1930			

Mechanical properties

Young's modulus	205	-	217	GPa
Shear modulus	77	-	85	GPa
Bulk modulus	160	-	176	GPa

Poisson's ratio	0.285	-	0.295	
Yield strength (elastic limit)	400	-	1.5e3	MPa
Tensile strength	550	-	1.76e3	MPa
Compressive strength	400	-	1.5e3	MPa
Elongation	3	-	38	% strain
Hardness - Vickers	140	-	693	HV
Fatigue strength at 10^7 cycles	* 248	-	700	MPa
Fracture toughness	14	-	200	MPa.m^0.5
Mechanical loss coefficient (tan delta)	* 1.8e-4	-	0.00116	

Thermal properties

Melting point	1.38e3	-	1.53e3	°C
Maximum service temperature	* 500	-	550	°C
Minimum service temperature	* -73.2	-	-43.2	°C
Thermal conductor or insulator?	Good conductor			
Thermal conductivity	34	-	55	W/m.°C
Specific heat capacity	410	-	530	J/kg.°C
Thermal expansion coefficient	10.5	-	13.5	µstrain/°C

Electrical properties

Electrical conductor or insulator?	Good conductor			
Electrical resistivity	* 15	-	35	µohm.cm

Optical properties

Transparency	Opaque

Processability

Castability	1	-	2
Formability	3	-	4
Machinability	3	-	4
Weldability	5		
Solder/brazability	5		

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)	Unacceptable
Citric acid (10%)	Unacceptable
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%)	Unacceptable
Sulfuric acid (70%)	Unacceptable

Durability: alkalis

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

Durability: fuels, oils and solvents

Amyl acetate	Excellent
Benzene	Excellent
Carbon tetrachloride	Excellent
Chloroform	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%)	Unacceptable
Glycerol	Excellent
Methyl alcohol (methanol)	Acceptable

Durability: halogens and gases

Chlorine gas (dry)	Acceptable
Fluorine (gas)	Acceptable
O2 (oxygen gas)	Limited use
Sulfur dioxide (gas)	Acceptable

Durability: built environments

Industrial atmosphere	Limited use
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	*	28.7	-	31.7	MJ/kg
CO2 footprint, primary production	*	1.93	-	2.13	kg/kg
Water usage	*	47.9	-	53	l/kg
Eco-indicator 95		110			millipoints/kg
Eco-indicator 99		198			millipoints/kg

Material processing: energy

Casting energy	*	10.9	-	12.1	MJ/kg
Extrusion, foil rolling energy	*	6.06	-	6.7	MJ/kg
Rough rolling, forging energy	*	3.17	-	3.51	MJ/kg
Wire drawing energy	*	21.9	-	24.2	MJ/kg
Metal powder forming energy	*	35.4	-	42.8	MJ/kg
Vaporization energy	*	1.09e4	-	1.2e4	MJ/kg

Coarse machining energy (per unit wt removed)	* 0.908	-	1	MJ/kg
Fine machining energy (per unit wt removed)	* 4.8	-	5.31	MJ/kg
Grinding energy (per unit wt removed)	* 9.13	-	10.1	MJ/kg
Non-conventional machining energy (per unit wt removed)	109	-	120	MJ/kg

Material processing: CO2 footprint

Casting CO2	* 0.819	-	0.906	kg/kg
Extrusion, foil rolling CO2	* 0.454	-	0.502	kg/kg
Rough rolling, forging CO2	* 0.238	-	0.263	kg/kg
Wire drawing CO2	* 1.65	-	1.82	kg/kg
Metal powder forming CO2	* 2.83	-	3.43	kg/kg
Vaporization CO2	* 815	-	901	kg/kg
Coarse machining CO2 (per unit wt removed)	* 0.0681	-	0.0753	kg/kg
Fine machining CO2 (per unit wt removed)	* 0.36	-	0.398	kg/kg
Grinding CO2 (per unit wt removed)	* 0.685	-	0.757	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	* 7.7	-	8.52	MJ/kg
CO2 footprint, recycling	* 0.606	-	0.669	kg/kg
Recycle fraction in current supply	40	-	44	%
Downcycle	✔			
Combust for energy recovery	✖			
Landfill	✔			
Biodegrade	✖			
Toxicity rating	Non-toxic			
A renewable resource?	✖			

Environmental notes

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

Supporting information

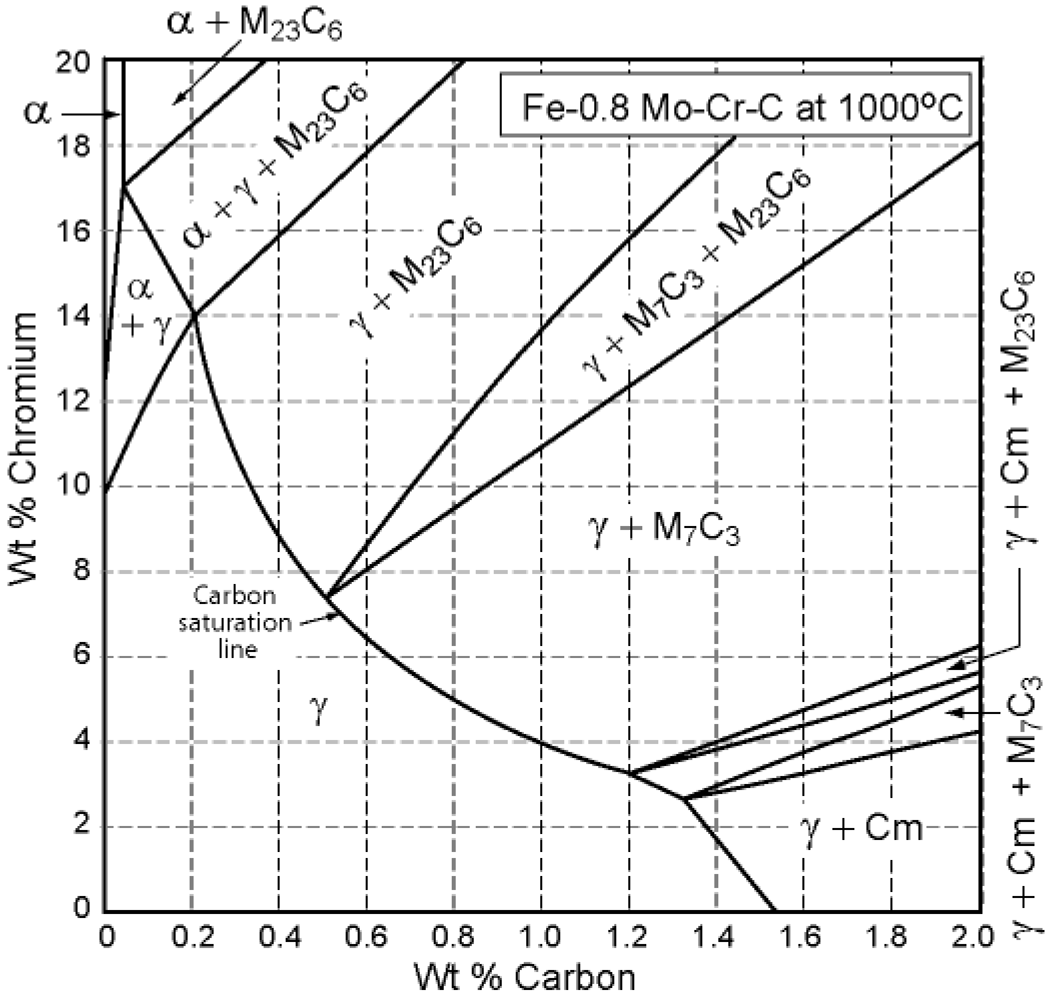
Design guidelines

Low alloy steels are heat treatable - most other carbon steels are not - and so are used for applications where hardness or strength is an important feature, particularly in large sections. They have greater abrasion resistance, higher toughness and better strength at high temperatures than plain carbon steels. Alloy steels with carbon content of 0.30 to 0.37 % are used for moderate strength and great toughness; 0.40 - 0.42% for higher strength and good toughness; 0.45 - 0.50% for high hardness and strength with moderate toughness; 0.50-0.62% for hardness (springs and tools); 1% for high hardness and abrasion resistance (ball bearings or rollers).

Technical notes

The SAE-AISI system for low alloy steels works the same way as that for plain carbon steels. Each steel has a four-digit code; the first two digits indicate the major alloying elements, the second two give the amount of carbon, in hundredths of a percent. Typical are the nickel-chrome-molybdenum steels with the designation 43xx, but the alloying elements can include any of the following: more than 2% silicon, more than 0.4% copper, more than 0.1% molybdenum, more than 0.5% nickel, more than 0.5% chromium. 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

High strength low alloy steels contain small (<5%) additions of chromium (Cr), molybdenum (Mo), nickel (Ni) and carbon (C).

Typical uses

Springs, tools, ball bearings, rollers; crankshafts, gears, connecting rods, knives and scissors, pressure

Links

Reference

ProcessUniverse

Producers