## Description

### Image

### Caption

1. Hair dryer with a Nichrome heating element. an alloy of nickel and chromium. © Granta Design 2. Toaster with a Nichrome heating element. an alloy of nickel and chromium. © Granta Design

### The material

Nickel forms a wide range of alloys, valued by the chemical engineering and food processing industries for their resistance to corrosion, and by the makers of furnaces and high temperature equipment for their ability to retain useful strength at temperatures up to 1200 C. Typical of these are the nickel-chromium (Ni-Cr) alloys, often containing some iron (Fe) as well. The chromium increases the already-good resistance to corrosion and oxidation by creating a surface film of Cr203, the same film that makes stainless steel stainless. The data given here are for nickel-chromium alloys. There are separate records for stainless steel and nickel-based super alloys.

### Compositional summary

Ni + 10 to 30% Cr + 0 to 10% Fe

## General properties

| | | | | | |
|---|---|---|---|---|---|
| Density | | 8.3e3 | - | 8.5e3 | kg/m^3 |
| Price | * | 22.5 | - | 25.5 | USD/kg |
| Date first used | | 1905 | | | |

## Mechanical properties

| | | | | | |
|---|---|---|---|---|---|
| Young's modulus | | 200 | - | 220 | GPa |
| Shear modulus | | 72 | - | 82 | GPa |
| Bulk modulus | | 155 | - | 285 | GPa |
| Poisson's ratio | | 0.305 | - | 0.315 | |
| Yield strength (elastic limit) | | 365 | - | 460 | MPa |
| Tensile strength | | 615 | - | 760 | MPa |
| Compressive strength | | 365 | - | 460 | MPa |
| Elongation | | 20 | - | 35 | % strain |

| | | | | |
|---|---|---|---|---|
| Hardness - Vickers | 160 | - | 200 | HV |
| Fatigue strength at 10^7 cycles | * 245 | - | 380 | MPa |
| Fracture toughness | * 80 | - | 110 | MPa.m^0.5 |
| Mechanical loss coefficient (tan delta) | * 4e-4 | - | 0.002 | |

## Thermal properties

| | | | | |
|---|---|---|---|---|
| Melting point | 1.35e3 | - | 1.43e3 | °C |
| Maximum service temperature | * 900 | - | 1e3 | °C |
| Minimum service temperature | -272 | - | -271 | °C |
| Thermal conductor or insulator? | Poor conductor | | | |
| Thermal conductivity | 9 | - | 15 | W/m.°C |
| Specific heat capacity | 430 | - | 450 | J/kg.°C |
| Thermal expansion coefficient | 12 | - | 14 | µstrain/°C |

## Electrical properties

| | | | | |
|---|---|---|---|---|
| Electrical conductor or insulator? | Good conductor | | | |
| Electrical resistivity | 102 | - | 114 | µohm.cm |

## Optical properties

| | |
|---|---|
| Transparency | Opaque |

## Processability

| | | | | |
|---|---|---|---|---|
| Castability | 3 | | | |
| Formability | 3 | - | 4 | |
| Machinability | 3 | | | |
| Weldability | 4 | - | 5 | |
| Solder/brazability | 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%) | Excellent |
| Acetic acid (glacial) | Excellent |
| Citric acid (10%) | Excellent |
| Hydrochloric acid (10%) | Acceptable |
| Hydrochloric acid (36%) | Unacceptable |
| Hydrofluoric acid (40%) | |

| | |
|---|---|
| | Acceptable |
| Nitric acid (10%) | Acceptable |
| Nitric acid (70%) | Limited use |
| Phosphoric acid (10%) | Acceptable |
| Phosphoric acid (85%) | Acceptable |
| Sulfuric acid (10%) | Acceptable |
| Sulfuric acid (70%) | Acceptable |

## 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 |
| 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 | 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) | Excellent |
| O2 (oxygen gas) | Excellent |

| | |
|---|---|
| Sulfur dioxide (gas) | Acceptable |

## 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) | Excellent |
| Tolerance up to 450 C (842 F) | Excellent |
| Tolerance up to 850 C (1562 F) | Excellent |
| Tolerance above 850 C (1562 F) | Unacceptable |

## Geo-economic data for principal component

| | | |
|---|---|---|
| Annual world production, principal component | 1.43e6 | tonne/yr |
| Reserves, principal component | 7.1e7 | tonne |

## Primary material production: energy, CO2 and water

| | | | | |
|---|---|---|---|---|
| Embodied energy, primary production | * 173 | - | 191 | MJ/kg |
| CO2 footprint, primary production | * 10.9 | - | 12.1 | kg/kg |
| Water usage | * 245 | - | 270 | l/kg |
| Eco-indicator 95 | 5.2e3 | | | millipoints/kg |
| Eco-indicator 99 | 2.83e3 | | | millipoints/kg |

## Material processing: energy

| | | | | |
|---|---|---|---|---|
| Casting energy | * 10.5 | - | 11.6 | MJ/kg |
| Extrusion, foil rolling energy | * 5.81 | - | 6.42 | MJ/kg |
| Rough rolling, forging energy | * 3.05 | - | 3.37 | MJ/kg |
| Wire drawing energy | * 21 | - | 23.2 | MJ/kg |
| Metal powder forming energy | * 34.3 | - | 37.9 | MJ/kg |
| Vaporization energy | * 1.17e4 | - | 1.29e4 | MJ/kg |
| Coarse machining energy (per unit wt removed) | * 0.768 | - | 0.849 | MJ/kg |
| Fine machining energy (per unit wt removed) | * 3.41 | - | 3.76 | MJ/kg |
| Grinding energy (per unit wt removed) | * 6.34 | - | 7 | MJ/kg |
| Non-conventional machining energy (per unit wt removed) | 117 | - | 129 | MJ/kg |

## Material processing: CO2 footprint

| | | | | |
|---|---|---|---|---|
| Casting CO2 | * 0.785 | - | 0.868 | kg/kg |
| Extrusion, foil rolling CO2 | * 0.44 | - | 0.48 | kg/kg |
| Rough rolling, forging CO2 | * 0.23 | - | 0.25 | kg/kg |
| Wire drawing CO2 | * 1.57 | - | 1.74 | kg/kg |
| Metal powder forming CO2 | * 2.75 | - | 3.03 | kg/kg |
| Vaporization CO2 | * 875 | - | 967 | kg/kg |
| Coarse machining CO2 (per unit wt removed) | * 0.0576 | - | 0.0637 | kg/kg |
| Fine machining CO2 (per unit wt removed) | * 0.255 | - | 0.282 | kg/kg |
| Grinding CO2 (per unit wt removed) | * 0.475 | - | 0.525 | kg/kg |
| Non-conventional machining CO2 (per unit wt removed) | 8.75 | - | 9.67 | kg/kg |

## Material recycling: energy, CO2 and recycle fraction

| | | | | |
|---|---|---|---|---|
| Recycle | ✓ | | | |
| Embodied energy, recycling | * 30.1 | - | 33.3 | MJ/kg |
| CO2 footprint, recycling | * 2.37 | - | 2.62 | kg/kg |
| Recycle fraction in current supply | 22 | - | 26 | % |
| Downcycle | ✓ | | | |
| Combust for energy recovery | ✗ | | | |
| Landfill | ✗ | | | |
| Biodegrade | ✗ | | | |
| Toxicity rating | Non-toxic | | | |
| A renewable resource? | ✗ | | | |

**Environmental notes**

Nickel alloys are non-toxic and can be recycled.

## Supporting information

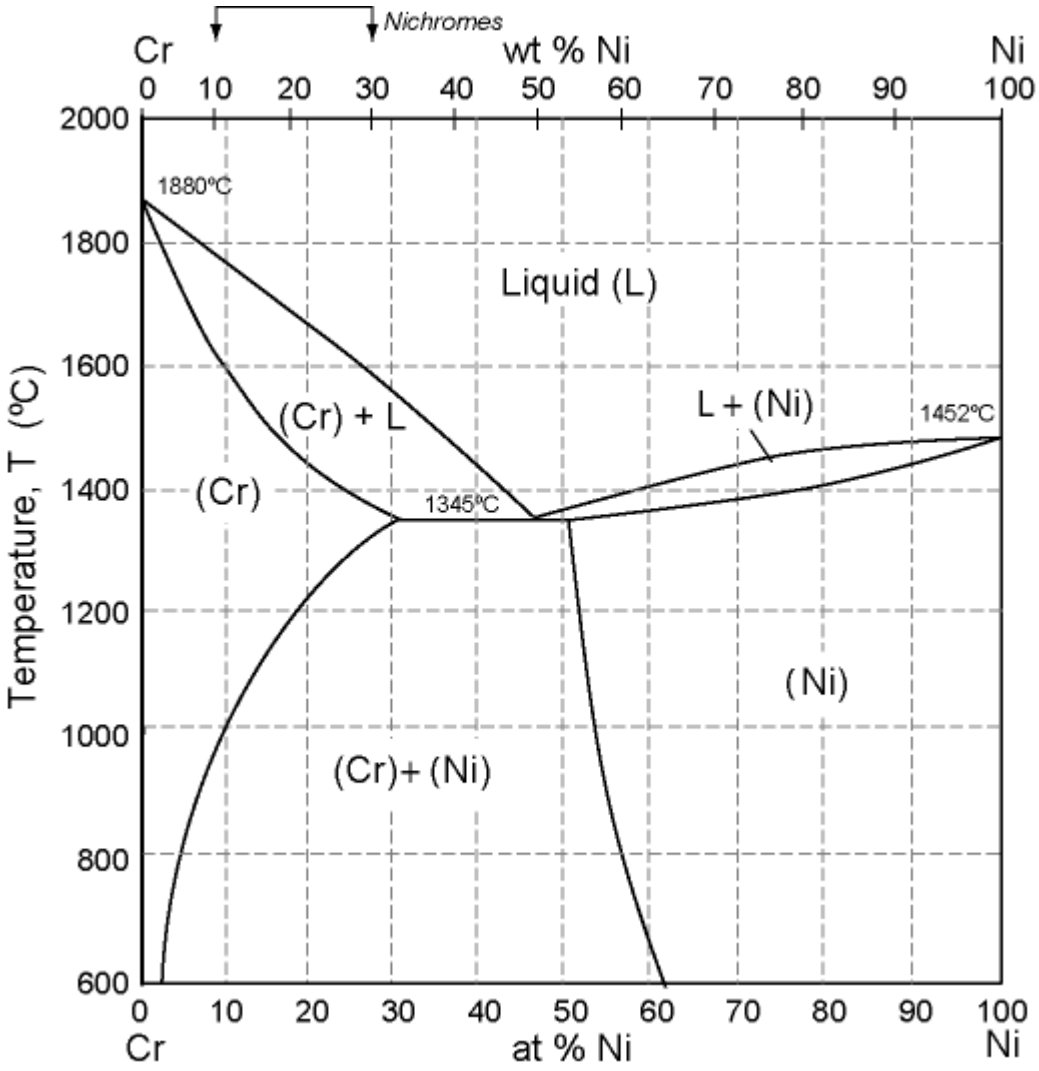
**Design guidelines**

Few other alloy systems can equal the nickel-based alloys in their combination of corrosion resistance and strength at low and high temperature. They are used in marine applications for heat exchanges in other structures. Nickel-iron alloys have high magnetic permeability (where electronic shielding and magnetic coils) and low thermal expansion (good for glass-to-metal joints). Invar, an alloy based on nickel, has essentially zero thermal expansion coefficient near room temperature; a magnetic contraction counteracts the ordinary thermal expansion, canceling it out. Nickel-chrome-iron alloys have high electrical resistance and are used as heating elements in toasters and industrial furnaces. Bi-metallic sheet of nickel bonded to copper is used as actuators for thermostats and safety devices. Alloys with titanium (Nitanols) have the remarkable property that they spring back to shape after severe deformation - they are called "shape memory alloys" for this reason.

**Technical notes**

Ni-Cr-Fe alloys are marketed under a bewildering catalog of tradenames. Chromels are straight Ni-Cr alloys with up to 20% Cr. Durimet and Nichromes contain iron. There are many more.

**Phase diagram**




**Phase diagram description**

Nichromes are alloys of nickel (Ni) with 10 - 30% chromium (Cr). They have useful strength and oxidation resistance to 1200 C.

**Typical uses**

Heating elements and furnace windings; bi-metallic strips; thermocouples; springs; food processing equipment; chemical engineering equipment.

## Links

Reference

ProcessUniverse

Producers