Table 1 Typical properties of electrical resistance alloys

Basic composition, %	Resistivity(a), nΩ · m(b)	TCR, ppm/°C(c)	Thermoelectric potential versus Cu, μV/°C	Coefficient of thermal expansion(d), μm/m · °C	Tensile strength(a)		Density(a)	
					MPa	ksi	g/cm³	lb/in.³
Radio alloys								
98Cu-2Ni	50	1400 (25–105 °C)	−13 (25–105 °C)	16.5	205–410	30–60	8.9	0.32
94Cu-6Ni	100	700 (25–105 °C)	−13 (25–105 °C)	16.3	240–585	35–85	8.9	0.32
89Cu-11Ni	150	450 (25–105 °C)	−25 (25–105 °C)	16.1	240–515	35–75	8.9	0.32
78Cu-22Ni	300	180 (25–105 °C)	−36 (0–75 °C)	15.9	345–690	50–100	8.9	0.32
Manganins								
87Cu-13Mn	480	±15 (15–35 °C)	1 (0–50 °C)	18.7	275–620	40–90	8.2	0.30
83Cu-13Mn-4Ni	480	±15 (15–35 °C)	−1 (0–50 °C)	18.7	275–620	40–90	8.4	0.31
85Cu-10Mn-4Ni(e)	380	±10 (40–60 °C)	−1.5 (0–50 °C)	18.7	345–690	50–100	8.4	0.31
Constantans								
57Cu-43Ni	500	±20 (25–105 °C)	−43 (25–105 °C)	14.9	410–930	60–135	8.9	0.32
55Cu-45Ni	500	±40 (−55–105 °C)	−42 (0–75 °C)	14.9	455–860	66–125	8.9	0.32
53Cu-44Ni-3Mn	525	±70 (−55–105 °C)	−38 (0–100 °C)	14.9	410–930	60–135	8.9	0.32
Nickel-chromium-aluminum alloys								
75Ni-20Cr-3Al-2(Cu, Fe, or Mn)	1333	±20 (−55–105 °C)	1.0 (25–105 °C)	12.6	825–1380	120–200	8.1	0.29
72Ni-20Cr-3Al-5Mn	1375	±20 (−55–105 °C)	1.0 (25–105 °C)	13	690–1380	100–200	7.1	0.26
Nickel-base alloys								
78.5Ni-20Cr-1.5Si	1080	80 (25–105 °C)	3.9 (25–105 °C)	13.5	790–1380	115–200	8.3	0.30
76Ni-17Cr-4Si-3Mn	1330	±20 (−55–105 °C)	−1 (20–100 °C)	15	900–1380	130–200	7.8	0.28
71Ni-29Fe	208	4300 (25–105 °C)	−40 (25–105 °C)	15	480–1035	70–150	8.4	0.31
68.5Ni-30Cr-1.5Si	1187	90 (25–105 °C)	−1.2 (25–105 °C)	12.2	825–1380	120–200	8.1	0.29
60Ni-16Cr-22.5Fe-1.5Si	1125	150 (25–105 °C)	0.9 (25–105 °C)	13.5	725–1345	105–195	8.4	0.30
37Ni-21Cr-40Fe-2Si	1080	300 (20–100 °C)	...	16.0	585–1135	85–165	7.96	0.288
35Ni-20Cr-43.5Fe-1.5Si	1000	400 (25–105 °C)	−1.1 (25–105 °C)	15.6	585–1135	85–165	8.1	0.29
Iron-chromium-aluminum alloys								
73.5Fe-22Cr-4.5Al	1350	60 (25–105 °C)	−3.0 (0–100 °C)	11	690–965	100–140	7.25	0.262
73Fe-22Cr-5Al	1390	40 (25–105 °C)	−2.8 (0–100 °C)	11	690–965	100–140	7.15	0.258
72.5Fe-22Cr-5.5Al	1450	20 (25–105 °C)	−2.6 (0–100 °C)	11	690–965	100–140	7.1	0.256
81Fe-15Cr-4Al	1250	±50 (25–105 °C)	−1.2 (0–100 °C)	11	620–900	90–130	7.43	0.268
Pure metals								
Aluminum (99.99+)	26.55	4290(a)	−3.4 (0–50 °C)	23.9(a)	50–110	7–16	2.70	0.098
Copper (99.99)	16.73	4270 (0–50 °C)	0	16.5(a)	115–130	17–19	8.96	0.324
Gold (99.999+)	23.50	4000 (0–100 °C)	0.2 (0–100 °C)	14.2(a)	130	19	19.32	0.698
Iron (99.94)	970	5000(a)	12.2 (0–100 °C)	11.7(a)	180–220	26–32	7.87	0.284
Molybdenum (99.9)	52	3300(a)	6.9 (0–100 °C)	4.9	690–2140	100–310	10.22	0.369
Nickel (99.8)	80	6000 (20–35 °C)	−22 (0–75 °C)	15	345–760	50–110	8.90	0.322
Platinum (99.99+)	105	3920 (0–100 °C)	7.6 (0–100 °C)	8.9(a)	125	18	21.45	0.775
Silver (99.99)	16	4100(a)	−0.2 (0–100 °C)	19.7	125	18	10.49	0.379
Tantalum (99.96)	125	3820 (0–100 °C)	−4.3 (0–100 °C)	6.5(a)	690–1240	100–180	16.6	0.600
Tungsten (99.9)	55	4500(a)	3.6 (0–100 °C)	4.3(a)	1825–4050	265–590	19.25	0.695

(a) At 20 °C (68 °F). (b) To convert to Ω · circ mil/ft, multiply by 0.6015. (c) Temperature coefficient of resistance is $(R - R_0)/R_0\,(t - t_0)$, where R is resistance at t °C and R_0 is resistance at the reference temperature t_0 °C. (d) At 25 to 105 °C. (e) Shunt manganin

tests of the purity of a metal is measurement of its temperature coefficient of resistance, which decreases sharply with increasing impurity or alloy content.

Ballast resistors are used extensively in industrial circuits to maintain constant currents over long periods of time. In such an application, a ballast resistor must be able to dissipate energy in such a way as to control current over a wide range of voltages. Wires with the proper temperature coefficient of resistance can be made to change resistance rapidly with changes in current, due to self heating, in such a manner that the current in the circuit will remain nearly constant even when there are fluctuations in voltage across the circuit. Because ballast resistors operate at elevated temperatures, mechanical properties are important also. Typical materials used in ballast resistors are pure iron, pure nickel, and nickel-iron alloys such as 71Ni-29Fe (see Table 1).

Reference resistors and virtually all other applications of resistance alloys demand temperature coefficients of resistance lower than ±20 ppm/°C (±20 μΩ/Ω · °C). This requirement stems from the fact that, for these applications, resistance errors resulting from the small changes in ambient temperature that are continually taking place cannot be tolerated. In the most demanding of these applications, resistors often are mounted in thermally insulated containers and are carefully maintained at a temperature slightly above the maximum anticipated ambient temperature.

The most important requirement of a resistor used as a reference standard is that its value be predictable within narrow limits over long periods of time. Many reference resistors exhibit a nearly linear change in resistance with time. Hence, resistance between dates of calibration can be determined by interpolation; resistance at future points in time can be determined by extrapolation, but undue reliance should not be placed on extrapolated values. Figure 1 shows the change in resistance with time for a 10-kΩ resistor made of a Ni-Cr-Al-Cu alloy.

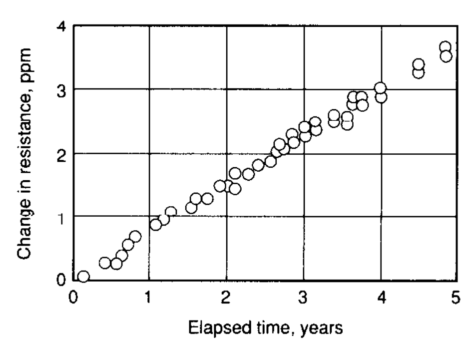

Fig. 1 Change in resistance of a 10-kΩ resistor with time