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ABSTRACT

Electrical resistivity data for metals which might be resistance-heated in heat-transfer tests have been compiled and are given as a function of temperature in ten figures.

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ELECTRICAL RESISTIVITY DATA FOR
HEAT-TRANSFER TEST-SECTION METALS

W. R. Gambill

In conducting heat-transfer tests, it is common practice to resistance heat a metallic conduit wall. When heat-transfer coefficients are being determined, inside wall temperatures (and film temperature differences) are usually calculated from measured outside wall temperatures by application of equations for heat flow with volume heat generation which are appropriate to the existing boundary conditions. Electrical resistivity data as a function of temperature are required for accurate calculations since a thermal gradient exists across the conduit wall. Such data are also needed for calculating the dimensions of test sections which will match the available electrical power supply with respect to current usage, heat generation rate, etc.

Pertinent data for electrical resistivity have been compiled from various sources and are given in Table 1 (for room-temperature data) and in Figs. 1-10 (for ρ as a function of temperature). Electrical resistivity varies enormously for known materials - from 1.50 $\mu\text{ohm-cm}$ for pure silver to $\sim 10^{25}$ $\mu\text{ohm-cm}$ for polytetrafluoroethylene (plastic); in this memorandum, ρ data are given only for metals and alloys which are or might be used in heat-transfer tests.

The values listed represent averages and are subject to some variation with specific composition and heat treatment. Though the variation in literature values for ρ of a given material is less than that for thermal conductivity data, there is a considerable scatter for some metals; and for precise

application, as in resistance thermometry, careful individual calibration is desirable.

In general, ρ for metals and alloys increases with temperature, with oxygen content, and with degree of cold work. For the resistance alloys (Fig. 8), however, the behavior with respect to cold work is opposite to the usual, and annealing increases ρ .

Metals for which data are given in the figures are usually not listed in Table 1. Notation is as follows: α = temperature coefficient of electrical resistivity, $(^{\circ}\text{C})^{-1}$; t = temperature, $^{\circ}\text{C}$; RT = room temperature; and ρ = electrical resistivity, $\mu\text{ohm-cm}$. The numbers in parentheses in Figs. 1-10 refer to the data sources upon which the adjacent curves were based.

For the effect of pressure on ρ , the reader is referred to Refs. 3, 5, and 10. Data for the ρ of single crystals and the effect of specific impurities on pure-metal resistivities may be found in Ref. 5. For ρ data at very low temperatures and a general discussion of the Wiedemann-Franz law and similar topics, see Ref. 32.

Table 1. Room-Temperature Electrical Resistivities

Metal	ρ ($\mu\text{ohm-cm}$)	t ($^{\circ}\text{C}$)	Remarks	Refs.		
Aluminum	2.8	20	Commercially pure	16, 22		
Aluminum Alloys						
EC	2.8	20	Wrought. Range given for various available tempers. The new Al Association designation follows the old commercial designation.	16		
2S(1100)	2.92 - 3.02	↓		↓		
63S(6063)	3.1 - 3.4					
A51S(6151)	3.1 - 3.8					
4S(3004)	4.10					
61S(6061)	3.8 - 4.3					
62S(6062)						
25S(2025)	3.45 - 4.31					
3S(3003)						
B18S(2218)						
18S(2018)						
11S(2011)	4.31					
A17S(2117)						
50S(5050)						
32S(4032)	4.3 - 4.9					
52S(5052)	4.93					
75S(7075)	5.7					
14S(2014)	3.45 - 5.75					
R301(2014)						
24S(2024)						
17S(2017)	3.83 - 5.75					
56S(5056)	5.94 - 6.39				↓	↓
Brass	7.0		20		Low brass	27
	8.3	20	High brass	27		
Bronze	13 - 18	20		5		
Cadmium	6.83	20		22		
Copper	1.673	20	Very pure	7		
	1.71	↓	Electrolytic tough pitch, annealed	7, 13		
	1.724		Commercial, annealed	22		
	1.771		Hard-drawn	22		
	2.03		Deoxidized commercial	13		

Table 1. Room-Temperature Electrical Resistivities (Continued)

Metal	ρ ($\mu\text{ohm-cm}$)	t ($^{\circ}\text{C}$)	Remarks	Refs.
Duralumin	3.35	20		5
Duranickel	43.2	20		7, 12, 14, 27
Gold	2.44	20		22
Inconel 700	118	20		6
Invar	75	20		5
Iridium	4.9	0		22
	5.3	20		13
Monel	48.2	20		6, 7, 15
	42.5 - 58.3	0, 20	Literature range	5, 13, 14
"H" Monel	61.6	0		14
"K" Monel	58.2	20		6, 7, 13, 14
"KR" Monel	58.3	0		14
"R" Monel	48.4	0		14
"S" Monel	63.3	0		14
Nickel	7.8	20	Commercially pure	22
	6.84 - 9.5	20	Literature range	5, 14, 15
"D" Nickel	16.7	0		14
	19	20		7
"E" Nickel	14	20		27
Niobium	13.0	20		12
	13.2	20	$\alpha_{20^{\circ}\text{C}} = 0.00395 (^{\circ}\text{C})^{-1}$	22
	14.2	20		13
Permanickel	15.8	0		14
Rhenium	19.1 - 19.8	20	$\alpha_{0-100^{\circ}\text{C}} = 0.00311 (^{\circ}\text{C})^{-1}$	26
	21.0	20	$\alpha_{0-2700^{\circ}\text{C}} = 0.00198 (^{\circ}\text{C})^{-1}$	22
Steels			ρ increases ~ 65% from	
1320, 1321, } 1330, 1335, } 1340	17	20	20° to 300°C for most of those listed.	13

Table 1. Room-Temperature Electrical Resistivities (Continued)

Metal	ρ ($\mu\text{ohm-cm}$)	t ($^{\circ}\text{C}$)	Remarks	Refs.
Steels		20	ρ increases ~ 65% from 20° to 300°C for most of those listed.	13
4023, 4032, 4042, 4053, 4063, 9255	19	↓	↓	↓
9261, 9440, 9450	20	↓	↓	↓
6120, 6145, 6150, 6152	21	↓	↓	↓
2317, 2330, 2512, 2515, 2517	28 - 28.5	49	↓	↓
4317, 4320, 4337, 4340, 8620, 8630, 8640, 8650, 8720, 8740, 8750	30	49	↓	↓
Stainless Steels				
(A) General		20	Approximately	15, 23
Martensitic	55 - 72	↓	↓	↓
Ferritic	60 - 67	↓	↓	↓
Cr-Mn	69	↓	↓	↓
Austenitic	72	↓	To 116 at 650°C	↓
Age-hardening	71 - 100	↓	↓	↓
(B) Specific		20		2, 12-15
501, 502	40	↓	↓	↓
420	55	↓	↓	↓
403, 410, 416	57	↓	↓	↓
405, 430, 430F, 440A, 440B, 440C	60	↓	↓	↓
442	64	↓	↓	↓
446	67	↓	↓	↓
201, 202	69	↓	↓	↓
414	70	↓	↓	↓

Table 1. Room-Temperature Electrical Resistivities (Concluded)

Metal	ρ ($\mu\text{ohm-cm}$)	t ($^{\circ}\text{C}$)	Remarks	Refs.
Stainless Steels				
(B) Specific (Cont.)		20		2, 12-15
301, 302, 302B, 304ELC, 305, 308, 321, 431	72	↓		↓
347	73			
316, 316ELC, 317	74			
309, 310	78			
314	94			
Stainless W	101			
Titanium	47.8	25	Pure	22
	54 - 55	25	Commercially pure	13, 19
Ti-150A alloy	60	20		12
Ti-175A alloy	60	20		12
Vanadium	25	20		12
Zirconium	39.6 - 54	20	Literature range	9, 14, 19, 22, 23
	39.6, 39.84	20	Degassed, annealed, and Hf-free	14, 23
	41.0	0	Commercially pure	9, 14, 23
			$\alpha_{0-200^{\circ}\text{C}} = 39.2 - 44.0$ $\times 10^{-4} (^{\circ}\text{C})^{-1}$	
Chromel and Alumel (0-1200 $^{\circ}\text{C}$) and miscellaneous steels (to 350 $^{\circ}\text{C}$)	-	-		31

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

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Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

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Fig. 9.

Fig. 10.

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